United States
Environmental Protection
Agency

Guidance Manual for Compliance with the Surface Water Treatment Rules: Turbidity Provisions

Office of Water (4606M)
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Disclaimer

This document provides guidance to states, tribes, and U.S. Environmental Protection Agency (EPA) exercising primary enforcement responsibility under the Safe Drinking Water Act (SDWA) and contains EPA's policy recommendations for complying with the suite of Surface Water Treatment Rules (SWTR). Throughout this document, the terms "state" and "states" are used to refer to all types of primacy agencies including states, U.S. territories, Indian tribes, and EPA.

The statutory provisions and EPA regulations described in this document contain legally binding requirements. This document is not a regulation itself, nor does it change or substitute for those provisions and regulations. Thus, it does not impose legally binding requirements on EPA, states, or the regulated community. This guidance does not confer legal rights or impose legal obligations upon any member of the public.

While EPA has made every effort to ensure the accuracy of the discussion in this guidance, the obligations of the regulated community are determined by statutes, regulations, or other legally binding requirements. In the event of a conflict between the discussion in this document and any statute or regulation, this document would not be controlling.

The general description provided here may not apply to a particular situation based upon the circumstances. Interested parties are free to raise questions and objections about the substance of this guidance and the appropriateness of the application of this guidance to a particular situation. EPA and other decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those described in this guidance, where appropriate.

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Acronyms

List of common abbreviations and acronyms used in this document and appendices:

AIDS	Acquired Immune Deficiency Syndrome
ASCE	American Society of Civil Engineers
AWOP	Area-wide Optimization Program
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation (now Water Research Foundation)
CCP	Composite Correction Program
CDC	Centers for Disease Control
CFE	Combined Filter Effluent
CFR	Code of Federal Regulations
CPE	Comprehensive Performance Evaluation
CTA	Comprehensive Technical Assistance
CWS	Community Water System
CWSS	Community Water System Survey
DBP	Disinfection Byproduct
DBPR	Disinfectants and Disinfection Byproduct Rule
DCS	Distributed Control Systems
DE	Diatomaceous Earth
EPA	Environmental Protection Agency
FBRR	Filter Backwash Recycling Rule
FR	Federal Register
FTU	Formazin Turbidity Units
GLI 2	Great Lakes Instrument Method 2
GPM	Gallons per Minute
GWUDI	Ground Water Under the Direct Influence
HAA	Haloacetic Acids
HAA5	Haloacetic Acids (five)
IESWTR	Interim Enhanced Surface Water Treatment Rule
IFE	Individual Filter Effluent
IPC	Instrument Performance Check Solution
ISO	International Organization for Standardization
JTU	Jackson Turbidity Units
LRAA	Locational Running Annual Average
LRB	Laboratory Reagent Blank
LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MGD	Million Gallons per Day
MPA	Microscopic Particulate Analysis
ML	Milliliter
MSDS	Material Safety Data Sheet
NAS	National Academy of Sciences
NOM	Natural Organic Matter
NPDES	National Pollution Discharge Elimination System
NPDWR	National Primary Drinking Water Regulation
NSF	National Science Foundation

NTNCWS	Non-Transient Non-Community Water System
NTU	Nephelometric Turbidity Units
OSHA	Occupational Safety and Health Administration
PAC	Powdered Activated Carbon
PBT	Performance Based Training
PCAL	Primary Calibration Standard
PCBs	Polychlorinated Biphenyls
PN	Public Notification
PWS	Public Water System
QA	Quality Assurance
QC	Quality Control
RTCR	Revised Total Coliform Rule
SCADA	Supervisory Control and Data Acquisition
SCAL	Secondary Calibration Standard
SDWA	Safe Drinking Water Act
SOP	Standard Operating Procedure
SWTR	Surface Water Treatment Rule
TNCWS	Transient Non-Community Water System
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
TT	Treatment Technique
UV	Ultraviolet

CHAPTER 1 – INTRODUCTION

In this chapter:

- *Purpose of Document*
- *Overview of SWTR, IESWTR, LT1ESWTR, and LT2ESWTR*
- *Other Applicable Rules*
- *Summary of chapters and appendices*

1.1 Purpose of Document

The objective of the guidance manual is to provide public water systems (PWSs) with guidance for complying with the turbidity provisions found in the Surface Water Treatment Rule (SWTR), Interim Enhanced Surface Water Treatment Rule (IESWTR), Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR), and Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The primary audience for the guidance manual is utility personnel at PWSs that utilize filtration and the staff of state drinking water programs that work with PWSs to protect water quality.

The original guidance manual (USEPA, 1999) focused on the requirements of the IESWTR as it relates to turbidity. This guidance manual focuses on technical information regarding specific requirements of the IESWTR, LT1ESWTR, and LT2ESWTR relating to turbidity. It is intended for experienced operators and others in the regulated community.

Copies of this document and other referenced documents can be obtained by:

- Contacting the appropriate state office.
- Accessing U.S. Environmental Protection Agency's (EPA) Safe Drinking Water website at https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-hotline.
- Downloading from EPA's website at: https://www.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules.
- Calling the National Service Center for Environmental Publications at 1-800-490-9198 or visiting its website at: www.epa.gov/ncepihom/.

1.2 Overview of Suite of Surface Water Treatment Rules (SWTRs)

SWTR

Under the 1989 SWTR (USEPA, 1989), EPA established treatment requirements for all PWSs using surface water or ground water under the direct influence (GWUDI) of surface water as a source. The requirements listed in 40 Code of Federal Regulations (CFR) 141.70 through 141.75 are intended to protect against the adverse health effects associated with *Giardia lamblia*, viruses, and *Legionella* and include:

- Maintenance of a disinfectant residual in water entering, and within the distribution system.

- Removal/inactivation of at least 99.9 percent (3-log) of *Giardia* and 99.99 percent (4-log) of viruses.

- Filtration, unless PWSs meet specified avoidance criteria.

- For filtered PWSs, a turbidity limit for the combined filter effluent (CFE) of 5 nephelometric turbidity units (NTUs) at any time, and a limit of 0.5 NTU in 95 percent of measurements each month for treatment plants using conventional treatment or direct filtration (with separate standards for other filtration technologies). These requirements were superseded by the 1998 IESWTR and the 2002 LT1ESWTR.

- Watershed control programs and water quality requirements for unfiltered PWSs.

PWSs that qualify for filtration avoidance determinations must meet source water quality and site-specific conditions to remain unfiltered. If any of the criteria for avoiding filtration are not met, PWSs must install filtration treatment within 18 months of the failure. One of the avoidance criteria established by the SWTR and later enhanced by the IESWTR and LT1ESWTR is that turbidity levels cannot exceed 5 NTU in the water immediately prior to the first point of disinfectant application. Turbidity measurements must be made at least once every four hours, and a filtration avoidance PWS must report to its primacy agency within 24 hours if it has exceeded the 5 NTU standard (40 CFR 141.71). This guidance manual does not further address the turbidity requirements for filtration avoidance PWSs. Unfiltered PWSs should discuss with their primacy agencies the requirements for successfully maintaining filtration avoidance status.

IESWTR

The IESWTR (USEPA, 1998) applies to PWSs serving at least 10,000 people and using surface water or GWUDI as a source. These PWSs were to comply with the IESWTR by January 2002. The requirements listed in 40 CFR 141.170 through 141.175 include:

- Removal of 99 percent (2-log) of *Cryptosporidium* for PWSs that provide filtration.

- For treatment plants using conventional treatment or direct filtration, a turbidity performance standard for the CFE of 1 NTU as a maximum, and 0.3 NTU as a maximum in 95 percent of monthly measurements, based on 4-hour monitoring (these limits supersede the SWTR turbidity limits).

- Continuous monitoring of individual filter effluent (IFE) turbidity in conventional and direct filtration plants and recording of IFE turbidity readings every 15 minutes.

- Filter profiles and/or assessments required under different monitoring results and scenarios, as detailed in Section 2.2.3 of this report.

- PWSs using alternative filtration techniques [defined as filtration other than conventional, direct, slow sand, or diatomaceous earth (DE)] must demonstrate to the state the ability to consistently achieve 2-log removal of *Cryptosporidium* and comply with specific state-established CFE turbidity requirements.

- The development of a disinfection profile and benchmark (to assess the level of microbial protection provided), before facilities change their disinfection practices in order to also meet the requirements of the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR).

- *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs.

- All new finished water reservoirs must be covered [40 CFR 141.170(c)].

LT1ESWTR

The LT1ESWTR (USEPA, 2002) extends most of the requirements of the IESWTR to surface water and GWUDI PWSs serving fewer than 10,000 people.

The LT1ESWTR requirements listed in 40 CFR 141.500 through 141.571 differ from the IESWTR in a few ways, including:

- If the PWS has two or fewer filters, it can perform continuous monitoring of the CFE in lieu of IFE monitoring.

- If turbidity monitoring equipment fails, a PWS has 14 days (rather than 5 working days under IESWTR) to resume continuous monitoring before incurring a violation.

- If the IFE turbidity exceeds 1.0 NTU for two or more consecutive 15-minute readings in one month, the PWS must report the cause of the turbidity exceedance, if known, but a filter profile is not required.

- If the IFE turbidity exceeds 2.0 NTU in two or more consecutive 15-minute readings for two months in a row, the PWS must arrange a Comprehensive Performance Evaluation (CPE) no later than 60 days after the filter exceeded 2.0 NTU for the second straight month (30 days under the IESWTR), and it must be completed, and the report submitted to the state within 120 days after the final exceedance (90 days under the IESWTR).

- Disinfection profiling requirements do not apply to transient noncommunity water systems (TNCWSs).

- PWSs are required to monitor weekly (rather than daily) when preparing a disinfection profile.

- PWSs using either chloramines, ozone, or chlorine dioxide for primary disinfection are required to complete a disinfection profile (PWSs using chlorine dioxide for primary disinfection under IESWTR were not required to complete a profile).

LT2ESWTR

EPA promulgated the LT2ESWTR in 2006 (USEPA, 2006a). The LT2ESWTR builds upon the requirements established by the SWTR, IESWTR, and the LT1ESWTR and can be found in 40 CFR 141.700 through 141.722. Key provisions of the LT2ESWTR include:

- Source water monitoring for *Cryptosporidium*, with reduced monitoring requirements for small PWSs.

- Additional *Cryptosporidium* treatment technique (TT) provisions for certain filtered PWSs based on source water *Cryptosporidium* concentrations.

- A variety of source, pre-filtration, treatment, additional filtration, and inactivation toolbox components for PWSs to use to receive *Cryptosporidium* credit.

- A requirement for inactivation of *Cryptosporidium* for all unfiltered PWSs.

- Requirements that PWSs conduct disinfection profiling and benchmarking to ensure continued levels of microbial protection while PWSs take the necessary steps to comply with new disinfection byproduct (DBP) standards.

- Requiring PWSs to cover an uncovered finished water reservoir or treat the water exiting the uncovered finished water reservoir prior to entering into the distribution system.

1.3 Other Applicable Rules

Other drinking water regulations may affect how successfully a PWS complies with the turbidity requirements of the SWTRs. Brief summaries of those regulations are provided in this section.

Filter Backwash Recycling Rule (FBRR)

The FBRR was published by EPA on June 8, 2001 (USEPA, 2001), and affects PWSs that meet all of the following criteria:

- The PWS is a surface water system or GWUDI system.

- The PWS treats water using conventional or direct filtration.

- The PWS recycles one or more of the following: spent filter backwash, thickener supernatant, or liquids from dewatering devices.

Affected PWSs were required to report information about their system to the state by December 8, 2003. The FBRR also requires regulated recycle streams to be returned through all processes of a PWS's existing conventional or direct filtration system or at an alternate location approved by the state. In addition, the FBRR has recordkeeping requirements for affected PWSs.

Revised Total Coliform Rule (RTCR)

The RTCR (USEPA, 2013) sets maximum contaminant levels (MCLs) and maximum contaminant level goals (MCLGs) for *E. coli*, sets a total coliform treatment technique (TT) requirement, and requires every regulated PWS to periodically collect samples and analyze them for total coliforms. The number of routine samples required each month depends on the system size. Samples must be collected according to a written Sample Siting Plan [40 CFR 141.853(a)]. Assessments and corrective action are required when monitoring results show that PWSs may be vulnerable to contamination.

Stage 2 Disinfectants and Disinfection Byproduct Rule (DBPR)

The requirements of the Stage 2 DBPR (USEPA, 2006b) apply to all community water systems (CWSs) and non-transient non-community water systems (NTNCWSs) that uses a primary or residual disinfectant other than ultraviolet (UV) light, or that deliver water that has been treated with a primary or residual disinfectant other than UV light.

The numerical MCLs for the Stage 2 DBPR are 0.080 mg/L for total trihalomethanes (TTHMs), and 0.060 mg/L for the five regulated haloacetic acids (HAA5). Compliance determinations for the Stage 2 DBPR are based on a locational running annual average (LRAA) (i.e., compliance must be met at *each* monitoring location) [40 CFR 141.620(a)]. EPA has adopted a population-based monitoring approach for the Stage 2 DBPR, where compliance monitoring requirements are based only on source water type and retail population served.

Because Stage 2 DBPR MCL compliance for some PWSs is based on individual DBP measurements at a location averaged over a four-quarter period, a PWS could measure higher TTHM or HAA5 levels than the MCL values, while at the same time maintaining compliance with the rule. This is because the high concentration could be averaged with lower concentrations at a given location. For this reason, the Stage 2 DBPR includes a requirement for operational evaluations that investigate the cause(s) of the high TTHM or HAA5 concentrations. A PWS has exceeded an operational evaluation level at any monitoring location when the sum of the two previous quarters' compliance monitoring results plus twice the current quarter's result, divided by four, exceeds 0.080 mg/L for TTHM or 0.060 mg/L for HAA5. If an operational evaluation level is exceeded, the PWS must conduct an "operational evaluation" and submit a written report of the evaluation to the state (40 CFR 141.626).

1.4 Summary of Chapters and Appendices

As noted, the document is divided into two parts. The main body of the manual (Chapters 1 through 6) outlines the specific turbidity requirements of the suite of SWTRs and includes information directly applicable to complying with those requirements. The remainder of the main body of this document consists of:

<u>Chapter 2 – Turbidity Requirements</u>

Chapter 2 outlines the regulatory requirements, reporting and recordkeeping requirements, and additional compliance aspects of the suite of SWTRs related to turbidity.

<u>Chapter 3 – Turbidity Methods & Measurement</u>

Chapter 3 provides information regarding approved turbidity methods, analytical issues associated with turbidimeters and turbidity measurement, quality assurance and quality control issues (QA/QC), and data collection and management issues.

<u>Chapter 4 – Treatment Optimization</u>

Chapter 4 provides information on compliance with turbidity requirements. This chapter focuses on plant optimization; highlighting areas which PWSs can most often improve to optimize water treatment.

<u>Chapter 5 – Individual Filter Self-Assessment</u>

Chapter 5 provides detailed guidance on conducting a filter self-assessment including a discussion of necessary components such as conducting filter profiles, assessing hydraulic loading conditions, and assessing support media and underdrains.

<u>Chapter 6 – Comprehensive Performance Evaluation</u>

Chapter 6 provides a general overview of the Composite Correction Program (CCP) and specifically the first component of the CCP, the CPE. Fundamental concepts are discussed including major CPE components, standard CPE activities and CPE QC measures. PWSs may be required to arrange for a CPE based on individual filter monitoring results.

The appendices to the manual provide additional information for readers related to the terminology and measuring of turbidity, including:

Appendix A – Glossary

Appendix A provides a list of definitions for terms used in the Guidance as well as other useful terms associated with turbidity.

Appendix B – Basic Turbidimeter Design and Concepts

Appendix B provides basic information on turbidimeter designs, measuring principles, design configurations, and various types of turbidimeters.

1.5 References

USEPA. 1989. National Primary Drinking Water Regulations: Surface Water Treatment Rule; Final Rule. 54 FR 27486. June 29, 1989. Available at: http://water.epa.gov/lawsregs/rulesregs/sdwa/swtr/upload/SWTR.pdf.

USEPA. 1998. National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule; Final Rule. 63 FR 69478. December 16, 1998. Available at: http://www.gpo.gov/fdsys/pkg/FR-1998-12-16/pdf/98-32888.pdf.

USEPA. 1999. Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions. EPA 815-R-99-010.

USEPA. 2001. National Primary Drinking Water; Filter Backwash Recycling Rule; Final Rule. 66 FR 31086. June 8, 2001. Available at: https://www.gpo.gov/fdsys/pkg/FR-2001-06-08/pdf/01-13776.pdf.

USEPA. 2002. National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule; Final Rule. 67 FR 1811. January 14, 2002. Available at: https://www.gpo.gov/fdsys/pkg/FR-2002-01-14/pdf/02-409.pdf.

USEPA. 2006a. National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule; Final Rule. 71 FR 653. January 5, 2006. Available at: http://www.gpo.gov/fdsys/pkg/FR-2006-01-05/pdf/06-4.pdf.

USEPA. 2006b. National Primary Drinking Water Regulations: Stage 2 Disinfectants and Disinfection Byproducts Rule; Final Rule. 71 FR 388, January 4, 2006 Available at: https://www.gpo.gov/fdsys/pkg/FR-2006-01-04/pdf/06-3.pdf.

USEPA. 2013. National Primary Drinking Water Regulations: Revisions to the Total Coliform Rule; Final Rule. 78 FR 10269, minor corrections 79 FR 10665, February 13, 2013. Available at: https://www.gpo.gov/fdsys/pkg/FR-2013-02-13/pdf/2012-31205.pdf.

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In this chapter:

- *Turbidity Performance Standards and Monitoring Requirements*
- *Reporting and Recordkeeping*
- *Additional Compliance Issues*
- *References*

CHAPTER 2 – TURBIDITY REQUIREMENTS

2.1 Introduction

This chapter outlines the regulatory requirements for turbidity including established turbidity performance standards by treatment technology, monitoring requirements, reporting requirements, recordkeeping requirements, and additional compliance aspects of the suite of SWTRs related to turbidity.

These requirements apply to PWSs that use surface water or GWUDI of surface water and treat their water with filtration. Any variations to the requirements based on system size will be noted where applicable. Turbidity requirements for PWSs that meet criteria to avoid filtration are discussed briefly in Section 1.2, but not covered in detail in this manual.

2.2 Performance Standards and Monitoring Requirements

As described in Chapter 1, the suite of SWTRs contains several key requirements related to turbidity. This Section will discuss requirements for CFE turbidity performance standards by treatment technology, IFE turbidity monitoring requirements, other requirements related to turbidity, and LT2ESWTR Toolbox options where turbidity is used to measure performance.

2.2.1 CFE Requirements

CFE is generated when the effluent water from individual filters in operation is combined into one stream. PWSs that use surface water or GWUDI of surface water and apply filtration treatment must monitor turbidity in the CFE using an approved method (discussed in Section 3.2) (40 CFR 141.173 and 40 CFR 141.550). PWSs that only have a single filter do not have a “combined” filter effluent. However, for the purposes of this document, all filter effluent will be referred to as CFE.

The CFE turbidity standards and some aspects of CFE turbidity monitoring vary by treatment technology. The following Sections discuss the standards and monitoring requirements based on three groups of treatment technologies:

- Conventional and Direct Filtration
- Slow Sand and DE Filtration
- Other Treatment Technologies (Alternative Filtration)

2.2.1.1 Conventional and Direct Filtration

Conventional filtration is defined as a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal. Direct filtration is defined as a series of processes including coagulation and filtration (but excluding sedimentation), also resulting in substantial particle removal.

Turbidity Standards

For conventional and direct filtration systems, the turbidity standard of representative samples of a PWS's filtered water must be less than or equal to 0.3 NTU in at least 95 percent of the measurements taken each month. The turbidity standard of representative samples of a PWS's filtered water must not exceed 1 NTU at any time. As discussed in Section 1.2, these turbidity standards were introduced with the promulgation of the IESWTR and LT1ESWTR and are more stringent than the original turbidity standards required by the SWTR (40 CFR 141.173 and 40 CFR 141.551).

Conventional and direct filtration CFE turbidity standards are:

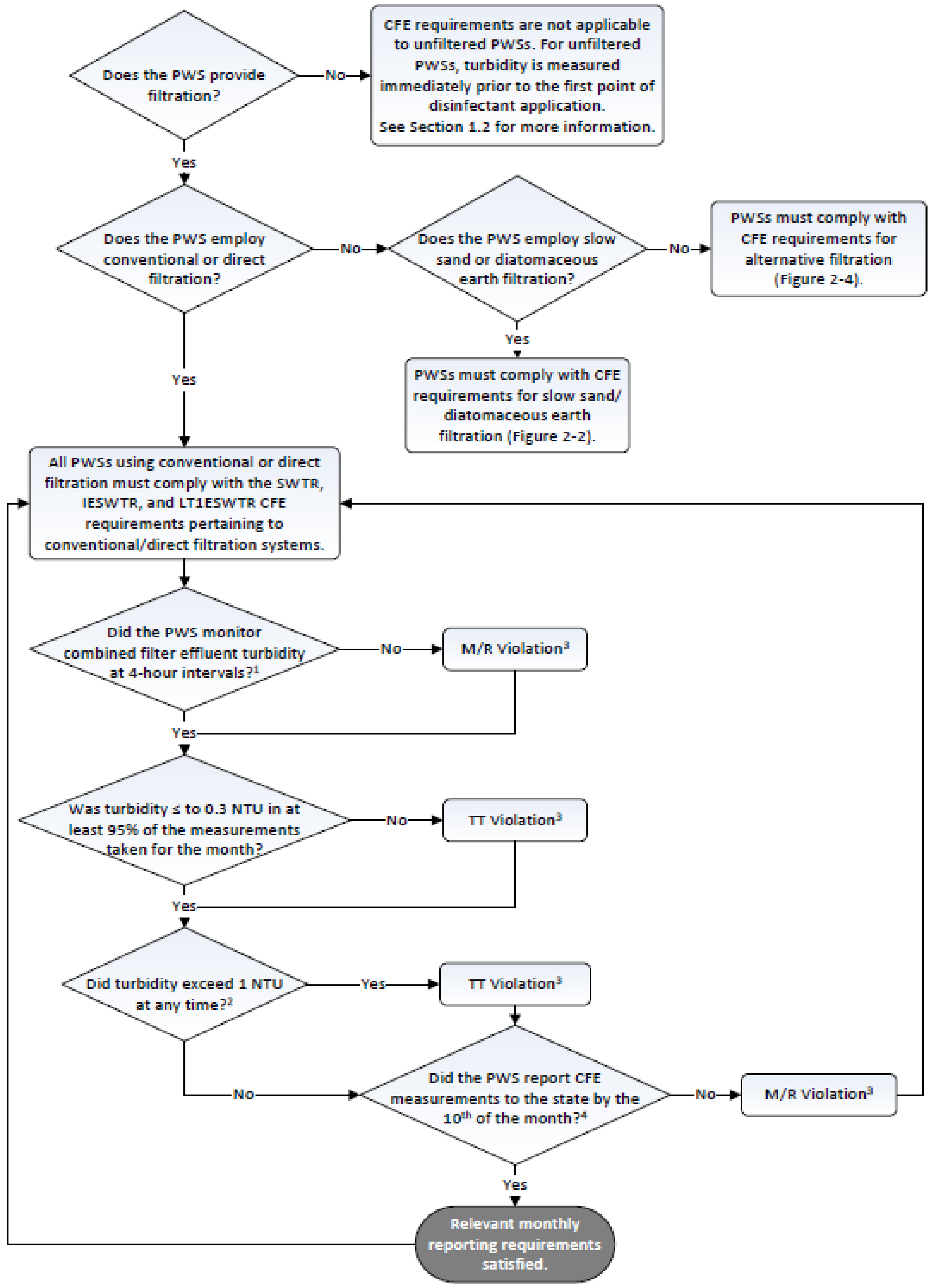
- Less than or equal to 0.3 NTU in 95 percent of measurements
- 1 NTU maximum

Monitoring Requirements

CFE turbidity must be measured every four hours during plant operation [40 CFR 141.74(c)(1)]. Monitoring frequency may be reduced for PWSs serving 500 or fewer persons to once per day if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance. Likewise, the state may require additional or more frequent monitoring for conventional or direct filtration systems of any size. PWSs should check with their state about their CFE turbidity monitoring requirements to ensure they are meeting state requirements.

A PWS may substitute CFE continuous turbidity monitoring for grab sample monitoring if the continuous turbidimeters are validated for accuracy on a regular basis using a protocol approved by the state.

Figure 2-1 presents a flowchart of the CFE turbidity provisions for conventional and direct filtration systems.



1. In accordance with the SWTR [40 CFR 141.74 (c)(1)], the state may reduce this monitoring frequency for PWSs serving 500 or fewer persons to one sample per day if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. PWSs must consult with their state no later than 24 hours after learning of the violation in accordance with the Public Notification Rule [40 CFR 141.203(b)(3)].
3. This violation requires public notification. The required Tier of public notification can be found in Appendix A to Subpart Q of 40 CFR Section 141.
4. PWSs must report to the state the total number of CFE turbidity measurements taken during the previous month, the number and percentage of CFE turbidity measurements that were less than or equal to 0.3 NTU, and the date and value of any CFE turbidity measurements exceeding 1 NTU [40 CFR 141.175(a) and 141.570(a)].

Figure 2-1. Flowchart of CFE Turbidity Provisions for Conventional and Direct Filtration Systems

2.2.1.2 SLOW SAND & DIATOMACEOUS EARTH (DE) FILTRATION

Unlike the other filtration technologies, the turbidity standards for slow sand and DE filters did not change from the original SWTR. These technologies accomplish 2-log *Cryptosporidium* removal with the turbidity limits set in the SWTR.

Turbidity Standards

For slow sand and DE filtration systems, the turbidity standard of representative samples of a PWS's filtered water must be less than or equal to 1 NTU in at least 95 percent of the measurements taken each month. The state may allow a higher turbidity limit if the state determines there is no significant interference with disinfection at the higher level. However, at no time can the turbidity standard exceed 5 NTU [40 CFR 141.73(b) and (c)].

Slow sand and DE CFE turbidity standards are

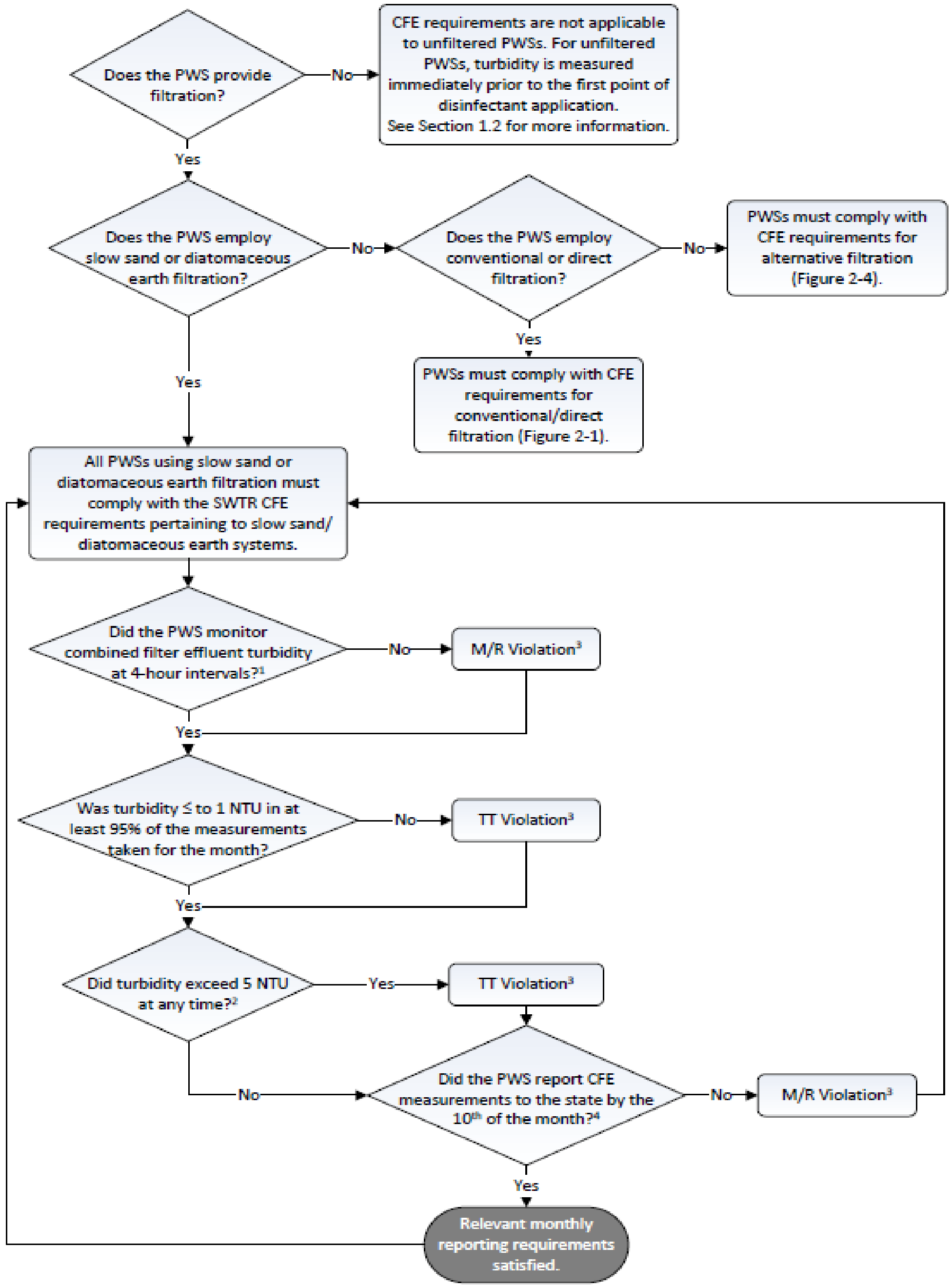
- Less than or equal to 1 NTU in 95 percent of measurements unless state allows a higher limit
- 5 NTU maximum

Monitoring Requirements

CFE turbidity must be measured every four hours that the PWS serves water to the public [40 CFR 141.74(c)(1)]. For slow sand filtration systems of any size and DE systems serving 500 or fewer persons, the state may reduce the sampling frequency to once per day if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance. Likewise, the state may require additional or more frequent monitoring for slow sand or DE systems of any size. PWSs should check with their states about their system's CFE turbidity monitoring requirements to ensure they are meeting state requirements.

A PWS may substitute continuous CFE turbidity monitoring for grab sample monitoring if the continuous turbidimeter is validated for accuracy on a regular basis using a protocol approved by the state.

Figure 2-2 presents a flowchart of combined filter provisions for slow sand and DE filtration. Figure 2-3 shows a slow sand filter in Idaho.



1. In accordance with the SWTR [40 CFR 141.74 (c)(1)], the state may reduce this monitoring frequency to one sample per day for any PWSs using slow sand filtration or for PWSs using DE filtration serving 500 or fewer persons if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. PWSs must consult with their state no later than 24 hours after learning of the violation in accordance with the Public Notification Rule [40 CFR 141.203(b)(3)].
3. This violation requires public notification. The required Tier of public notification can be found in Appendix A to Subpart Q of 40 CFR Section 141.
4. PWSs must report to the state the total number of turbidity measurements taken during the previous month, the number and percentage of turbidity measurements that were less than or equal to 1 NTU, and the date and value of any turbidity measurements exceeding 5 NTU.

Figure 2-2. Flowchart of CFE Turbidity Provisions for Slow Sand and DE Filtration Systems

Figure 2-3. Slow Sand Filter in Idaho

2.2.1.3 Other Treatment Technologies (Alternative Filtration)

Alternative filtration CFE turbidity standards are

- Less than or equal to the state-established limit (not to exceed 1 NTU) in 95 percent of measurements
- State-established maximum (not to exceed 5 NTU)

Alternative filtration technologies are technologies other than conventional, direct, slow sand, and DE filtration and can include cartridges filters, bag filters, or membrane filtration. PWSs using alternative filtration technologies must demonstrate to the state using pilot plant studies or other means, that the technology in combination with disinfection treatment will meet the following requirements (40 CFR 141.173(b) and 40 CFR 141.552):

- 2-log removal of *Cryptosporidium* oocysts.
- 3-log removal/inactivation of *Giardia lamblia* cysts.
- 4-log removal/inactivation of viruses.

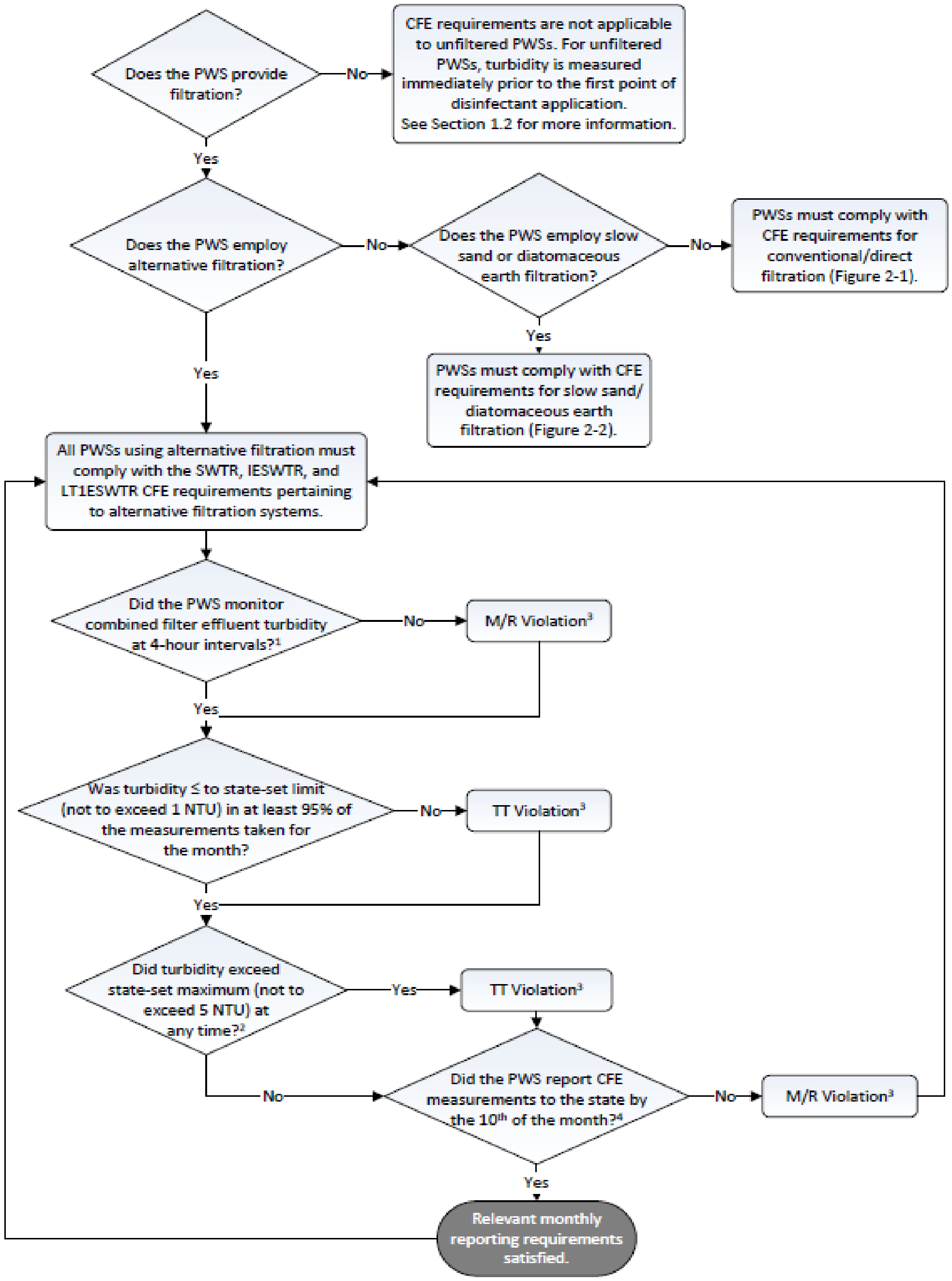
Turbidity Standards

The state establishes the turbidity standards for PWSs using alternative filtration based on demonstration of a PWS's performance. The CFE turbidity for alternative filtration systems must be less than or equal to the state-established limit (not to exceed 1 NTU) for 95 percent of the readings taken each month and may at no time exceed the state-established maximum (not to exceed 5 NTU) for any reading (40 CFR 141.173(b) and 40 CFR 141.551).

Monitoring Requirements

CFE turbidity must be measured every four hours that the PWS serves water to the public [40 CFR 141.74(c)(1)]. For alternative filtration systems of any size, the state may reduce the sampling frequency to once per day if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance. Likewise, the state may require additional or more frequent monitoring for alternative filtration systems of any size. PWSs should check with their state on CFE monitoring requirements to ensure they are meeting state requirements.

Figure 2-4 presents a flow chart of CFE turbidity provisions for alternative filtration technologies. Figure 2-5 shows two cartridge filters at a small PWS.



1. In accordance with the SWTR [40 CFR Section 141.74 (c)(1)], the state may reduce this frequency to one sample per day if the state determines that less frequent monitoring is sufficient to indicate effective filtration performance.
2. PWSs must consult the state no later than 24 hours after learning of the violation in accordance with the Public Notification Rule [40 CFR 141.203(b)(3)].
3. This violation requires public notification. The required Tier of public notification can be found in Appendix A to Subpart Q of 40 CFR Section 141.
4. PWSs must report to the state the total number of CFE turbidity measurements taken during the previous month, the number and percentage of CFE turbidity measurements that were less than or equal to the state-set limit (not to exceed 1 NTU), and the date and value of any CFE turbidity measurements exceeding the state-set maximum value (not to exceed 5 NTU).

Figure 2-4. Flowchart of CFE Turbidity Provisions for Alternative Filtration Systems

Figure 2-5. Cartridge Filters Installed at a Small PWS

2.2.2 Special Provisions for PWSs that Use Lime Softening

Sometimes PWSs that practice lime softening may experience elevated turbidities due to carryover of lime from the softening processes. If this significantly affects filter effluent turbidities, PWSs may apply to the state for alternative exceedance levels if they can demonstrate that higher turbidity levels in individual filters are due to lime carryover only and not due to degraded filter performance (40 CFR 141.175(b) and 40 CFR 141.564). Systems may acidify representative CFE turbidity samples prior to analysis using a protocol approved by the state [40 CFR 141.173(a)(3) and 40 CFR 141.553].

EPA recommends that acidification protocols lower the pH of samples to less than 8.3. EPA also recommends that the acid used be either hydrochloric acid or sulfuric acid of Standard Lab Grade. Care should be taken when handling the acid. EPA recommends that PWSs maintain documentation regarding the turbidity with and without acidification, pH values before and after acidification, and the quantity of acid added to a given sample volume.

2.2.3 IFE Turbidity Requirements

In addition to the CFE turbidity monitoring discussed above, those PWSs that use ***conventional treatment*** or ***direct filtration*** must conduct continuous turbidity monitoring of each individual filter's effluent to provide information on each filter's performance (40 CFR 141.174 and 40 CFR 141.560). PWSs that use filtration techniques other than conventional or direct filtration are not required to conduct IFE turbidity monitoring, although EPA recommends such PWSs consider doing so to enhance the operation of their treatment plants.

Continuous Turbidity Monitoring: Requirements

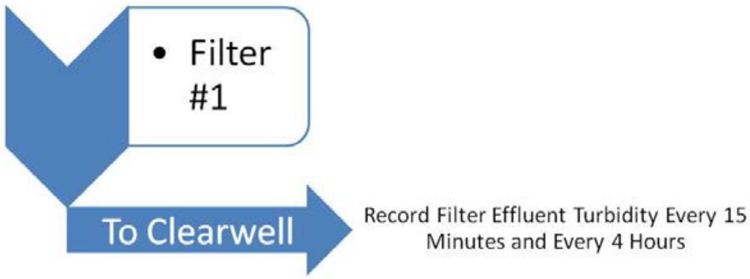
PWSs with more than two filters must continuously monitor and record each individual filter's effluent turbidity at least every 15 minutes. PWSs with two or fewer filters may conduct continuous monitoring of CFE turbidity in lieu of IFE turbidity. Systems that have two filters are therefore not required to monitor individual filters if the CFE turbidity from both filters is continuously monitored and recorded at least every 15 minutes. Systems should check with their primacy agency to confirm that this is acceptable. If a filter is not providing water which contributes to the CFE, (i.e., it is not operating, is filtering to waste, or is being backwashed) the PWS does not need to record or monitor turbidity for that specific filter during that period (40 CFR 141.174 and 40 CFR 141.560).

A brief summary of turbidity monitoring requirements for the specified number of filters is shown in Table 2-1. Figure 2-6 provides an illustration of IFE and CFE turbidity monitoring requirements.

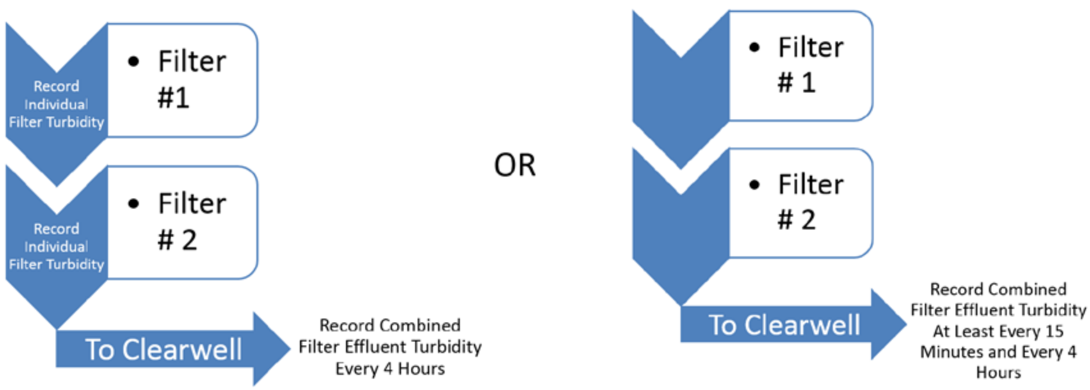
Table 2-1. CFE and IFE Turbidity Monitoring Requirements for Conventional and Direct Filtration Systems

Number of Filters	Monitoring Requirements
1	• IFE turbidity continuously monitored and recorded at least every 15 minutes. • 4-hour turbidity readings must be recorded [40 CFR 141.74(c)(1)].
2	• CFE turbidity continuously monitored and recorded at least every 15 minutes or IFE turbidity recorded at least every 15 minutes. • CFE turbidity must be recorded every 4 hours [40 CFR 141.74(c)(1)].
More Than 2	• Individual filters are continuously monitored, and the IFE turbidity results are recorded at least every 15 minutes. • CFE turbidity must be recorded every 4 hours [40 CFR 141.74(c)(1)].

For PWSs with one filter, IFE turbidity must be recorded at least every 15 minutes and every 4 hours.



For PWSs with two filters, CFE turbidity or IFE turbidity must be recorded at least every 15 minutes. In addition, CFE turbidity must be recorded every 4 hours:



For PWSs with more than two filters, IFE turbidity must be recorded at least every 15 minutes and CFE must be recorded at least every 4 hours:

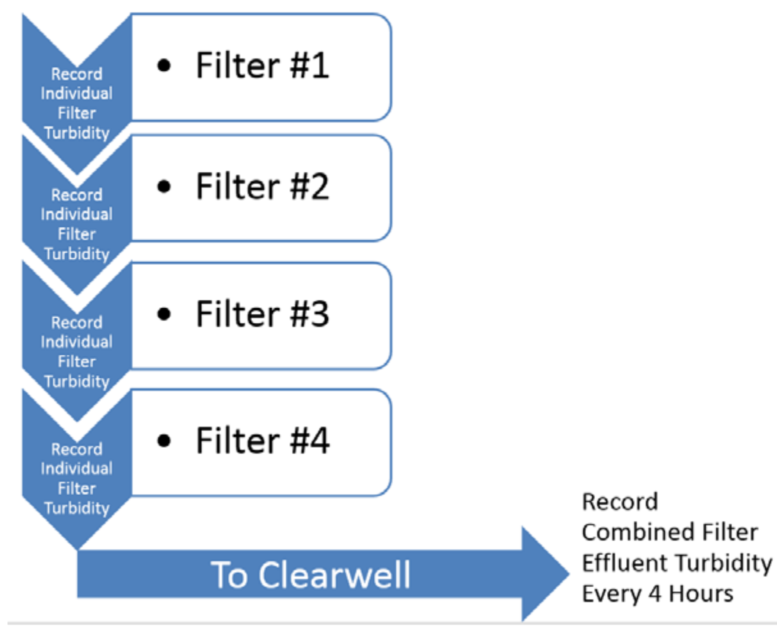


Figure 2-6. Turbidity Monitoring Requirements for Conventional and Direct Filtration Plants [40 CFR 141.74(c)(1), 40 CFR 141.174, 40 CFR 141.560, and 141.562]

Monitoring must be conducted using an approved method [40 CFR 141.74(a)]. Calibration of turbidimeters must be conducted using procedures specified by the manufacturer. More information on turbidity sampling, including approved methods, is provided in Chapter 3 of this manual.

In the event of a failure of continuous turbidity monitoring equipment, the PWS must conduct grab sampling every 4 hours in lieu of continuous monitoring until the equipment is replaced or repaired. PWSs serving 10,000 or more persons must resume continuous monitoring within 5 working days following the failure of the equipment [40 CFR 141.174(b)]. PWSs serving fewer than 10,000 persons have 14 days to resume continuous monitoring (40 CFR 141.561).

Continuous Turbidimeter Repair Schedule:

- PWSs serving 10,000 or more persons have 5 working days
- PWSs serving fewer than 10,000 persons have 14 days

Continuous Turbidity Monitoring: Follow-up Actions

Follow-up actions are triggered based on exceedances of 15-minute interval IFE turbidity values (even if readings are taken more frequently for operational purposes). Follow-up actions vary from notification of the state to having a comprehensive performance evaluation (CPE) performed. It is important to note that state regulations for IFE monitoring and reporting may be more stringent. In addition, PWSs that practice lime softening may apply to the state for alternative turbidity exceedance values. PWSs must be able to demonstrate to the state that the higher turbidity levels are due to lime carryover only and are not due to degraded filter performance [40 CFR 141.175(b) and 40 CFR 141.564].

Table 2-2 describes the follow-up actions that are required based on the 15-minute readings.

Table 2-2. Follow-up Requirements in Response to IFE Turbidity Triggers (40 CFR 141.175(b) and 40 CFR 141.563)

If the turbidity of an individual filter (or the turbidity of CFE for PWSs with 2 filters that monitor CFE in lieu of individual filters) exceeds…	Then the PWS must:
1.0 NTU for two or more consecutive 15-minute readings in one month…	• Report to the state by the 10th of the following month and include the filter number(s), corresponding date(s), the turbidity value(s) that exceeded 1.0 NTU, and the cause (if known) for the exceedance(s). • For PWSs serving 10,000 or more persons, if the PWS does not know the cause of the exceedance, it must produce a filter profile for the filter within seven days of the exceedance and report to the state that the profile has been produced.

If the turbidity of an individual filter (or the turbidity of CFE for PWSs with 2 filters that monitor CFE in lieu of individual filters) exceeds…	Then the PWS must:
0.5 NTU for two or more consecutive 15- minute readings at the end of the first four hours of continuous filter operation after the filter has been backwashed or otherwise taken offline… (*This scenario only applies to PWSs that serve 10,000 or more persons*.)	• Report to the state by the 10th of the following month and include the filter number(s), corresponding date(s), the turbidity values that exceeded 0.5 NTU, and the cause (if known) for the exceedance. • If the PWS does not know the cause of the exceedance, it must produce a filter profile for the filter within seven days of the exceedance and report to the state that the profile has been produced.
1.0 NTU in two or more consecutive 15-minute readings for three consecutive months…	• Report to the state by the 10th of the following month and include the filter number(s), corresponding dates, and turbidity values. • The PWS must also conduct a filter self-assessment of the filter(s) within 14 days of the day the filter exceeded the 1.0 NTU in two consecutive measurements for the third straight month and report to the state that the self-assessment was conducted (unless a CPE is required). • PWSs with two filters that monitor CFE instead of IFE must conduct a self-assessment of both filters.[1]
2.0 NTU in two or more consecutive 15-minute readings for two months in a row...	• Report to the state by the 10th of the following month and include the filter number(s), corresponding dates, and turbidity values. • The PWS must also arrange for a CPE (conducted by the state or third party approved by the state), no later than 30 days for PWSs serving 10,000 or more persons, or 60 days for PWSs serving fewer than 10,000 persons[2] following the day the filter exceeded 2.0 NTU for two consecutive measurements for the second straight month. • The CPE must be completed and submitted to the state no later than 90 days for PWSs serving 10,000 or more persons and 120 days for PWSs serving fewer than 10,000 persons following the CPE trigger date.

1. The self-assessment must consist of at least the following components: assessment of filter performance; development of a filter profile; identification and prioritization of factors limiting filter performance; assessment of the applicability of corrections; and preparation of a filter self-assessment report.
2. For PWSs serving fewer than 10,000 persons, if a CPE has been completed by the state or a third party approved by the state within the 12 prior months or the PWS and state are jointly participating in an ongoing Comprehensive Technical Assistance project at the PWS, a new CPE is not required.

2.2.4 LT2ESWTR Toolbox Options

PWSs can receive treatment credits for *Cryptosporidium* under the LT2ESWTR by meeting certain conditions as outlined in the microbial toolbox options of this rule. Some of the toolbox options use turbidity as the measure of performance including:

- Combined filter performance.
- Individual filter performance.
- Presedimentation basin with coagulation.
- Bank filtration.
- Membrane filtration.

Table 2-3 summarizes the turbidity requirements related to each of these toolbox options. Turbidity must be measured using approved methods as described in Chapter 3 of this manual [40 CFR 141.74(a)].

Table 2-3. Microbial Toolbox Options that Incorporate Turbidity and their Turbidity Criteria [40 CFR 141.715(b)]

Toolbox Option	Turbidity Criteria
Combined filter performance	CFE turbidity ≤ 0.15 NTU in 95 percent of samples each month.
Individual filter performance	IFE turbidity is ≤ 0.15 NTU in at least 95 percent of samples each month in each filter and is never greater than 0.3 NTU in two consecutive measurements in any filter.
Pre-sedimentation basin with coagulation	Basins must achieve a monthly mean reduction of 0.5-log or greater in turbidity or alternative state-approved performance criteria.
Bank filtration	Average turbidity for each well must be less than 1 NTU.
Membranes (microfiltration, ultrafiltration, nanofiltration, reverse osmosis)	Monitor effluent turbidity (or state-approved alternative parameter) every 15 minutes. Maintain turbidity at ≤ 0.15 NTU.

The toolbox options that incorporate turbidity are discussed in more detail in the following Sections. A complete list of toolbox options and all of the associated requirements can be found in the *LT2ESWTR Toolbox Guidance Manual* (USEPA, 2010a) which is available at: https://www.epa.gov/dwreginfo/long-term-2-enhanced-surface-water-treatment-rule-documents.

2.2.4.1 COMBINED FILTER PERFORMANCE

Under the LT2ESWTR, states may grant additional *Cryptosporidium* treatment credit to PWSs with plants that use conventional or direct filtration processes and maintain finished water turbidity at levels significantly lower than what is required under the IESWTR or LT1ESWTR (0.3 NTU). PWSs operating conventional or direct filtration plants may receive an additional 0.5-log credit towards *Cryptosporidium* treatment requirements if the CFE turbidity is less than or equal to 0.15 NTU in at least 95 percent of the measurements taken each month. Compliance with this criterion must be based on turbidity measurements of the CFE taken every 4 hours (or more frequently) while the plant serves water to the public [40 CFR 141.718(a)].

States may not grant this credit to PWSs with membrane, bag/cartridge, slow sand, or DE plants, due to the lack of documented correlation between filter effluent turbidity and *Cryptosporidium* removal for these processes. States may, however, grant PWSs removal credit for using membrane filtration (including the membrane technologies of microfiltration, ultrafiltration, nanofiltration, and reverse osmosis) as described in Section 2.2.4.5 below.

2.2.4.2 *Individual Filter Performance*

Under the LT2ESWTR, states may grant PWSs with conventional or direct filtration processes 0.5-log *Cryptosporidium* treatment credit (in addition to credit for combined filter performance) if IFE turbidity measurements meet the following criteria:

1. Filtered water turbidity is less than or equal to 0.15 NTU in at least 95 percent of the 15-minute values recorded at each filter in each month; and

2. No individual filter has a measured turbidity level greater than 0.3 NTU in two consecutive measurements taken 15 minutes apart.

If the individual filter is not providing water which contributes to the CFE (i.e., it is not operating, is filtering to waste, is being backwashed, or its filtrate is being recycled), the PWS does not need to report turbidity for that specific filter.

If the PWS receives credit for this toolbox option and fails to meet both criteria, the PWS incurs a treatment technique violation unless the state determines:

- The failure was due to unusual and short-term circumstances that could not reasonably be prevented through optimizing treatment plant design, operation, and maintenance.

- The PWS has experienced no more than two such failures in any calendar year.

2.2.4.3 *Presedimentation Basin with Coagulation*

Presedimentation is a preliminary treatment process used to remove gravel, sand, and other material from the raw water and reduce particle loading fluctuations to the rest of the treatment plant. Presedimentation basins with coagulant addition may receive 0.5-log *Cryptosporidium* removal credit under the LT2ESWTR if the following criteria are met:

- The presedimentation basin must be in continuous operation and must treat all of the flow taken from a surface water or GWUDI source [40 CFR 141.717(a)(1)].

- A coagulant must be continuously added to the presedimentation basin while the plant is in operation [40 CFR 141.717(a)(2)].

- The presedimentation basin must achieve a monthly mean reduction of 0.5-log or greater of influent turbidity (or state-approved alternative). This reduction must be determined using daily turbidity measurements in the presedimentation process influent and effluent and must be calculated as follows: $\log_{10}$ (monthly mean of daily influent turbidity) − $\log_{10}$ (monthly mean of daily effluent turbidity) [40 CFR 141.717(a)(3)].

2.2.4.4 BANK FILTRATION

Bank filtration is a surface water pretreatment process that uses the bed or bank of a river (or lake) and the adjacent aquifer as a natural filter. To accomplish this, a pumping well located in the adjacent aquifer induces surface water infiltration through the bed and bank. PWSs that propose to install bank filtration wells to meet additional treatment requirements under the LT2ESWTR may be eligible for 0.5- or 1.0-log *Cryptosporidium* removal credit. For this toolbox option, PWSs are required to monitor turbidity in bank filtration wells to provide assurance that the assigned log removal credit is appropriate. The following monitoring is required [40 CFR 141.717(b)(5)]:

- Turbidity measurements must be performed on representative water samples from each wellhead every four hours that the bank filtration system is in operation or more frequently if required by the state.

- Continuous turbidity monitoring at each wellhead may be used.

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

2.2.4.5 MEMBRANE FILTRATION

Under the LT2ESWTR, states may grant PWSs removal credit for using membrane filtration (including the membrane technologies of microfiltration, ultrafiltration, nanofiltration, and reverse osmosis). Three types of tests are used to ensure the membrane filtration system can and will operate according to manufacturer specifications: challenge testing, direct integrity testing, and indirect integrity testing.

- Challenge testing is performed before the membrane system is in service and determines the membrane's ability to remove introduced *Cryptosporidium* oocysts or surrogates in simulation of operational conditions.

- Direct integrity testing is a physical test applied to the membrane unit in order to identify and isolate integrity breeches and is conducted at a frequency of not less than once each day that the membrane unit is in operation.

- Indirect integrity monitoring involves monitoring an aspect of filtered water quality that indicates how much particulate matter is removed. PWSs must continuously monitor and record effluent turbidity (or an alternative parameter approved by the state) for each membrane unit at least every 15 minutes. If the filtrate turbidity readings are above 0.15 NTU for a period greater than 15 minutes (i.e., two consecutive 15-minute readings are above 0.15 NTU), direct integrity testing must immediately be performed on the associated membrane unit [40 CFR 141.719(b)(4)].

The maximum removal credit that a membrane filtration process is eligible to receive is based on the removal efficiency demonstrated during challenge testing or the maximum removal efficiency that can be verified through direct integrity testing, whichever is lower.

2.3 Reporting and Recordkeeping

Under the suite of SWTRs, PWSs are required to report to the state certain information associated with CFE and IFE turbidity monitoring. In addition, PWSs that are required to utilize toolbox options under LT2ESWTR have additional reporting requirements for the selected toolbox option(s). PWSs have additional public notification requirements that are discussed in Section 2.4.2.1.

2.3.1 CFE Reporting

PWSs must report turbidity measurements related to CFE monitoring to the state within 10 days after the end of each month the PWS serves water to the public [40 CFR 141.75(b)(1), 40 CFR 141.175(a) and 40 CFR 141.570(a)]. The required information differs depending on the PWS's treatment technology. PWSs are required to report:

Conventional and Direct Filtration

- The total number of CFE turbidity measurements taken during the month.
- The number and percentage of CFE turbidity measurements taken during the month which were less than or equal to the PWS's required 95th percentile limit of 0.3 NTU.
- The date and value of any CFE turbidity measurement taken during the month that exceeded 1 NTU.

Slow Sand and DE Filtration

- The total number of CFE turbidity measurements taken during the month.
- The number and percentage of CFE turbidity measurements taken during the month which were less than or equal to the PWS's required 95th percentile limit of 1 NTU.
- The date and value of any CFE turbidity measurement taken during the month that exceeded 5 NTU.

Alternative Filtration

- The total number of CFE turbidity measurements taken during the month.
- The number and percentage of CFE turbidity measurements taken during the month which were less than or equal to the PWS's required 95th percentile state-established limit (not to exceed 1 NTU).
- The date and value of any CFE turbidity measurement taken during the month which exceeded the state-established maximum limit (not to exceed 5 NTU).

2.3.2 IFE Reporting

PWSs utilizing conventional and direct filtration must report the information included in Table 2-4 to the state for IFE monitoring [40 CFR 141.175(b) and 40 CFR 141.570(b)].

Table 2-4. Reporting Requirements for IFE Monitoring [40 CFR 141.175(b) and 141.570(b)]

Description of Information to Report	Frequency
That the PWS conducted individual filter turbidity monitoring during the month.	By the 10th day of the following month.
The filter number(s), corresponding date(s), and the turbidity value(s) which exceeded 1.0 NTU during the month, but only if two consecutive measurements exceeded 1.0 NTU.	By the 10th day of the following month.
For PWSs serving 10,000 or more persons, the filter number(s), corresponding date(s), and the turbidity values which exceeded 0.5 NTU during the month, but only if two consecutive measurements exceeded 0.5 NTU at the end of the first four hours of continuous operation. PWSs must also report the cause for the exceedance. If the PWS does not know the cause, it must produce a filter profile within seven days of the exceedance, and report to the state that the profile has been produced.	By the 10th day of the following month.
If a PWS is required to conduct a filter self-assessment, the PWS must report to the state, the date that it was triggered and the date that it was completed.	By the 10th day of the following month (or 14 days after the filter self-assessment was triggered only if the filter self-assessment was triggered during the last four days of the month). See Chapter 5 for more information on the filter self-assessment process.
If a PWS is required to conduct a CPE, the PWS must report to the state that the CPE is required and the date that it was triggered.	By the 10th day of the following month.
Copy of the completed CPE report.	Within 90 days after the CPE was triggered for PWSs serving 10,000 or more persons and 120 days after the CPE was triggered for PWSs serving fewer than 10,000 persons. See Chapter 6 for more information on CPEs.

2.3.3 LT2ESWTR Toolbox Reporting Requirements

PWSs that are required to utilize a toolbox option, are required to report certain information to the state based on the selected toolbox option:

Combined Filter Performance

In order to receive the 0.5-log removal credit for the combined filter performance toolbox option, a PWS must report to the state, by the 10th day of the following month, verification that it has achieved CFE turbidity levels that are less than or equal to 0.15 NTU in at least 95 percent of the four-hour CFE turbidity measurements taken each month [40 CFR 141.721(f)(6)]. Note that if a PWS uses this toolbox option, the PWS is still required to report the CFE turbidity information discussed in Section 2.3.1.

Individual Filter Performance

In order to receive the 0.5-log removal credit for the individual filter performance toolbox option, a PWS must report to the state, by the 10th day of the following month, verification that it has achieved IFE turbidity levels that are less than or equal to 0.15 NTU in at least 95 percent of all maximum daily IFE turbidity measurements taken each month for each filter (excluding the 15 minute period following startup after backwash), and that there were no IFE turbidity measurements greater than 0.3 NTU in two consecutive readings 15 minutes apart for any filter [40 CFR 141.721(f)(7)]. Note that if a PWS uses this toolbox option, the PWS is still required to report IFE turbidity information discussed in Section2.3.2.

Presedimentation Basin with Coagulation

In order to receive the 0.5-log removal credit for the presedimentation basin with coagulation toolbox option, a PWS must report to the state, by the 10th day of the following month, verification that the presedimentation basin was in continuous operation, 100 percent of the flow was treated with the coagulant, there was a continuous addition of coagulant, and there was at least 0.5-log mean reduction of influent turbidity (or compliance with alternative state-approved performance criteria) [40 CFR 141.721(f)(3)].

Bank Filtration

After establishing a log removal credit for the bank filtration toolbox option (either 0.5- or 1.0-log removal credit), a PWS is only required to report to the state if the monthly average of the daily maximum turbidity is greater than 1 NTU. If this occurs, the PWS must report the result to the state, and submit an assessment of the cause within 30 days following the month in which the PWS conducted the monitoring [40 CFR 141.721(f)(5)].

Membrane Filtration

After reporting results of the challenge test and the initial direct integrity test to establish log-removal credit for the membrane filtration toolbox option, a PWS must routinely report to the state, by the 10th day of the following month, all direct integrity tests above the control limit; and if applicable, any turbidity or alternative state-approved indirect integrity monitoring results triggering direct integrity testing, and the corrective action taken by the PWS [40 CFR 141.721(f)(10)].

2.3.4 Recordkeeping Requirements

PWSs must keep CFE turbidity monitoring records and any other turbidity analyses, with the exception of IFE monitoring records, for at least 5 years. PWSs must keep records from IFE turbidity monitoring for at least 3 years. These records must be readily available for state representatives to review during sanitary surveys or other site visits [40 CFR 141.33(a), 40 CFR 141.175(b) and 40 CFR 141.571(a)].

Section 2.4.2.2 includes information on PWS record keeping requirements for public notification (PN).

2.4 Additional Compliance Issues

The following Section outlines additional compliance issues associated with the suite of SWTRs. These include individual filter follow-up actions, PN, and variances and exemptions.

2.4.1 Individual Filter Follow-up Actions

As discussed in Section 2.2.3, a PWS may have to conduct follow-up actions due to persistently high turbidity levels at an individual filter which may include:

- A filter profile because of abnormal filter performance that cannot be identified.
- An individual filter self-assessment.
- A CPE.

2.4.1.1 Abnormal Filter Operations- Filter Profile

PWSs of any size must produce a filter profile if the PWS is required to conduct a filter self-assessment. For PWSs that serve 10,000 or more persons, a filter profile must be developed if the PWS cannot identify an obvious reason for abnormal filter performance [40 CFR 141.175(b)(1) and (2)].

A filter profile is a graphical representation of individual filter performance based on continuous turbidity measurements or total particle counts versus time for an entire filter run, from startup to backwash inclusively that includes assessment of filter performance while another filter is being backwashed. The run length during this assessment should be representative of typical plant filter runs. The profile should include an explanation of the cause of any filter performance spikes during the run.

An example filter profile is included in Figure 2-7.

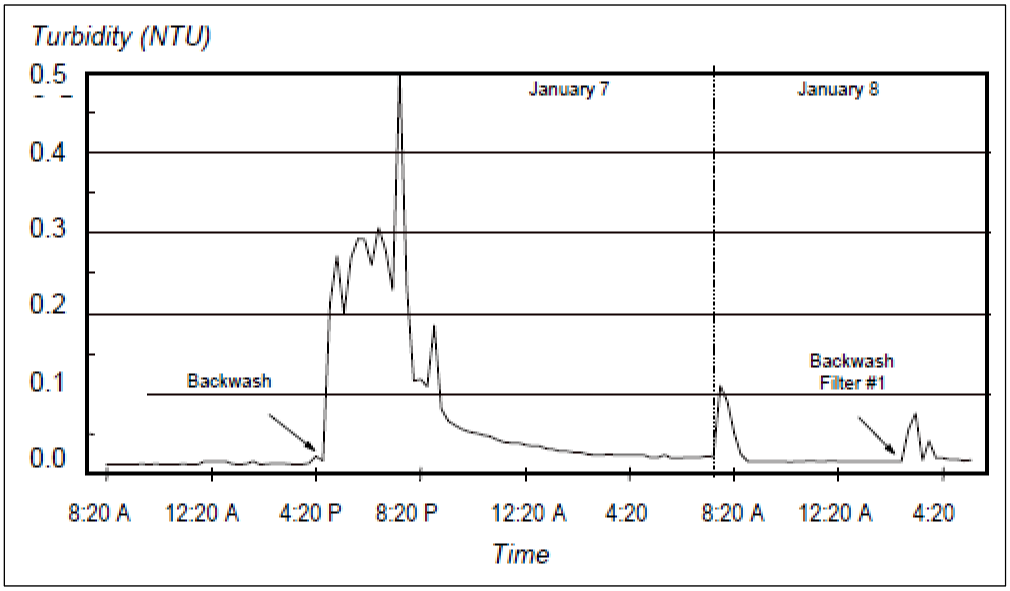


Figure 2-7. Example Filter Profile

Examples of possible abnormal filter operations (which may be obvious to operators), include:

- Outages or maintenance activities at processes within the treatment train.
- Coagulant feed pump or equipment failure.
- Filters being run at significantly higher loading rates than approved.

It is important to note that while the reasons for abnormal filter operation may appear obvious, there could also be other reasons which are more difficult to identify. These may include situations such as:

- Disruption in filter media.
- Excessive or insufficient coagulant dosage.
- Hydraulic surges due to pump changes or other filters being brought on/offline.

In addition to meeting filter profile requirements, PWSs need to use best professional judgment and discretion in determining when to develop a filter profile. Attention at this stage may help PWSs avoid the necessity to take additional follow-up actions, as described below.

2.4.1.2 INDIVIDUAL FILTER SELF-ASSESSMENT

A PWS must conduct an individual filter self-assessment for any individual filter that has a measured turbidity level of greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart in each of three consecutive months. The PWS must report to the state, the filter number, the turbidity measurement, and the dates on which the exceedances occurred [40 CFR 141.175(b)(3) and 40 CFR 141.563(b)]. Chapter 5 discusses how to conduct an individual filter self-assessment, which must consist of the following components:

- assessment of filter performance;
- development of a filter profile;
- identification and prioritization of factors limiting filter performance;
- assessment of the applicability of corrections; and
- preparation of a filter self-assessment report.

2.4.1.3 COMPREHENSIVE PERFORMANCE EVALUATION (CPE)

A PWS must conduct a CPE if any individual filter has a measured turbidity level of greater than 2.0 NTU in two consecutive measurements taken 15 minutes apart in two consecutive months. The PWS must report the filter number, the turbidity measurement, and the date(s) on which the exceedance occurred. The PWS shall contact the state, or a third party approved by the state, to conduct a CPE [40 CFR 141.175(b)(4) and 40 CFR 141.563(c)].

Chapter 6 briefly discusses how to conduct a CPE. Additionally, EPA has developed additional guidance that can be found in EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998) which is available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents .

2.4.2 Notification

PWSs are required to notify the state and the public of certain violations or situations related to turbidity. The requirements for public notification are discussed below.

2.4.2.1 PUBLIC NOTIFICATION (PN)

PWSs must notify the public according to the PN requirements 40 CFR subpart Q. PWSs subject to the suite of SWTRs may be required to provide PN for violations or situations related to turbidity.

PN is divided into three Tiers depending on the severity of the violation or situation. Each Tier has its own timing and delivery requirements.

- Tier 1 PN is required for violations or situations that have significant potential to have serious adverse effects on human health as a result of short-term exposure.
- Tier 2 PN is required for violations or situations with potential to have serious adverse effects on human health.
- Tier 3 PN is required for all violations or situations not included in Tier 1 and Tier 2.

Table 2-5 shows each violation for turbidity and its required PN by Tier [40 CFR 141 Subpart Q, Appendix A]. Additional guidance on the PN requirements for both turbidity related violations and all other National Primary Drinking Water Regulations (NPDWRs), can be found in EPA's *Revised Public Notification Handbook* (USEPA, 2010b). TNCWSs should reference EPA's *Public Notification Handbook for Transient Non-Community Water Systems* (USEPA, 2010c). Both documents are available at: https://www.epa.gov/dwreginfo/public-notification-rule-compliance-help-water-system-owners-and-operatorsv.

Table 2-5. Turbidity Violations by Public Notification Tier [40 CFR 141 Subpart Q, Appendix A]

Tier	Violation
Tier 1	• A single exceedance of the allowable turbidity limit where the state determines, after consultation with the PWS, that a Tier 1 PN is required or where consultation does not take place within 24 hours after the PWS learns of the violation.[1]
Tier 2	• A single exceedance of the allowable turbidity limit where the state determines, after consultation with the PWS, that a Tier 2 PN is appropriate. • Exceeding a prescribed turbidity limit for filtered systems in more than 5 percent of the monthly CFE samples. The prescribed turbidity limits are based on the type of treatment employed by the PWS and are discussed in Section 2.2.1 of this chapter.

Tier	Violation
Tier 3	• Turbidity monitoring and testing violations. • For conventional and direct filtration PWSs, individual filter monitoring is not performed using an approved method, calibration of the turbidimeters is not conducted using procedures specified by the manufacturer, or results of turbidity monitoring are not recorded every 15 minutes. • For conventional and direct filtration PWSs, failure to conduct grab sampling every four hours if there is a failure of the continuous turbidity monitoring equipment or failure to repair the equipment within 5 business days for PWSs serving 10,000 or more persons and 14 days for PWSs serving fewer than 10,000 persons. • For conventional and direct filtration PWSs, failure to perform individual filter follow-up actions as triggered by results of continuous turbidity monitoring. The results that trigger follow-up action are discussed in Section 2.2.3 of this chapter.

1. PWSs are required to consult with the state after learning of a single exceedance of the allowable turbidity limit. For filtered systems, the limits are based on the type of treatment employed by the PWS and are discussed in Section 2.2.1 of this chapter. For PWSs approved for filtration avoidance, the limit is 5 NTU.

2.4.2.2 State Notification

As discussed in Section 2.4.2.1, if a single exceedance of the allowable turbidity limit occurs, PWSs must notify the state within 24 hours of learning of the violation. For all other turbidity violations, PWSs are required to notify the state within 48 hours [40 CFR 141.31(b), 40 CFR 14175(c)(3)(ii) and 40 CFR 141.175(c)].

The PWS must also submit to the state, a representative copy of each PN that the PWS distributes, publishes, posts, and/or makes available to persons served by the PWS and/or the media. The PWS must also certify that it has fully complied with the PN regulations within 10 days of completing the notice [40 CFR 141.31(d)]. The PWS must retain copies of public notices and certifications provided to the state for three years [40 CFR 141.33(e)].

2.5 References

AWWA. 1991. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Systems. Denver, CO.

Logsdon, G., M.M. Frey, T.D. Stefanich, S.L. Johnson, D.E. Feely, J.B. Rose, and M. Sobsey. 1994. The Removal and Disinfection Efficiency of Lime Softening Processes for Giardia and Viruses. AWWARF, Denver, CO.

NSF International. Verification Testing Protocol for Equipment for Physical Removal of Microbiological and Particulate Contaminants. Available at: http://www.epa.gov/etv/pubs/059205epadwctr.pdf.

Sawyer, C.N., P.L. McCarty, and G.F. Parkin. 1994. Chemistry for Environmental Engineering. Fourth Edition. McGraw Hill, New York, NY.

Viessman, W., and M.J. Hammer. 1993. Water Supply and Pollution Control. Fifth Edition. Harper Collins, New York, NY.

Von Huben, H. 1995. Water Treatment: Principles and Practices of Water Supply Operations. Second Edition. AWWA.

Von Huben, H. 1995. Basic Science Concepts and Applications: Principles and Practices of Water Supply Operations. Second Edition. AWWA.

USEPA. 1998. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA/625/6-91/027. Revised August 1998. Available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents.

USEPA. 2010a. LT2ESWTR Toolbox Guidance Manual. EPA 815-R-09-016. April 2010. Available at: https://www.epa.gov/dwreginfo/long-term-2-enhanced-surface-water-treatment-rule-documents.

USEPA. 2010b. Revised Public Notification Handbook. EPA 816-R-09-013. March 2010. Available at: https://www.epa.gov/dwreginfo/public-notification-rule-compliance-help-water-system-owners-and-operators.

USEPA. 2010c. Public Notification Handbook for Transient Non-Community Water Systems. EPA 816-R-09-009. March 2010. Available at: https://www.epa.gov/dwreginfo/public-notification-rule-compliance-help-water-system-owners-and-operators.

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In this chapter:

- *Approved Turbidity Methods*
- *Turbidimeters*
- *QA/QC Issues*
- *Data Collection and Management*
- *References*

CHAPTER 3 – TURBIDITY METHODS & MEASUREMENT

3.1 Introduction

PWSs required to comply with the SWTRs are required to measure the turbidity of the CFE. PWSs that use conventional or direct filtration are also required to measure individual filter effluent turbidity. Because these measurements are used for reporting and compliance purposes (as described in Chapter 2), accurate measurement and strict adherence to approved methods is of paramount importance. This chapter describes approved methods, analytical issues associated with turbidimeters, QA/QC issues, and data collection and management.

3.2 Approved Turbidity Methods

Currently, the U.S. EPA has approved four methods for the measurement of turbidity as listed in 40 CFR 141.74. PWSs must utilize turbidimeters which conform to one of the following methods for compliance purposes. If the instrument does not conform, then it may not be used for monitoring. The following is a brief description of each of the methods.

3.2.1 EPA Method 180.1

EPA method 180.1, "Determination of Turbidity by Nephelometry," is found in EPA's publication, *Methods for Chemical Analysis of Water and Wastes*. The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension; the higher the intensity of scattered light, the higher the turbidity. Readings, in NTUs, are made by a nephelometer designed according to specifications laid out in the method.

3.2.2 Standard Method 2130B

Standard Method 2130B, found in *Standard Methods for the Examination of Water and Wastewater* (1995), is similar to EPA Method 180.1. The method is also based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions.

3.2.3 Great Lakes Instrument Method 2 (GLI 2)

GLI 2 is an instrument-specific, modulated four beam method using a ratiometric algorithm to calculate the turbidity value from the four readings that are produced. The comparison is also based on a comparison of light scattered by the sample under defined conditions with the intensity of the light scattered by the reference suspension. Readings are made by a nephelometer designed according to specifications in the method.

3.2.4 Hach FilterTrak Method 10133

Hach FilterTrak Method 10133 is an instrument-specific method. Like the other turbidity methods, this method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. A higher scattered light intensity equates to a higher turbidity value. Turbidity readings are made using the Hach FilterTrak laser nephelometer.

3.3 Turbidimeters

As noted, turbidimeters must conform to one of the four approved methods for measuring turbidity. For regulatory reporting purposes, either a continuous or a benchtop turbidimeter may be used to monitor the CFE. A continuous turbidimeter should be used to monitor IFE because continuous monitoring is required. If a PWS chooses to utilize continuous units for monitoring CFE, they must validate the continuous measurements for accuracy on a regular basis using a protocol approved by the state [40 CFR 141.74(a)].

3.3.1 Bench Top Turbidimeters

Bench top units are used exclusively for grab samples and include glass cuvettes for holding the sample. Measurement with bench top units requires strict adherence to the manufacturer's sampling procedure to reduce errors from dirty glassware, air bubbles in the sample, and particle settling. Plant operators should read and be familiar with the operation manuals for all bench-top turbidimeters used in the plant. Many maintenance and operational issues are specific to each turbidimeter's make and model, and instruments are usually supplied with a thorough user's manual.

Bench-top Basics

Although durable, turbidimeters need to be stored and operated in a safe and protected environment. Moisture and dust need to be prevented from entering and accumulating. Humidity also needs to be controlled to prevent condensation inside the instrument. Turbidimeters should also be located where they will not be exposed to corrosive chemicals or fumes. Chemicals such as chlorine and acids can ruin instrumentation. Finally, turbidimeters should be located in an environment that is temperature controlled, at a consistent temperature between 0°C and 50°C.

Generally, the instrument should be left on at all times (unless otherwise specified in the user's manual). If any instrument is not left on at all times, it may require a warm-up period before sample analysis.

The length of the sample piping or tubing from the sampling location to the point where the sample is drawn off, should be minimized. It is best to limit sample lines to ten feet or less. Long sample lines can lead to problems with biological fouling and scaling which can impact turbidity values. Long sample lines can also cause confusion due to the lag time as the sample travels through the piping. The longer the lag time, the more difficult it is to correlate turbidity fluctuations to actual process changes that might be occurring.

Sample taps in piping should be located on the sides of pipes. Samples taken from the top or bottom will not accurately represent the turbidity of the water. Samples taken from the bottom will often contain sediment while samples from the top may contain a greater number of air bubbles. Ideally, sample taps should be angled into the water flow at an angle of 0 to 45 degrees and should extend into the center of the flow channel. Sample taps should be located away from items which disturb flow such as fittings, bends, meters, or pump discharges.

Bench-top Operation and Maintenance

Preventative and routine maintenance should be carried out according to manufacturers' instructions. PWSs should not make repairs to the instrument unless specified in the instruction manual. If the PWS makes any maintenance or repairs, they should be recorded on a log sheet kept next to the unit.

PWSs should maintain bench-top instruments in accordance with the manufacturer's recommendations. The following includes a list of recommended practices:

- Inspect the cleanliness of bulb and lenses daily.
- Clean lenses, light sources, and other glassware with appropriate materials to avoid scratches and dust accumulation.
    - Incandescent turbidimeter lamps should be replaced at least annually, or more frequently if recommended by the manufacturer. Also, the instrument should be recalibrated whenever optical components (e.g., lamp, lens, photodetector, etc.) of the turbidimeter are replaced or cleaned.
- Avoid the use of chemicals or other materials when cleaning unless instructed by the manufacturer.
- Do not touch the optical components with bare hands (soft cotton gloves are recommended).
- Recalibrate the instrument after any significant maintenance or cleaning procedure.

Bench-top turbidimeters, just like most instruments, have an effective service life. Various elements within the instrument can deteriorate over time and with repeated use. Daily usage can result in wear on electronics due to movement and temperature. Microprocessor-based electronics are also prone to memory loss during power supply fluctuations. Service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Since turbidimeters have become integral parts of a water treatment plant operation and reporting, it is imperative to maintain instruments and budget for replacements. PWSs may also want to consider having backup storage to ensure records are kept.

Bench-top Calibration and Verification

Calibration is an essential part of accurate turbidity measurement. EPA recommends that, at a minimum, turbidimeters should be thoroughly cleaned and calibrated with primary standards ***at least quarterly***. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools.

In addition, instruments should be verified on a daily basis using a secondary standard. If verification indicates significant deviation from the secondary standard (true) value (greater than ±10%), the instrument should be thoroughly cleaned and recalibrated using a primary standard. If the problem persists, the manufacturer should be contacted. Calibration and verification are discussed in detail in Section 3.4.5.

3.3.2 Continuous Turbidimeters

Continuous turbidimeters are process instruments which sample a side stream split-off from the treatment process. The sample flows through the continuous instrument for measurement and then is wasted to a drain or recycled through the treatment process.

Continuous Turbidimeter Basics

Selection of the flow rate through continuous turbidimeters should be in accordance with manufacturer specifications. The sample flow should be constant without variations due to pressure changes or surges. Installation of a flow control device such as a rotameter on the sample line can eliminate fluctuations in flow rate.

To the extent possible, turbidimeter samples should be obtained directly from the process flow and not pumped to a remote instrument location. Pumped samples can be non-representative of the process flow due to changes in the character of particles caused by the pump or the addition of bubbles due to rapid pressure changes. If pumping is required, the use of peristaltic pumps is desirable, as they have the least amount of impact on particles in the sample.

Several of the continuous turbidimeters available today have various sample chamber sizes. It is important to note that the size of the sampling chamber will affect the instrument response. The path length of the light passing through the sample is inversely proportional to resolution of the instrument. Therefore, the larger the sample size the more likely that the turbidity reading will be dampened.

Continuous turbidimeters should be installed in accordance with manufacturer instructions. The goal of proper installation is to ensure proper operation; easy access for maintenance and calibration procedures; and to obtain an accurate, representative, and timely sample. Proper installation should take into account:

- The location of the sample tap, which should provide a representative sample of the water being monitored. If an individual filter is being monitored, the sample tap should be located as close to the filter as possible. The tap should provide a sample from the centerline of the pipe, as opposed to the bottom or top of the pipe where sediment or air bubbles may interfere with sample integrity. Ideally, the sample will flow by gravity from the sample tap to the turbidimeter without a sample pump. Sample pumps may have an effect on turbidimeter measurements.

- The length of conduit between the sample tap and the instrument, which should be minimized, to the extent possible. Lengthy sample runs can delay instrument response time and may cause changes in sample quality (i.e., settling of particulate matter, increased opportunity for biological growth). In selecting sample tubing or pipe, the required sample flow rate and pressure should be considered. Sample lines of insufficient diameter may not provide adequate flow to the instrument and may be prone to clogging. Excessively large diameter sample lines will delay the instrument response and may permit settling of particulate matter. Line flushing valves and ports may be necessary depending on the water being sampled.

- A location and plumbing arrangement that will minimize the potential for bubble formation. Most continuous turbidimeters have the capability to eliminate minor bubble interference through baffles and/or degassing chambers, but if the problem is severe, the turbidity measurements may be affected.

- Ease of access for routine maintenance and calibration procedures. The turbidimeter should be protected from direct sunlight, extreme temperatures (<32ºF/0ºC and >104ºF/40ºC), and rapid temperature fluctuations. It should also be firmly mounted so as to avoid vibrations, which may interfere with the accuracy of turbidity measurements.

- That the turbidimeter drain should provide easy access for flow verification and collection of calibration verification samples. Flow rate and calibration verification samples are important in establishing data validity. Therefore, hard piping the turbidimeter drain without an air gap is not recommended.

Continuous Turbidimeter Operation and Maintenance

Preventive and routine maintenance should be carried out according to manufacturer's instructions and a regular cleaning schedule is necessary to ensure proper operation of continuous turbidimeters. The following includes a list of recommended practices:

- A weekly inspection is recommended, but this frequency may vary depending on the instrument's location and raw water quality. Warm or turbid samples may dictate more frequent cleaning. An instrument mounted in a dusty environment may also require more frequent cleaning.

- Inspect and clean, among other things, lenses, light sources, sample reservoirs, air bubble traps, and sample lines.

    - Lenses, light sources, and other glassware should be cleaned with appropriate materials to avoid scratches and dust accumulation. During maintenance, care should be taken not to touch the surface of any bulbs or detectors without properly covering the fingers. Soft cotton gloves should be worn when changing bulbs or detectors.

    - Incandescent turbidimeter lamps should be replaced annually or more frequently if recommended by the manufacturer. The instrument should be recalibrated whenever optical components (e.g., lamp, lens, photodetectors, etc.) of the turbidimeter are replaced.

- Verifying sample flow rates on a weekly basis. Flow rates should be within a range specified by the manufacturer.

- Recalibrating the instrument after any significant maintenance or cleaning procedure.

Continuous turbidimeters, just like most instruments, have an effective service life. Various elements within the instrument can deteriorate over time and with repeated use. Daily usage can result in wear on electronics due to movement and temperature. Microprocessor based electronics are also prone to memory loss during power supply fluctuations. Many continuous units with unsealed sensor electronics are vulnerable to damage by outside contamination and splashing. Service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Since turbidimeters have become integral parts of a water treatment plant operation and reporting, it is imperative to maintain instruments and budget for replacements.

Continuous Turbidimeter Calibration and Verification

EPA recommends that, at a minimum, continuous turbidimeters be thoroughly cleaned and calibrated with primary standards ***at least quarterly***. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the PWS should use these tools to verify proper calibration and operation.

In addition, continuous turbidimeters should be verified on a weekly basis if the turbidimeter is being used for CFE monitoring. Less frequent verification may be more appropriate for turbidimeters monitoring IFE turbidity. EPA recommends that verification be conducted with a frequency of **at least** once per month for those units.

Continuous instrument verification can be completed using secondary standards or by comparison to a properly calibrated turbidimeter. If verification indicates significant deviation from the standard (true) value (i.e., greater than ±10%), the instrument should be thoroughly cleaned and recalibrated using a primary standard. If problems persist, the manufacturer should be contacted. For additional information on calibration and verification see Section 3.4.5.

3.4 Quality Assurance/Quality Control (QA/QC)

Although using proper techniques and equipment is an important part of conducting proper turbidity measurements, it is imperative that PWSs are aware of factors in the processes which may lead to poor quality data. Such factors include poor lab techniques, calculation mistakes, malfunctioning or poorly functioning instrumentation, and out-of-date and deteriorated chemicals. Development of a QA/QC plan will help ensure that lapses (which will allow for inaccurate measurements or erroneous reporting), do not occur; and will provide assurances that measurements are being made accurately and consistently.

3.4.1 QA Organization and Responsibilities

A good QA/QC plan provides clear organization, defines who is responsible for each of the aspects laid out in the plan, and the responsibilities for each position. The appropriate training or skills necessary for each position should also be included.

3.4.2 QA Objectives

The objectives of the QA Program need to be laid out and understood by all staff members. Objectives should be succinct, and clear. PWSs may wish to include one primary objective, followed by a number of goals which all relate to the objective. An example of a primary objective with associated goals is included in the text box to the right.

Example of a QA objective statement: The primary objective of this QA Program is to ensure that turbidity measurements are accurate and consistent. Based on this, the goals at our water treatment plant include:

- To adhere to proper sampling techniques as set forth in the SOP.
- To maintain and operate all turbidimeters at the plant properly in accordance with manufacturer instructions and SOP.
- To perform calibration of instruments on a routine and as-necessary basis.
- To communicate and report all, malfunctions, abnormalities, or problems which may compromise the ability to accurately and consistently measure turbidity.

One part of developing a comprehensive QA Program should include the development of Standard Operating Procedures (SOPs). SOPs should be developed with input from staff, enabling them to effectively conduct work activities in compliance with applicable requirements.

3.4.3 SOPs

SOPs are a way to ensure that activities are accomplished in a consistent manner, and that each activity is understood by all involved. SOPs should be kept as simple as possible in order to ensure that each operator is consistent in undertaking the task at hand. The title of the procedure should be clear, concise, and descriptive of the equipment, process, or activity. As related to turbidity, PWSs should consider adopting SOPs for the following activities:

- Sample collection and procedures (see Section 3.4.4).
- Cleaning turbidimeters.
- Creating formazin standards.
- Calibrating turbidimeters (see Section 3.4.5).
- Referencing index samples.
- Validating continuous turbidimeters.

Instructional steps should be concise and precise, using the following guidelines:

- Steps should contain only one action.
- Commands should be written with an action verb at the beginning.
- Limits/and or tolerances for operating parameters should be specific values and consistent with the accuracy of the instrumentation. Procedures should not include mental arithmetic.
- **"Cautions"** should be used to attract attention to information that is essential to safe performance.
- **"Notes"** should be used to call attention to supplemental information. Notes present information that assists the user in making decisions or improving task performance.
- Documentation methods should be incorporated as part of the procedure including what data needs to be recorded, if the individual needs to sign or date data, etc.

After developing an SOP, the author(s) should consider the following questions:

- Can the procedure be performed in the sequence it is written?
- Can the user locate and identify all equipment referred to in the procedure?
- Can the user perform the procedure without needing to obtain direct assistance or additional information from persons not specified by the procedure?
- Are words, phrases, abbreviations, or acronyms that have special or unique meaning to the procedure adequately defined?
- Is there a need for special controls on data collection and recordkeeping?

After completing the SOP it should be tested to the extent possible. It is also a good idea to ask a technical reviewer to verify the accuracy of the procedure. SOPs should be reviewed at least once every two years to determine if the procedure and requirements are still accurate.

The following is a simplified example of an SOP written for the development of formazin.

Creating a 4000 NTU Formazin Stock Suspension

1. Dissolve 1.000 g of ACD grade hydrazine sulfate, $N_2H_4\ H_2SO_4$ in ultra-filtered deionized water and dilute to 100 mL in a Class A, 100 mL volumetric flask.

2. Dissolve 10.00 g of analytical grade hexamethylenetetramine, $(CH_2)_6N_4$, in ultra-filtered deionized water and dilute to 100 mL in a Class A, 100 mL volumetric flask.

3. Combine the equal volumes of the hydrazine sulfate solution and the hexamethylenetetramine solution into a clean, dry flask and mix.

4. Let the mixture stand for 48 hours at 24-26 ºC.

5. Store the suspension in a bottle that filters ultraviolet light.

3.4.4 Sampling Strategy and Procedures

The procedure for conducting sampling should be laid out clearly and concisely, preferably in SOPs (discussed in Section 3.4.3). It should include information such as sampling location and frequency, collection methods, sample handling, and any logistical considerations or safety precautions which are necessary. Adherence to proper techniques is an important step for minimizing the effects of instrument variables and other interferences (Sadar, 1996). Measurements will be more accurate, precise, and repeatable if operators follow and incorporate the techniques listed in this Section.

All turbidimeter manufacturers emphasize proper techniques and include detailed instructions in their literature. Water treatment plant operators responsible for conducting turbidity measurements are urged to review these instructions and incorporate them into their SOPs. Specific instruction for securing samples and measuring turbidity will differ for the various instrument manufacturers and models, but there are certain universally accepted techniques that should be utilized when conducting measurements. The following paragraphs highlight some of these techniques.

Handling of Cuvettes/Sample Tubes

Sample cells need to be handled with absolute care to avoid contamination or damage, such as marks and scratches, which might change the optical characteristics of the glass. Scratches, fingerprints, and water droplets on the sample cell or inside the light chamber can cause stray light interference leading to inaccurate results. Cells can be acid washed periodically and coated with a special silicone oil to fill small scratches and mask the imperfections in the glass. Since the silicone oil required for this application should have the same refractive characteristics as glass, it is recommended that the oil be obtained from the instrument manufacturer. Care should be taken to not apply excessive oil that could attract dirt or contaminate the sample chamber in the instrument. Once the oil has been applied to the cell, the excess oil should be removed with a lint-free cloth. The result should be a sample cell surface with a dry appearance, but with all imperfections filled with oil. Sample cells should always be handled at the top of the cell or by the cap to avoid fingerprints or smudges. After a cell has been filled with a sample and capped, the outside surface should be wiped with a clean, lint-free absorbent cloth until it is dry. Store cells in an inverted position on clean surfaces to reduce contamination by dirt or dust or store capped and filled with low turbidity water.

Orientation and Matching of Sample Cells

Since imperfections in the sample cell glass can influence light scattering, the cell should be inserted in the turbidimeter with the same orientation each time it is used. At the Philadelphia Water Department, new cells are indexed and are not allowed to vary by more than 0.01 NTUs. Philadelphia reports that as many as one quarter of the cells are never used due to imperfections in sample cells (Burlingame, 1998).

Matched sample cells are required to minimize the effects of optical variation among cells. If possible, it is better to use a single sample cell for all measurements to minimize the variability due to cell-to-cell imperfections. Once the orientation of a cell has been established, the operator should always use the same orientation when placing the sample cell into the instrument. An example protocol for indexing and matching cells is described below.

- ***Indexing Cells (Steps 1-2) and Matching Cells (Steps 1-3)***

  - Step 1. Pour ultra-pure dilution water into a sample cell (several cells if performing matching) that has been cleaned according to the techniques described previously in this Section.

  - Step 2. Select sample cell and place it into the turbidimeter. Rotate the cell within the instrument until the display reads the lowest value. Record the reading. Using a marker or pen, place a mark on the top of the sample cells neck. **Do not put the mark on the cap.** Use this mark to align sample cells each time a measurement is made.

  - Step 3. Select another sample cell, place it into the turbidimeter and rotate the cell slightly until the reading matches that of the first sample cell (within 0.01 NTUs). Using a marker or pen, place a mark on the top of the sample cells neck. If unable to match the readings, select a different sample cell. Repeat the process until the appropriate number of cells has been matched.

Degassing of the Sample

Water samples almost always contain substantial amounts of entrained gasses that can be released during turbidity measurement. Bubbles are either generated during the filling of a sample container, occur due to temperature fluctuations resulting in a reduced solubility of the gas in a liquid, or are due to chemical and/or biological processes. Bubbles within a sample act much like particles and can scatter light resulting in an incorrect measurement. Many continuous turbidimeters contain apparatuses inside the instrument that serve to trap, collect, and vent air bubbles. Usually these consist of baffled entries or membranous chambers. Some vendors also manufacture add-on units which can be placed in the sample line before the continuous turbidimeter. There are several other options for removing bubbles from water (degassing) to reduce the effect they have on measurements. The most commonly used methods include:

- Addition of a **surfactant** compound to a water sample lowers the surface tension of the water and allows entrained gases to readily escape. There are a variety of surfactants used in turbidity measurements. Because of the variety in chemical composition, it is difficult to provide guidance for their use. It is important to note that some surfactants may have constituents which serve as a coagulant and cause particles to aggregate and settle out. Other chemicals might contain constituents with an ionic charge that cause particles to rise to the surface. The use of surfactants is more appropriate for measurement of highly turbid waters such as raw water. The most appropriate instrument-specific advice regarding the use of surfactants can be obtained by contacting the instrument manufacturer.

- Application of a **partial vacuum** to a sample lowers the partial pressure above the liquid surface and allows entrained gases to escape. Partial vacuums can be created by a simple syringe or by use of a vacuum pump. Some instrument manufacturers and suppliers provide pre-made vacuum kits that include syringes for degassing samples. The most common arrangement is the use of a syringe and a stopper sized for the opening of the sample cell or test tube.

- The use of an **ultrasonic bath** creates vibrations in the sample to facilitate the escape of gases. Ultrasonics is a specialty field/science that utilizes an inaudible spectrum of sound frequencies ranging from about 20,000 cycles per second to 100,000 cycles per second. Ultrasonic baths are used for thoroughly cleaning supplies in the medical, electronic, and metals industries. When high frequency sound waves are passed through a cleaning fluid, such as water with suitable detergent additive, many millions of microscopic bubbles form and then rapidly collapse. The bubbles are the result of the stretch and compress phases of the sound waves within the fluid, a process known as cavitation. Ultrasonic devices may be most effective in severe turbidity conditions or with viscous samples, however if used for degassing samples, samples should be sonified **for no more than 1 to 2 seconds**. Sonification can change particle size ranges, affecting a turbidimeters response if improperly utilized (Burlingame, 1998).

Timeliness of Samples

Samples should be measured expeditiously after being collected to prevent changes in particle characteristics due to temperature and settling. Temperature can affect particles by changing their behavior or creating new particles if precipitates are created. Dilution water may dissolve particles or change their characteristics (Sadar, 1996). Operators are encouraged to draw samples only when turbidimeters are ready to be operated. Do not draw a sample and allow it to sit while the instrument warms up or is being readied.

Other Important Sampling Techniques

- Samples should not be violently agitated as particles can be broken apart or air may be entrained into the fluid. Gentle agitation such as swirling the sample cell is advisable to reduce particle settling.

- Sample cells should be used only with the instruments for which they were intended. Do not mix and match.

- A visual observation should be performed of the sample cell every time a measurement is made. It should be verified that there are no visible bubbles in the sample and the cell is clean and free of scratches.

- Samples entering the turbidimeters should be at the same temperature as the process flow samples. Changes in temperature can cause precipitation of soluble compounds and affect readings.

- Sample cells should be evaluated with a low turbidity water (after cleaning) to determine if cells remain matched. If the evaluation determines that a cell is corrupted, discard the cell. PWSs should consider conducting this evaluation weekly.

- When in doubt, throw it out - If there is a question as to whether a sample cell is too scratched or stained, it should be replaced.

3.4.5 Calibration and Verification

Turbidimeters, like all instrumentation, need to be calibrated periodically to ensure that they are working properly and provide true and accurate readings.

Calibration should always be conducted according to the manufacturer's instructions. PWSs' should review these instructions and incorporate them into an SOP that should be read, learned, and followed by operators at the plant. The SOPs for conducting a calibration should be posted next to the turbidimeter.

The appropriate technical requirements should be determined for calibration based on the following:

- Manufacturer.
- Model name and/or number.
- Parameters to be calibrated.
- Range to be calibrated.
- Acceptance criteria.
- Mandatory calibration procedures or standards.
- Required calibration program.

After calibration, performance of the turbidimeter should be verified with a secondary standard. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools to verify proper calibration and operation.

Calibration Standards

A calibration standard must be used to conduct a calibration [40 CFR 141.74(a)]. Standards are materials with a known value which, when placed in the instrument, should be used to adjust the instrument to read the known value.

There are a variety of standards on the market today which are used to calibrate turbidimeters. They are most often characterized as primary, secondary, or alternative standards. *Standard Methods for the Examination of Water and Wastewater* (1995) describes a primary standard as a standard which is prepared by the user from traceable raw materials, using precise methodologies and under controlled environmental conditions. *Standard Methods* also defines secondary standards as those standards a manufacturer (or an independent testing organization) has certified to give instrument calibration results equivalent (within certain limits) to results obtained when an instrument is calibrated with a primary standard.

Standard Methods and EPA differ in their definitions of each of these standards. EPA recognizes the following three standards for approved use in the calibration of turbidimeters.

- Formazin (user prepared and commercially produced).
- AMCO-AEPA-1® MICROSPHERES.
- STABLCAL® (stabilized formazin).

PWSs need to realize that some instruments have been designed and calibrated using specific primary standard(s) listed above. For optimal results, PWSs should contact the manufacturer of the instrument to determine the recommended primary standard to be used for calibration.

Verification Standards

Additionally, EPA recognizes secondary standards for use in monitoring the day-to-day accuracy of turbidimeters by verifying the calibration. This check is used to determine if calibration with a primary standard is necessary. Secondary standards are used to verify whether an instrument produces measurements within acceptable limits around a nominal value (typically 10 percent). Examples of secondary standards include:

- GELEX®.
- Glass/ceramic cubes.
- Manufacturer provided instrument specific secondary standards.

The need to reconcile the definitions and differences among primary and secondary standards will be a continuing issue. It has been recognized that the standards need to be unbiased, easy to use, safe, available for a range of turbidities, and reproducible.

Conducting the Calibration

All turbidimeters should be factory-calibrated before leaving the manufacturer. As described previously, turbidimeters, like most instrumentation, tend to lose accuracy over time due to a variety of factors, making periodic calibration very important to maintain accurate measurements. The most important point to remember is:

Calibration should always be conducted according to the manufacturer's instructions.

Manufacturers differ in their steps to conduct a calibration, but the following points are applicable to all calibrations.

- Standards should be checked to ensure they have not expired. Never pour a standard back into its original container.

- Care should be taken when preparing formazin. If a spill occurs, clean up immediately according to the Material Safety Data Sheets (MSDSs) provided with your chemicals. Make sure to inspect the tube/cuvette for scratches and chips prior to pouring in the solution.

- The tube/cuvette should be checked to make sure it is lined up properly according to the indexing. Care should be taken to not scratch the tube when inserting; and ensure that the tube/cuvette is free of dust, smudges, and scratches.

- When obtaining the reading, the value should be written legibly onto a form similar to the one found in Figure 3-1. The date of the calibration should be recorded as well as the individual conducting the calibration, the value, and any peculiar situations or deviations from normal calibration procedures (e.g., switch to a new lot of formazin, switch in standards, use of a new tube/cuvette, etc.). These measurements will allow for an understanding of whether the performance of a turbidimeter is in question. For example, if for 6 months a turbidimeter reads approximately 20.152 when calibrated using polystyrene beads and one morning it reads 25.768, this could be an indication that the bulb in the turbidimeter has a problem. Conversely, if the standard in use was switched that morning, the resulting change might be due to change in standards.

- The calibration should be conducted the same way each time. Variations in how the calibration is conducted could yield inaccurate measurements.

- It is extremely important that individuals who conduct the calibration have been trained to do so.

CALIBRATION CHECKLIST **Month__________** **Year ___________**				
Date	**Initials**	**Value**	**Standard**	**Comments**

Figure 3-1. Calibration Checklist

Calibration and Verification Frequencies

EPA recommends that the calibration of bench top units be verified daily and continuous units that measure CFE be verified weekly with secondary standards. For both units, recalibration with primary standards should occur at least quarterly. Specific calibration procedures should be developed for each individual instrument location. Listed below are guidelines for selecting calibration frequencies and procedures:

- Frequencies for checking instrument calibration with secondary standards and for full re-calibration of instrument with primary standards should be determined.

- PWSs should establish the acceptable deviation from the primary standard during secondary verifications. Readings in excess of the deviation should trigger immediate re-calibration of the instrument. (±10 percent is recommended by EPA).

- A time of day should be chosen when full attention can be devoted to the calibration. Calibration at the end of a shift or right before a break can often lead to mistakes and sources of error. A calibration time should be established when operators are fully alert and focused on completing the task.

- The dates for full turbidimeter calibration should be identified and scheduled in advance and recorded on the plant calendar or work scheduling chart.

- Preparations should be made, and adequate supplies maintained to prevent delays in the calibration schedule. It is important to keep an appropriate stock of standards. Due to the limited shelf-life of various standards, the age of the stored standards should be monitored so they can be replaced or reformulated as needed.

- Calibration duties should be assigned to a select group of individuals and made one of their standard activities. All appropriate individuals/operators should be trained in conducting a calibration in the event that one of the regular individuals is not available.

3.4.6 Data Screening and Reporting

The methods for data screening and reporting should be detailed to ensure that measurements are recorded, calculated, and reported correctly. These methods should be designed to meet the quality assurance objectives. Again, the development and implementation of SOPs will facilitate those goals.

3.4.7 Performance and System Audits

Performance and system audits should be conducted periodically to determine the accuracy of the total measurement system(s) or component parts thereof. Performance audits may include review of documentation and logbooks for legibility and completeness. A system audit consists of evaluation of all components of the sampling and measurement systems to determine their proper selection and use. This audit includes a careful evaluation of both field and laboratory QC procedures and can include verification of written procedures and analyst(s) understanding, verification and documentation of procedures, as well as adherence to any SOPs.

3.4.8 Preventative Maintenance

Preventive maintenance should be conducted on all instrumentation and a maintenance program should consist of both scheduled/preventive maintenance (e.g., regular battery checks and maintenance of a sufficient stock of spare parts and supplies) and non-scheduled maintenance procedures. Maintenance procedures and schedules should be made available for the appropriate staff, and all maintenance and the results of calibrations should be documented. The schedule recommended by the respective manufacturers should be followed for each instrument as manufacturers' procedures identify the schedule for servicing critical items to minimize downtime of the measurement system. Adherence to maintenance schedules and procedures may be investigated during a system audit.

3.5 Data Collection and Management

The final steps in turbidity measurement deal with the collection of data and management of collected data. This Section describes several methods available to PWSs for the collection of data and provides a brief description of the management of that data.

Data obtained from Supervisory Control and Data Acquisition (SCADA), data recorders, or strip charts should be verified on a weekly basis by comparing the turbidimeter reading with the data recording device reading. If verification indicates greater than ±10% deviation, the electronic signal should be recalibrated according to the manufacturer's instructions.

3.5.1 Data Collection Methods

Acquisition of data from turbidimeters is an important step in the turbidity measurement process. As discussed previously, the individual filter turbidity requirements include continuously monitoring each filter's effluent. Each of the methods discussed below are typically used for continuous turbidimeters. Readings using benchtop units are typically recorded by hand or entered into a computer without the use of the data collection equipment listed below. PWSs may have experience using these methods in monitoring other water quality parameters.

Strip Recorders and Circular Chart Recorders

Strip Chart and Circular Chart Recorders are a relatively established technique for recording data. The units are set to obtain a reading at a timed interval. A pen records the reading on paper at the interval. As additional readings are taken, the pen moves back and forth (or up and down in the case of a circular recorder) recording the values that are being monitored.

Newer models include digital readouts as well as the capability to transfer data to data loggers or other data acquisition systems. The greatest disadvantage to using chart recorders is the difficulty in incorporating data into electronic format and archiving such data. Recorders also require the purchasing of replacement pens and charts.

Data Loggers

Data Loggers are "black boxes" which store data which is received from input channels. The box records the data in memory which can then be downloaded at a future time. Data loggers consist of two distinct components: hardware and software.

Hardware

The units themselves typically consist of a device containing solid state memory encased in a plastic weatherproof enclosure. Units have a varying number of inputs that can be either analog (records actual numbers) or digital (records a series of 0s and 1s), as well as an output to download data. Systems most often are battery powered, but some can be connected to existing power supplies. Nearly all systems contain lithium or other batteries to keep memory active in the event of a power failure.

Software

Two software components are important to data loggers/acquisition devices. First, specialized software is necessary to configure the logging unit. This configuration specifies the unit frequency at which to obtain turbidity readings. The second part of the software is used to retrieve the data from the logger and import it into a usable format on a computer. Most companies offer integrated packages that allow users to import the data and immediately plot and graph the data to depict trends or produce reports. Data should be downloaded at regular intervals, as data loggers cannot store data indefinitely.

Several methods exist to transfer data from the logger into a computer. Data acquisition systems are often equipped to be compatible with telemetry to upload data to computers via telephone, cellular telephone, or radio. Alternatively, either a laptop or tablet can be connected to the unit to download information, or the data logger can be brought into the office where the computer is located and plugged into one of the input/output ports on the computer. The better method could necessitate utilizing a second data logger to take the place of the first logger when it is being downloaded. PWSs may wish to schedule downloads to occur at times when a filter may not be in operation (when off-line or being backwashed).

Supervisory Control and Data Acquisition (SCADA)

SCADA systems are devices used for industrial measurement and control. They consist of a central host (base unit), one or more field gathering and control units (remotes), and a collection of standard and/or custom software used to monitor and control remotely located field data elements. The base unit and the remote units are linked via telemetry, and the base unit receives data and provides instructions as specified in the software. SCADA systems at treatment plants are also often times referred to as distributed control systems (DCSs). DCSs function the same as SCADA systems except that field gathering and control units are located in a more confined area and communications may be via a LAN as opposed to remote telemetry.

SCADA systems can take inputs from a variety of sources and instruments. These systems collect and display the data produced by a variety of instruments so that the plant operator can monitor the entire treatment process from one location. SCADA systems are typically used for a variety of functions at a water treatment plant including flow control, pH and temperature monitoring, automated disinfection dosing, and a host of other functions. Control may be automatic or initiated by operator commands. The inclusion of continuous turbidity monitoring could be incorporated into the regime of items being measured and controlled by a SCADA/DCS system at a treatment plant.

SCADA systems can also be used to log and store data for recording purposes. Signals sent from remote instruments located at the plant site are interpreted at the base unit. This unit provides the logic to interpret all of the different signals and display real-time measurements. The central unit could be programmed to automatically transfer historical data to other storage media such as a flash drive, dedicated computer, and/or online server.

3.5.2 Data Management

There are two distinct objectives to the management of turbidity data: (1) regulatory compliance; and (2) checking process control and treatment plant optimization. The turbidity reporting and monitoring requirements set forth in Chapter 2 establish the types of data which must be collected and the analysis which must be done to meet the requirements of the suite of SWTRs. In order to meet these requirements, PWSs need to understand three areas of data management:

- Data Format.
- Data Storage.
- Data Interpretation and Analysis.

Data Format

Storage of the data in a usable format is the first step to effective data management. PWSs should have the ability to download data from their acquisition equipment into a usable and manageable format. Data is typically placed in one of many different formats such as Excel, Access, and dBASE. Data should be converted into a format that can be used by the facility. Many PWSs currently utilize software such as those listed above. The key to selecting a format is the ease at which the data can be viewed, manipulated, and or converted. Certain software packages allow users to create reports, tables, or graphs based on the data.

Data Storage

Storage of the data is the next step in effective data management. Maintaining these data points for future analysis may pose a problem due to the amount of computer memory required. PWSs should consider the use of flash drives or external hard drives for storage of data. Hard drives can be used to store data while manipulating or evaluating. PWSs may want to provide redundant storage as backup should an online storage location fail or become corrupted.

Data Interpretation and Analysis

Data analysis is the last step in effective data management. The Partnership for Safe Water has developed spreadsheets to assist utility partners in collecting performance data. The spreadsheets can capture turbidity data from the raw water, sedimentation basin effluent, and filter effluent; but can also be used to measure repetitive data of any kind, from any point in the process for up to 365 days. Macros have been written to generate frequency distributions on a monthly and annual basis, to help evaluate trends and summarize large amounts of data. Graphics capabilities of the spreadsheets are also built in to automatically plot trend charts and frequency distributions. There are also capabilities for generating summaries of the data to report as background information. Other data summaries within the capabilities of each spreadsheet software version could be generated as well. The latest software can be obtained by contacting the Partnership for Safe Water at partnership@awwa.org.

The software, which can be custom designed for SCADA/DCS systems, also allows operators to trend and analyze data. Easy-to-use software provides clear graphics for operators to evaluate. Typically, data can be exported to various spreadsheets or database programs for later analysis. Software is typically interactive, with the ability to change colors, and graph sizes.

PWSs should analyze turbidity data to check process control and treatment plant optimization. PWSs may wish to evaluate backwash turbidity spikes for individual filters, how storm events affect the filtration capabilities, or the effect of various chemical dosages on filtered effluent. Analysis could be undertaken to compare different filters within a system or the effect of different flow rates. Chapter 5 provides information on conducting a filter self-assessment and analysis which PWSs may wish to implement.

3.6 References

AWWARF. 1998. Treatment Process Selection for Particle Removal, AWWARF International Water Supply Association.

Burlingame, G.A., M.J. Pickel, and J.T. Roman. 1998. Practical Applications of Turbidity Monitoring. *J. AWWA.* 90(8):57-69.

California Department of Health Services (CDHS). 1998. Turbidity Monitoring Guidelines, June 18.

Great Lakes Instruments, Inc. 1992. Turbidity. GLI Method 2. Milwaukee, WI.

Great Lakes Instruments, Inc. "Turbidity Measurement." Technical Bulletin Number T1 Rev 2-193. Milwaukee, WI.

Hach Company. 2000. Hach Method 10133 — Determination of Turbidity by Laser Nephelometry. Revision 2.0. January 7, 2000.

Hach Company. 1997. "Low Level Turbidity Measurement." Loveland Colorado, September.

Hach Company. 1995. "Excellence in Turbidity Measurement."

Hart, V.S., C.E. Johnson, and R.D. Letterman. 1992. An Analysis of Low-level Turbidity Measurements. *J. AWWA.* 84(12):40.

International Standardization Organization (ISO). 1990. ISO 7027 Water Quality-Determination of Turbidity.

King, K. 1991. Four-Beam Turbidimeter For Low NTU Waters. *Journal of the Australian Water and Wastewater Association*, October.

Lex, D. 1994. Turbidimeter Technology Turns on the High Beams. Intech. 41(6).

Sadar, M. 2005. Introduction to Laser Nephelometry: An Alternative to Conventional Particulate Analysis Methods. 5th Edition. Hach Company.

Sadar, M. 1996. Understanding Turbidity Science, Technical Information Series-Booklet No. 11, Hach Company.

Sadar, M. Turbidity Standards, Technical Information Series-Booklet 12, Hach Company, Loveland, CO.

Sethi, V., P. Patanaik, P. Biswas, R.M. Clark, and E.W. Rice. 1997. Evaluation of Optical Detection Methods for Waterborne Suspensions. *J. AWWA.* 89(2): 98-112.

Standard Methods. 1995. Standard Methods for the Examination of Water and Wastewater. Nineteenth Edition. Franson, M.H., Eaton, A.D., Clesceri, L.S., and Greenberg, A.E., (editors). American Public Health Association, AWWA, and Water Environment Federation. Port City Press, Baltimore, MD.

USEPA. 1993. Methods for the Determination of Inorganic Substances in Environmental Samples. EPA-600/R-93-100. August 1993. Available at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30002U3P.txt.

USEPA. 1993. Determination of Turbidity by Nephelometry. Methods for Chemical Analysis of Water and Wastes. August 1993. Available at: https://www.epa.gov/sites/production/files/2015-08/documents/method_180-1_1993.pdf.

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In this chapter:

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- *References*

CHAPTER 4 – TREATMENT OPTIMIZATION

4.1 Introduction

To optimize a treatment facility's ability to remove turbidity, a PWS should first assess the performance of each unit process against the performance goals that define optimized performance and identify which processes could benefit from minor or major adjustments or improvements. This chapter provides tools available to PWSs for optimizing their treatment facilities as well as suggestions for evaluating each unit process.

The primary goals of treatment optimization are to:

- Provide safe drinking water and maximize compliance with required standards.
- Maximize performance without making major capital expenditures.

These goals should be kept in mind when considering process modifications.

It is important to remember that the items listed in this chapter may not apply to all PWSs. Optimizing water treatment plants is by nature a site-specific process. For that reason, this chapter does not try to provide a one-plan-fits-all for optimizing a water treatment plant, but does however, highlight the areas that most often can be improved to optimize water treatment and improve turbidity removal.

4.2 Tools Available for Optimization

A thorough treatment plant evaluation and improvement program, along with distribution system optimization practices, are the best way to ensure pathogen-free drinking water. With an emphasis on improved performance of existing facilities, optimization is a proactive approach that can help with compliance with the turbidity requirements. Currently, three programs serve as resources for PWSs wishing to follow a systematic and proven approach to optimizing water treatment plant performance. These are:

- A Composite Correction Program (CCP); which includes a regulatory requirement for PWSs that are not meeting IFE turbidity levels;

- An area-wide optimization program (AWOP); (a collaborative program between EPA, the Association of State Drinking Water Administrators (ASDWA) and individual primacy agencies); and,

- The Partnership for Safe Water; a program managed by the American Water Works Association (AWWA) and a Steering Committee of partner organizations.

4.2.1 Composite Correction Program Approach

The CCP approach is a systematic approach that regulators, consultants, and utility personnel can implement to improve performance of existing water treatment plants. The CCP approach consists of both a CPE and Comprehensive Technical Assistance (CTA).

- The CPE is a systematic step-by-step evaluation of an existing treatment plant resulting in a comprehensive assessment of the unit treatment process capabilities and the impact of the operation, maintenance and administrative practices on the performance of the plant. Based on individual filter monitoring requirements in the Interim IESWTR and LT1ESWTR, some PWSs may be required to arrange for a CPE. CPEs are discussed in greater detail in Chapter 6.

- If a CPE indicates that optimization of existing major unit processes can result in the desired finished water quality, the CTA phase is implemented. The CTA systematically addresses those factors identified and prioritized in the CPE. For additional information on the CCP, including detailed CPE procedures and qualifications for CPE providers, see EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998a) which is available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents.

4.2.2 Area-Wide Optimization Program (AWOP)

EPA and state drinking water programs are responsible for, among other things, the oversight of surface water systems that represent a variety of source water characteristics, plant capabilities, finished water quality and distribution system characteristics. AWOP implementation focuses on proactive measures to improve treatment performance and system operation beyond the minimum requirements of the NPDWRs as well as respond to issues of continuing compliance such as disinfection byproducts. While participation in an AWOP is voluntary, those that have utilized AWOP have realized tangible benefits.

Overview of an AWOP

EPA's Office of Ground Water and Drinking Water (OGWDW), participating EPA Regional Offices, and ASDWA manage the national program and facilitate participating primacy agency representatives to effectively implement AWOP in their respective individual agencies. Implementation of an AWOP uses approaches designed to optimize the performance of existing treatment processes, through enhanced process control and operational practices within water treatment plants and distribution systems. A "train the trainer" approach is then utilized to empower primacy agency staff to impact water system regulatory compliance while building an awareness of the benefit of moving beyond regulatory requirements, thus increasing public health protection. AWOP activities focus on optimization of existing treatment processes using more effective process control, which can limit the need for unnecessary major capital expenditures and/or inform the need for needed capital improvements.

AWOP approaches have been developed for turbidity control, as well as minimizing disinfection byproduct (DBP) formation in water plants and distribution systems, while maintaining distribution system water quality in wholesale and consecutive systems. The focus of this discussion will be on turbidity optimization in keeping with the scope of this document.

Components of an AWOP

Effective AWOP implementation is achieved through activities by a state drinking water program which support three interrelated functional areas described as:

- Status activities.
- Targeted performance activities.
- Maintenance activities.

The intent of these activities is to create a sustainable program that continually facilitates optimized performance of treatment facilities at the water system level and documents impacts of the program.

Status Activities

Status activities for turbidity performance include adopting, building awareness of, and establishing turbidity performance goals that a state uses to assess performance of water treatment plants. Tools are available to assist in the implementation and documentation of treatment plant-specific performance assessments.

Under an AWOP, a state develops criteria to prioritize and rank surface water systems relative to chosen indicators of public health risk (e.g., turbidity removal performance, population served, violations). Once criteria have been established, the state uses turbidity data and other information obtained about the participating water systems to prioritize treatment plants, identifying and targeting the highest risk plants and water systems. In doing this, the state can more effectively apply available resources and appropriate tools.

This framework allows a state to monitor and assess these plants on a regular basis, proactively providing technical assistance, if needed. Another benefit of the status component activities is that it allows state staff to develop or strengthen relationships with the water utilities while encouraging them to pursue continuous performance improvement.

AWOP utilizes data-based decision making and therefore has tools to assess and impact the integrity of each data point from sampling through reporting. The Washington Department of Health described its data integrity approaches for turbidity and disinfection in two published articles. (Deem and Feagin, 2014; Deem and Feagin, 2016)

Targeted Performance Activities

The focus of targeted performance improvement activities is to assess which of the various evaluation, training and/or technical assistance tools are most appropriate to enhance the performance of each treatment plant. These decisions are informed based on a treatment plant's relative ranking as determined by the status activities. In the development of an AWOP, the state assesses their existing implementation activities and develops new tools that can be used to assist plants with achieving the AWOP performance goals for the long-term.

A variety of tools have been developed and are available to use to improve performance at surface water plants. These can range from inspections to direct technical assistance. Options for an AWOP include, but are not limited to, enhanced inspections and surveys, CPEs, CTAs, performance-based training (PBT), technical assistance modules, as well as agency awards and recognition programs. States have the flexibility to incorporate the tools they find most appropriate given their skill level and available resources. Implementing an AWOP can help states utilize existing information and technical assistance tools and organize it in a way to target oversight activities to achieve long-lasting improved performance on a system-by-system basis.

Other sources of assistance that do not use state personnel can also be used. PWSs may be encouraged to join national programs such as the Partnership for Safe Water. States may also choose to work with third-party technical assistance providers to make sure that their assistance complements the AWOP performance goals.

Maintenance Activities

Maintenance activities, such as documentation, application to other state programs, and ongoing improvement support three functional areas: (1) sustain; (2) integrate; and (3) enhance. Sustaining an AWOP includes maintaining ongoing documentation of performance improvements for use by decision-makers and ensuring there is a robust internal capability to implement the program. Integrating an AWOP into an existing state drinking water program allows state program staff to take lessons they have learned from the implementation of the status and targeted performance activities and apply them to other related areas of the program (e.g., design reviews, permitting, training activities, inspections and/or sanitary surveys, and enforcement). Efforts to sustain capability and improvement of all AWOP activities can be enhanced by training state drinking water program staff on new technical tools. State drinking water programs that participate in AWOP benefit through improved treatment plant performance and public health protection, effective compliance assistance for water systems, enhanced state and water system staff capability and morale, and effective use of state resources. AWOP can help states track water system performance and more effectively allocate their resources to water systems that are most in need.

Partnership for Safe Water

As noted in Section 3.5.2, the Partnership for Safe Water is a voluntary effort between AWWA, other drinking water organizations, and more than 300 water utilities throughout the United States (as of 2020). The goal of this cooperation is to provide an added measure of to millions by encouraging water utilities to voluntarily improve performance beyond regulatory requirements.

There are four phases in the treatment plant optimization program of the Partnership for Safe Water. The first three phases are required to be in the program while the fourth phase is optional:

- Phase I: Commitment – PWSs that partner with the Partnership for Safe Water must be committed to the program by changing the focus to go beyond just meeting drinking water regulations to thinking of ways to improve and optimize the system.

- Phase II: Baseline and Annual Data Collection – PWSs provide a year's worth of performance data to AWWA including raw and filtered water turbidity data. PWSs then receive a technical manual with approaches for plant optimization and software applications that will graph turbidity data collected for trend analysis.

- Phase III: Self-Assessment – PWSs assess existing operations and administration practices and identify performance limiting factors. PWSs complete a checklist and write a report that includes a plan to make improvements that address limiting factors. Reports are provided to a committee of trained professional peers to review and ensure that the findings are useful and constructive.

- Phase IV: Fully Optimized System – This phase is for awarding PWSs that achieve the highest level of optimization. To be considered for the two awards offered, PWS performance must be assessed against stringent performance goals.

More information on the Partnership for Safe Water's Treatment Plant Optimization Program can be found on AWWA's website at https://www.awwa.org/Resources-Tools/Programs/Partnership-for-Safe-Water and at https://www.awwa.org/Portals/0/AWWA/Partnerships/PSW/PSWFactSheet.pdf.

4.3 Evaluating System Processes

This section provides suggestions for evaluating system processes. The objective is to optimize plant performance to maximize meeting all required drinking water standards. Keep in mind, however, optimizing the plant to meet the requirements for one rule will not necessarily optimize water treatment for compliance with all standards. For additional information on simultaneous compliance, see EPA's *Microbial and Disinfection Byproducts Rules Simultaneous Compliance Guidance Manual* (USEPA, 1999a) which is available at: https://www.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules and EPA's *Simultaneous Compliance Guidance Manual for the Long Term 2 And Stage 2 DBP Rule* (USEPA, 2007) at https://www.epa.gov/dwreginfo/stage-1-and-stage-2-compliance-help-community-water-system-owners-and-operators#simcom.

Certain technologies, especially those involving large financial expenditures, should be implemented only with appropriate engineering guidance. The following should be considered during the evaluation:

- Quality and type of source water including variations over the course of the year and over multiple years;
- Turbidity of source water;
- Economies of scale and potential economic impact on the community being served;
- Treatment and waste disposal requirements; and,
- Future rules and requirements.

Under the Lead and Copper Rule [40 CFR 141.90(a)(3)], prior to the addition of a new source or any long-term change in water treatment, a PWS is required to submit written documentation to the state describing the change or addition. The state must review and approve the addition of a new source or long-term change in treatment before it is implemented by the water system. Also, states may have additional requirements for notification prior to changes.

4.3.1 Coagulation/Rapid Mixing

Coagulation is the process by which small particles are combined to form larger aggregates and is an essential component in water treatment operations. Evaluation and optimization of the coagulation/rapid mixing step of the water treatment process includes a variety of aspects:

- Optimal coagulant dosages are critical to filter performance. Maintaining the proper control of these chemicals can mean the difference between an optimized surface plant and a poorly run surface plant.
- Inadequate mixing of chemicals or their addition at inappropriate points within the treatment plant can limit performance.

- The raw water characteristics will affect the type and amount of chemicals used. Changes in raw water pH, temperature, alkalinity, total organic carbon (TOC), and turbidity will affect coagulation and, subsequently, filtration and finished water quality. Jar tests are an excellent way to determine the best type and amount of chemical (or combination of chemicals) to use for varying raw water characteristics. More detailed information on jar testing can be found in M37 Operational Control of Coagulation and Filtration Processes, Third Edition (AWWA, 2011a).

Chemicals

An evaluation of the water quality and chemicals used in the treatment process can identify the appropriateness of the coagulation chemicals being used. A thorough understanding of coagulation chemistry is necessary, and changes to coagulation chemicals should not be made without careful consideration. The following questions and considerations may be useful for evaluating coagulation chemical systems:

- What is the protocol for low-turbidity waters?
  - Generally, primary coagulant should not be shut off, regardless of raw water turbidity.
- Are chemicals being dosed properly, paying special attention to pH? Is dose selection based on frequent jar testing or other testing methods such as streaming current monitoring, zeta potential, or pilot filters?
  - Relying exclusively on past practice is not always good practice.
- Do written process control procedures, or SOPs exist for coagulation controls?
  - PWSs should develop SOPs that may include decision trees or flow-charts, that establish a decision-making and testing method that is suited to the plant and personnel.
- Are effective chemicals being used? Is the appropriate coagulant being used for the situation?
  - Changing coagulant chemicals or adding coagulant aids may improve the settleability of the flocculated water and in turn optimize performance. Coagulants may also be changed seasonally.
- Do operators understand the principles of coagulation in order to respond to varying source water quality by making the necessary adjustments to the coagulation controls to ensure optimum performance? Do operators understand and follow established process control SOPs?
  - PWSs should ensure operators are engaged in understanding coagulation chemistry so that they can continue to produce water that meets requirements.
- Are solutions used promptly? Are chemicals utilized before the manufacturer's recommended expiration or use-by dates? Are manufacturer safety data sheets with this information readily accessible?
  - Some solutions should be utilized within 48 hours of their formulation.

- Does the pH need to be adjusted for there to be proper coagulation and floc formation?

    - Adding a supplemental source of alkalinity, such as lime or soda ash, may be necessary for proper floc formation. However, adding lime (or other alkali supplements) and iron- or aluminum-based coagulants at the same point can degrade turbidity removal performance. Adding coagulant and alkalinity at different locations in the process may be necessary depending on the water chemistry.

    - Adding an acid, such as sulfuric acid, may be necessary for some PWSs to lower the pH to optimize coagulation. These systems usually adjust the pH up again with a base (e.g., sodium hydroxide) before the water enters the distribution system. PWSs making such adjustments should consider carefully the impacts of pH changes on other treatment processes (e.g., disinfection CT, corrosion control).

- Are chemicals being added in the correct order?

    - The order in which chemicals are added is very important, as certain chemicals interfere with others. For example, if both powdered activated carbon (PAC) and a coagulant are added during rapid mixing, interference from the coagulant could reduce the adsorption rate of the PAC with organic contaminants. Water treatment knowledge, jar tests, and/or desktop studies should be utilized to develop optimal sequences (AWWA, 2011b).

- Is the chemical feed system operating properly?

    - Operators should consider checking the accuracy of systems at least once daily or once per shift. The PWS may want to install calibration columns on chemical feed lines to perform pump calibrations and verify proper dosage or provide some other form of calibration. PWSs should not set the chemical feed pumps to operate at maximum stroke and feed rates, which can damage the pumps.

- Are chemicals properly mixed, particularly chemicals that are diluted?

    - The PWS may want to consider an automatic mixer in the chemical tank to provide thorough mixing.

Feed Systems

Feed systems are another important aspect of the coagulation step in typical treatment processes. These systems are responsible for delivering coagulants into the system at rates necessary for optimal performance. The following aspects should be evaluated regarding feed systems:

- Is redundancy a consideration?

    - Redundancy built into the feed systems can help the proper feeding of chemicals in the event of failure or malfunction of primary systems.

- Is the feed system large enough to address variable raw water quality conditions?

    - Feed systems should be sized so that chemical dosages can be adjusted to meet expected raw water quality conditions.

- Are chemical pumping equipment and piping checked on a regular basis? How is the system calibrated and how often?
  - Maintenance of these systems should be a priority and incorporated into routine maintenance performed at the system.
- Is a diaphragm pump used?
  - Diaphragm pumps feed chemicals in a pulsing flow pattern particularly at low stroke and speed settings unless they include a variable eccentric drive which minimizes pulsation and produces a more continuous flow. Continuous pumping allows better contact with chemicals and water.
- Does the plant stock repair parts for all critical equipment?
  - Repair parts with a long lead-time for delivery should be reordered as soon as possible after removal from inventory.

Satisfactory Dispersal/Application Points

Coagulation and mixing also depends on satisfactory dispersal of coagulation chemicals at appropriate application points. Coagulants should be adequately dispersed so that optimal coagulation may occur. Enough feed points should exist such that chemicals have the opportunity to mix completely. Utilities should evaluate the following items:

- Is adequate dispersion taking place? Is adequate mixing time built into the process?
  - Coagulation is optimal when chemical coagulants are thoroughly and rapidly mixed mechanically with the water.
- Are coagulants being added at the proper points?
  - Metal salts should be introduced at the point of maximum energy input. Low molecular weight cationic polymers can be fed with metal salts at the rapid mix or to second stage mixing following the metal salt. High molecular weight nonionic/anionic floc/filter aids should be introduced to the process stream at a point of gentle mixing. Most polymers have specific preparation instructions that should be followed.
- Is rapid mixing equipment checked frequently?
  - PWSs should check the condition of equipment, and ensure that baffling provides for adequate, even-flow.

4.3.2 Flocculation

Flocculation is the next step in most treatment plants. It is a time-dependent process that directly affects clarification efficiency by providing multiple opportunities for particles suspended in water to collide through gentle and prolonged agitation. The process typically takes place in a basin equipped with a mixer that provides agitation. This agitation should be thorough enough to encourage interparticle contact but gentle enough to prevent disintegration of existing flocculated particles. Effective flocculation is important for the successful operation of the sedimentation process. Several issues regarding flocculation should be evaluated by utilities to ensure optimal operation of flocculation basins.

Flocculation Mixing and Time

Proper flocculation requires long, gentle mixing. Mixing energy should be high enough to bring coagulated particles constantly into contact with each other, but not so high as to break up those particles already flocculated. Utilities should consider evaluating:

- Is the mixing adequate to form desired floc particles?
  - Tapered mixing (i.e., decreasing velocity gradient through the basin) is most appropriate.
- Are mechanical mixers functioning properly? Are flocculator paddles rotating at the correct rates?
  - If the speed of the paddles is too slow in the earlier stages of the flocculation process, the result can be insufficient floc formation. If the speed of the paddles is too fast in the later stages, the floc that is formed could shear or break apart.
- If flow is split between two flocculators, are they mixing at the same speed?
  - Same-speed mixing between two flocculators will ensure floc formation is occurring at the same rate in both flocculators.

Flocculator Inlets and Outlets

If water passes through the flocculation basin in much less time than the volumetric residence time, the influent stream has short circuited. Inlet and outlet turbulence is oftentimes the major source of destructive energy in flocculation basins that contributes to short circuiting. Utilities should evaluate the following:

- Do basin outlet conditions prevent the breakup of formed floc particles?
  - Basin outlets should avoid floc breakup. The velocity gradient at any point from the flocculation basin to the sedimentation basin should be less than the velocity gradient in the last flocculation stage. For information on how to calculate velocity gradient refer to Water & Treatment, Sixth Edition (AWWA, 2011b).
- Do inlet conditions prevent the breakup of formed floc particles?
  - Inlet diffusers improve the uniformity of the distribution of incoming water. Secondary entry baffles across inlets to basins impart head loss for uniform water entry.
- What size are the conduits between the rapid mix basin and the flocculation basin?
  - Larger connecting conduits help reduce turbulence which can upset floc.

Flocculator Basin Circulation

Baffles are used in flocculator basins to direct the movement of water through the basin. Baffling near the basin inlet and outlets improves basin circulation and achieves more uniform circulation. A PWS may think about the following items when evaluating flocculation.

- Is current baffling adequate? Can baffling be added to improve performance or does existing baffling require repair?

  - Baffling should allow head loss through opening to prevent short-circuiting and to allow plug flow conditions. Dividing the process into two or more defined stages or compartments will help prevent short-circuiting and permit defined zones of reduced energy input. To ensure that short-circuiting does not occur, baffles are typically placed between each stage of flocculation. For mechanical (non-hydraulic) flocculation basins, the baffles are designed to provide an orifice ratio of approximately 3 to 6 percent or a velocity of 0.3 m/s (0.9 fps) under maximum flow conditions (USEPA, 1999b).

- If the PWS uses a solids contact clarifier, it may want to evaluate the recirculation rate of water through primary and secondary reaction zones, sludge blanket depth, settling rate, percent solids, and raw water flow rate. Sudden changes in raw water flow rate may upset the sludge blanket and cause sludge carry-over to the effluent collectors and onto filters. There are several types of solids contact clarifiers, and each has unique flow patterns and sludge blanket requirements. Therefore, PWSs should consult their operations manual for proper operation and troubleshooting of performance problems.

4.3.3 Sedimentation

Sedimentation is the next step in conventional filtration plants (direct filtration plants omit this step). The purpose of sedimentation is to enhance the filtration process by removing particulates. Sedimentation requires that water flow through the basin at a slow enough velocity to permit particles to settle to the bottom before the water exits the basin. PWSs should consider the following items when evaluating sedimentation basins:

- Conducting a tracer study in the sedimentation basin. Often, relatively simple design changes such as modifications to the inlet or outlet can be made to improve sedimentation basin performance. For more information on tracer studies, consult Appendix C in the Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources (USEPA, 1991) or Tracer Studies in Water Treatment Facilities: A Protocol and Case Studies (Teefy, 1996).

- Is sludge collection and removal adequate?

  - Inadequate sludge collection and removal can cause particles to become re-suspended in water or upset circulation.

  - PWSs that maintain a sludge blanket, should disrupt it as little as possible. Sludge draw-off rates can affect the sludge blanket. Sludge draw off procedures should be checked periodically, making sure sludge levels are low; and sludge should be wasted if necessary.

  - Sludge pumping lines should be inspected routinely to ensure that they are not becoming plugged. These lines should also be flushed occasionally to prevent the buildup of solids.

- Do basin inlet and outlet conditions prevent the breakup of formed floc particles?
  - Settling basin inlets are often responsible for creating turbulence that can break up floc. Improperly designed outlets are also often responsible for the break-up of floc. Finger launders (small troughs with V–notch weir openings that collect water uniformly over a large area of the basin) can be used to decrease the chance of short-circuiting.
- Is the floc the correct size and density?
  - Poorly formed floc is characterized by small or loosely held particles that do not settle properly and are carried out of the settling basin. This is the result of inadequate rapid mixing, improper coagulant dosages, or improper flocculation. PWSs should look to previous steps in the treatment train to solve this problem.
- Is the basin subject to short circuiting?
  - If the basin is not properly designed, water bypasses the normal flow path through the basin and reaches the outlet in less time than the normal detention time. The major cause of short-circuiting is poor influent baffling. If the influent enters the basin and hits a solid baffle, strong currents will result. A perforated baffle can successfully distribute inlet water without causing strong currents. Tube or plate settlers also improve efficiency, especially if flows have increased beyond original design conditions. Tube settlers can significantly increase the basin's original settling capacity.
- Are basins located outside and subject to windy conditions?
  - Wind can create currents in open basins that can cause short-circuiting or disturbances to the floc. If wind poses a problem, barriers lessen the effect and keep debris out of the unit.
- Are basins subject to algal growth?
  - Although primarily a problem in open, outdoor basins, algae can also grow as a result of window placement around indoor basins. Algae should be removed regularly to avoid buildup.
- If using solids contact clarifiers, is the sludge blanket maintained properly?
  - Operators should be able to measure the sludge depth and percent solids to ensure the sludge blanket is within the manufacturer's recommendations. A timing device to ensure consistent blanket quality characteristics should control sludge removal rates and schedule.
- Is the recirculation rate for solids contact clarifiers within the manufacturer's recommendations?
  - Various designs have different recirculation rates and flow patterns. PWSs should refer to the manufacturer's operation manual.

4.3.4 Filtration

Filtration is the last step in the particle removal process. There are several filtration technologies that are used to accomplish particulate removal, including:

- Granular bed filters (e.g., rapid granular bed and pressure filters).
- Slow sand filters.
- Diatomaceous earth (DE) (precoat) filters.
- Membrane filters.

Improperly designed, operated, or maintained filters can contribute to poor water quality and sub-optimal performance. There are a host of items which PWSs will need to evaluate regarding filters that may be contributing to poor performance. This Section focuses on optimization of granular bed filters.

Design of Filter Beds

It is important to verify that the filters are constructed and maintained according to design specifications. PWSs should consider the following items when evaluating the design of filter beds:

- Is the correct media being used? Issues such as size and uniformity coefficient should be evaluated. Is the media at the proper depth?

  - Media can be lost during backwash operations or when air trapped in the media is suddenly released. Only a small amount of media may be lost at a time, but it will add up to a substantial reduction in media depth over time. Media depth should be verified and recorded at least annually. Consistent losses may be indicative of other problems such as inadequate freeboard to the wash water collectors. Media should be added any time the depth changes by more than two inches across the filter.

- Is the PWS aware of the condition of filter underdrains? Are underdrains adequate or have they been clogged, damaged, or disturbed?

Filter Rate and Rate Control

The rate of filtration and rate control is another important aspect of filters that should be evaluated. Without proper control, surges may occur which would force suspended particles through the filter media. Items to consider are:

- Do the filters experience sudden flow surges?

  - PWSs should avoid sudden changes to filter flow rates.

- Is the plant operating at the appropriate flow rate?

  - At some plants (typically smaller PWSs), the flow may be operated at a level that hydraulically overloads unit processes. Operating at lower flow rates over longer periods of time prevents overloading and increases plant performance.

  - Underloading filters can also be a problem. If a PWS is treating an extremely low flow rate, it may choose to take some filters off-line for a period of time so that the remaining filters can achieve the design loading rate. However, issues can arise when filters are taken off-line because they still have standing water in them which can contribute to the growth of microorganisms and anaerobic conditions in the filter. Therefore, it is usually better to use all filters and allow water to move through the filters instead of taking filters off-line during low plant flow periods. If this mode of operation is not possible, the PWS may want to consider disinfection of the filter prior to placing it back on-line.

Filter Backwashing

Filter backwashing has been identified as a critical step in the filtration process. Many of the operating problems associated with filters are a result of inadequate backwashing. Utilities should consider the following items when evaluating filter backwash practices:

- Is the rate of filter backwash appropriate for the filter?
  - Filters can be either under-washed or over-washed. Utilities need to determine the appropriate flow that will clean the filter and prevent mudballs but will not upset the filter media to the extent that the underdrain is damaged, or filter media is lost (20-50 percent bed expansion is typical).
- Are criteria set for initiating backwash?
  - PWSs should establish criteria such as time, head loss, turbidity, or particle counts for initiating backwash procedures. If more than one criterion is used, the criteria should be prioritized to identify which one is most critical for establishing when to backwash the filter.
- How are filters brought back on-line?
  - Media should be allowed to settle after backwashing before bringing filters back on-line. Filters should be brought back online slowly. Several filters should not be brought online at the same time. Filters should not be brought back on-line without backwashing first.
- When a filter is backwashed, is more water diverted to the remaining filters, causing them to be overloaded during backwash?
  - During the backwash, flow going to the remaining filters may need to be cut back to ensure the filters are not overloaded or “bumped” with a hydraulic surge causing particle pass through.
- Is flow divided equally among the filters that are online?
- Is the loading rate gradually increased until the design hydraulic loading rate is achieved?
  - Starting the filter slowly will purge trapped air in the media.

Air Binding

Air binding happens when large amounts of air bubbles accumulate in the filter bed. This may result in a large head loss through the filter bed. If a high-water level is maintained in the filter, air binding may be minimized due to the increased head applied to the bed. This practice may not be possible with some package plants because package plants are limited regarding the depth of water over the filter. Air binding may be more common when water is cold during the winter or spring, when there is a high concentration of dissolved air in the water. The degree of air binding may be reduced or even eliminated if filter backwashing is frequently initiated whenever the head loss reaches four to five feet.

Control of Initial Turbidity Breakthrough

PWSs may sometimes have a high initial turbidity breakthrough after placing a filter back on-line after backwashing. This breakthrough can be controlled by:

- Filter to waste (discarding filter effluent that is produced during the filter ripening period immediately after backwash due to its impaired quality);
- Delayed start of the filter;
- Slowly starting the filter;
- Adding polymer or coagulant to backwash water; and/or,
- Adding coagulant chemical or cationic polymer to settled water as it fills the filter box after backwash is terminated.

Filter-to-waste consists of wasting water to a site other than the clearwell until the filter effluent meets an acceptable turbidity (regulatory or plant performance standard) or particle count value. Some PWSs may filter-to-waste for a preset time, but filter-to-waste may be more effective if terminated based on a specific turbidity or particle count value. Some filtration plants may not have adequate piping to carry the wasted filtrate when the filter is operated at its full filtration rate. In this circumstance, filter-to-waste should be conducted with the filter operating at a reduced rate, and after filter-to-waste has ended, the filtration rate should be increased to the appropriate level. PWSs should carefully manage the filter rate change because sudden increases in the hydraulic loading rate could also result in unwanted turbidity spikes. If a plant does have filter-to-waste capabilities, it should make sure that the waste line does not create a cross connection for the plant. One method to consider is to provide an air gap between the filter waste line and the receiving device (whether it is a recycle line, sanitary sewer pipe, or trough).

Delayed start of the filter has also been shown to reduce initial turbidity spikes. In a study conducted by Hess et. al. (2000), the results showed up to 50 percent reduction in peak particle counts between delayed start filters and filters that were placed on-line immediately after backwash. PWSs should be aware that resting a filter before starting a new run is not a cure-all; some plants have reported that the delayed start did not consistently control initial turbidity.

Slow-starting a filter consists of starting the filter at a low filtration rate and gradually increasing the rate over a period of time, such as 15 minutes. To slow-start a filter, the filter should be equipped with rate control valves that can be gradually increased. This approach has been found to be effective at some plants while failing to eliminate the initial turbidity spike at other plants.

PWSs could also consider adding a polymer during the backwash process to accelerate the filter ripening process and reduce initial turbidity spikes (USEPA 1998a). The polymer is typically added during the last couple of minutes of backwash.

Overdosing either an inorganic coagulant or a polymer could have a negative effect on the filter. Applying chemical overdose for too long at the beginning of a run may cause filtered water turbidity to rise at the end of the dosing. In addition, if excessive alum is added to the influent settled water, mudballs might develop in the filter. Excess polymer dosages can also result in short filter runs and mudball formation. PWSs should start at very low coagulant or polymer dosages and gradually increase the dose until positive effects are seen in the filtered effluent quality. Jar testing helps PWSs determine effective coagulant doses; PWSs using both coagulant and polymer should include both chemicals when jar testing.

PWSs should also perform filter runs with and without the coagulant or polymer for comparison purposes. Some utilities have found that using a combination of the above procedures provides the best control of initial turbidity spikes.

Turbidity Breakthrough in Late Stages of the Filter Cycle

Filters may sometimes experience high turbidity or sudden spikes prior to the end of the filter cycle. This type of breakthrough can be controlled by strengthening the floc and increasing the adsorption capability of the filter bed. Two options a PWS should consider are to feed cationic polymer as a coagulant, with or without alum, or to feed minute amounts of nonionic polymer to the filter influent as a filtration aid. Polymers can sometimes counteract each other, and the addition of one polymer may require a PWS to increase the feed amount of another polymer.

4.4 References

AWWA. 1994. Preventing Waterborne Disease: How to Optimize Treatment, Participant Guide. AWWA Satellite teleconference.

AWWA. 2011a. M37 Operational Control of Coagulation and Filtration Processes, Third Edition. Denver, CO.

AWWA. 2011b. Water Quality & Treatment, A Handbook on Drinking Water, Sixth Edition. McGraw Hill.

Bucklin, K., A. Amirtharajah, and K. Cranston. 1998. Characteristics of Initial Effluent Quality and its implications for the Filter to Waste Procedure. AWWARF, Denver, CO.

Deem, S. and N. Feagin. 2014. A Turbidity Data Verification Project in Washington. *J. AWWA.* 106(12):32-38.

Deem, S., and N. Feagin. 2016. Disinfection Data Integrity in Washington State. *J. AWWA.* 108(10):24-30.

Hess, A., M. Chipps, G. Logsdon, and T. Rachwal. 2000. An International Survey of Filter O&M Practices. National AWWA Conference, Denver, CO.

Huben, H. 1995. Water Treatment. Second Edition. AWWA.

Kawamura, S. 2000. Integrated Design and Operation of Water Treatment Facilities, Second Edition. John Wiley & Sons, Inc., New York.

Logsdon, G., A. Hess, P. Moorman, and M. Chipps. 2000. Turbidity Monitoring and Compliance for the Interim Enhanced Surface Water Treatment Rule. National AWWA Conference, Denver, CO.

Logsdon, G. 1987. Evaluating Treatment Plants for Particle Contaminant Removal. *J. AWWA.* 79(9):82-92.

Najm, I., V. Snoeyink, B. Lykins Jr., and J. Adams, J. 1991. Using Powdered Activated Carbon: A Critical Review. J. AWWA. 83(1):65-76.

Partnership for Safe Water. 1995. Voluntary Water Treatment Plant Performance Improvement Program Self Assessment Procedures. October.

Teefy, Susan. 1996. Tracer Studies in Water Treatment Facilities: A Protocol and Case Studies. AWWA Research Foundation and American Water Works Association. Denver, CO.

USEPA. 1989. Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities. EPA/625/4-89/023, Center for Environmental Research Information, Cincinnati, OH.

USEPA. 1991. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources. Washington, DC.

USEPA. 1998a. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA/625/6-91/027. August 1998. Available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents.

USEPA. 1998b. Regulatory Impact Analysis for the Interim Enhanced Surface Water Treatment Rule. Office of Ground Water and Drinking Water, Washington, D.C.

USEPA. 1999a. Microbial and Disinfection Byproducts Rules Simultaneous Compliance Guidance Manual (EPA 815-R-99-015, August 1999)

USEPA. 1999b. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of Water, Washington, D.C.

USEPA. 2007. Simultaneous Compliance Guidance Manual for the Long Term 2 And Stage 2 DBP Rule. EPA 815-R-01-017 Available at: https://www.epa.gov/dwreginfo/stage-1-and-stage-2-compliance-help-community-water-system-owners-and-operators#simcom.

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In this chapter:

- *Components of a Filter Self-Assessment*
- *References*

CHAPTER 5 – INDIVIDUAL FILTER SELF-ASSESSMENT

5.1 Introduction

Filter self-assessments are required only under certain circumstances for conventional and direct filtration systems (Refer to Table 2.2 in Chapter 2 for the turbidity values that trigger a filter self-assessment). However, PWSs using filtration technologies other than conventional and direct may find some useful information in this chapter. This chapter describes the process of an individual filter self-assessment and is intended to provide clarity regarding which areas can limit the performance of a filter. For more information on additional procedures to consider (e.g., carbonate precipitation) refer to the AWWA 2018 Filter Evaluation Procedures for Granular Media, Second Edition (Nix and Taylor, 2018).

For any situation regarding a single poorly performing filter, or a bank of poorly performing filters:

- Performance limitations observed at the start of a filter run are most often attributed to improper chemical conditioning of the filter;
- Limitations observed during the filter run are most often attributed to changes in hydraulic loading conditions; and
- Limitations observed at the end of the filter run are most often related to excessive filter runs.

Filter performance issues may only be apparent during excessive hydraulic loading and care should be taken to not attribute all turbidity spikes to hydraulic bumping or overloading. In some circumstances performance "symptoms" for other causes may only be evident during these hydraulic episodes. Oftentimes disrupted filter media may cause filter performance problems. This chapter describes the process of an individual filter self-assessment and is intended to provide clarity regarding which of these areas are limiting the performance of a filter.

Filters represent the key unit process for the removal of particles in surface water treatment. Although filters represent only one of the "barriers" in a treatment process their role is often the most critical as the final physical "barrier" to prevent passage of pathogenic microorganisms into distribution systems. Properly designed filters used in conjunction with coagulation, flocculation, and sedimentation processes (if in use), when in proper physical and operational condition, are capable of treating raw water to meet NPDWRs.

This chapter describes each of the following components of an individual filter assessment:

- Development of a filter profile.
- Assessing hydraulic loading conditions of the filter.
- Assessing condition and placement of filter media.
- Assessing condition of support media/underdrains.
- Assessing backwash practices.
- Assessment of placing a filter back into service.
- Assessing rate-of-flow controllers and filter valving infrastructure.

- Other considerations.
- Assessment of applicability of corrections.
- Preparation of a report.

Prior to beginning the assessment, PWSs should refer to their state drinking water requirements to see if there are any requirements related to how filters should be operated (e.g., hydraulic loading rates, filtering to waste). PWSs should record a general description of the filter being assessed including size, configuration, placement of wash water troughs and surface wash type (if applicable), filter media design (e.g., type, depth, and placement) and if filter-to-waste is present and/or used; and if any special conditions exist regarding placing a filter back into service (e.g., is the filter rested, and is polymer or coagulant added prior to placement into service). Table 5-1 provides a worksheet to assist the evaluator in collecting this information as well as any other information gathered during the assessment.

Table 5-1. Individual Filter Self-Assessment Worksheet

Topic	Description	Information
General Filter Information	Type (mono, dual, mixed)	
	Number of filters	
	Filter control (constant, declining)	
	Surface wash type (rotary, fixed, none)/Air Wash	
	Configuration (rectangular, circular, square)	
	Dimensions (length, width, diameter)	
	Filter-to-waste (capability/specify if used)	
	Surface area per filter (ft^2)	
Hydraulic Loading Conditions	Average operating flow [million gallons per day (MGD)]	
	Peak instantaneous operating flow (MGD)	
	Average hydraulic surface loading rate (gallons per minute (gpm)/ft^2)	
	Peak hydraulic surface loading rate (gpm/ft^2)	
	Changes in hydraulic loading rate (gpm/ft^2)	
Media Conditions	Depth	

Topic	Description	Information
	Media 1 – Sand	
	Media 2 (if applicable) – Anthracite	
	Media 3 (if applicable) – Garnet	
	Presence of mudballs, debris, excess chemical, cracking, worn media, media coating	
Support Media/Underdrain Conditions	Is the support media evenly placed (deviation <2 inches) in the filter bed?	
	Evidence of media in the clearwell or plenum	
	Evidence of boils/vortexing during backwash	
Backwash Conditions	Backwash initiation (head loss, turbidity/particle counts, time)	
	Sequence (surface wash, air scour, flow ramping, filter-to-waste)	
	Duration (minutes)	
	Introduction of wash water (via pump, head tank, distribution system pressure)	
	Backwash rate (gpm/ft^2)	
	Bed expansion (percent)	
	Dose of coagulant or polymer added to wash water	
	Backwash termination (time backwash turbidity, visual inspection, or other)	
	Backwash SOP (exists and current)	
Placing a Filter Back into Service	Delayed start, slow start, polymer addition, or filter-to-waste	
Rate-of-Flow Controllers and Filter Valves	Leaking valves	
	Malfunction rate of flow control valves	
	Equal flow distribution to each filter	

Topic	Description	Information
Other Considerations	Chemical feed problems	
	Rapid changes in raw water quality	
	Turbidimeters (calibrated)	
	Other	

5.2 Developing a Filter Profile

Section 2.4.1.1 details when PWSs must produce filter profiles based on regulatory requirements. Additionally, as discussed in Section 2.4.1.2, a filter profile must be developed as part of the filter self-assessment process [40 CFR 141.175(b)(3) and 141.563(b)]. The purpose of this requirement is to help identify turbidity spikes (sudden increases in turbidity) or high turbidity levels during the filter run and to determine the probable causes of those spikes. Performance should be shown by turbidity or particle count measurements. Use of particle counting in conjunction with turbidity monitoring of filter effluents may offer additional insights to filter performance, however, care should be taken in the interpretation of particle count results. The interpretation should focus on the change in count levels as opposed to the discreet particle count numbers.

Plotting the performance data versus time on a continuous basis is the desirable approach for development of the filter profile. For purposes of developing a filter profile, PWSs may want to consider taking turbidity readings more frequently than every 15 minutes (the requirement) and may consider recording readings once every 5 minutes, every minute, or more frequently, if possible. This increased frequency will allow PWSs to more accurately capture spikes. The filter profile should represent a typical filter run and should include (if representative of normal filter operations) the time period when another filter is being backwashed or is out of service in order to determine if such practices have an impact on finished water quality. The filter profile should include an explanation of the cause (if known), of performance spikes during the run. Flow and changes in flow to the filter should be identified on the filter profile. When possible, the profile should be plotted using data collected during the turbidity event that prompted the filter self-assessment.

Table 5-2 describes filter performance examples for complete filter runs for six different scenarios. Figure 5-1 through 5-6 show filter profiles for each of these scenarios.

Table 5-2. Filter Performance Examples for Six Scenarios

Scenario	Filter Performance Example
1 (Figure 5-1)	Optimized filter with turbidity values well below 0.1 NTU with the exception of an initial spike (less than 15 minutes in duration) after returning filter to service following a backwash cycle. The 'clean' filter needs time to 'ripen.' Ripening occurs when flocculated particles begin to fill the void spaces in the filter media and recharge the media improving the filter's ability to remove particles from the water.

Scenario	Filter Performance Example
2 (Figure 5-2)	An otherwise optimized filter with an approximately 8-hour spike in turbidity. The cause could be due to many factors including failure of coagulant dosing equipment or an instance where the filter hydraulic loading rate (gpm/ft^2) (discussed in Section 5.3) is exceeded beyond design limits due to a hydraulic surge (e.g., adjustments to plant flow) or when other filters are taken off-line.
3 (Figure 5-3)	A filter run with inadequate filter ripening. This could be a result of putting the filter back into service too soon after a backwash or over cleaning the filter during backwash requiring a longer period of time for the filter to ripen.
4 (Figure 5-4)	An otherwise optimized filter with filter breakthrough at the end of the run cycle. This indicates that the filter was in operation too long. The filter should have been taken off-line and backwashed after 30 hours in operation.
5 (Figure 5-5)	A filter with several turbidity spikes occurring for about 4 hours every 2 to 3 hours. The cause could be due to periodic exceedances of the filter hydraulic loading rate (gpm/ft^2) beyond this filter's design capabilities which could result from hydraulic surges (e.g., adjustments to plant flow) or when other filters are taken off-line.
6 (Figure 5-6)	A filter with continuously high turbidity which could be a result of issues with coagulant dosing (equipment problems or insufficient quantity being dosed) which should also be apparent in treatment processes prior to filtration, improper or inadequate backwashing, or issues with the filter media (e.g., worn, cracking media) or underdrains.

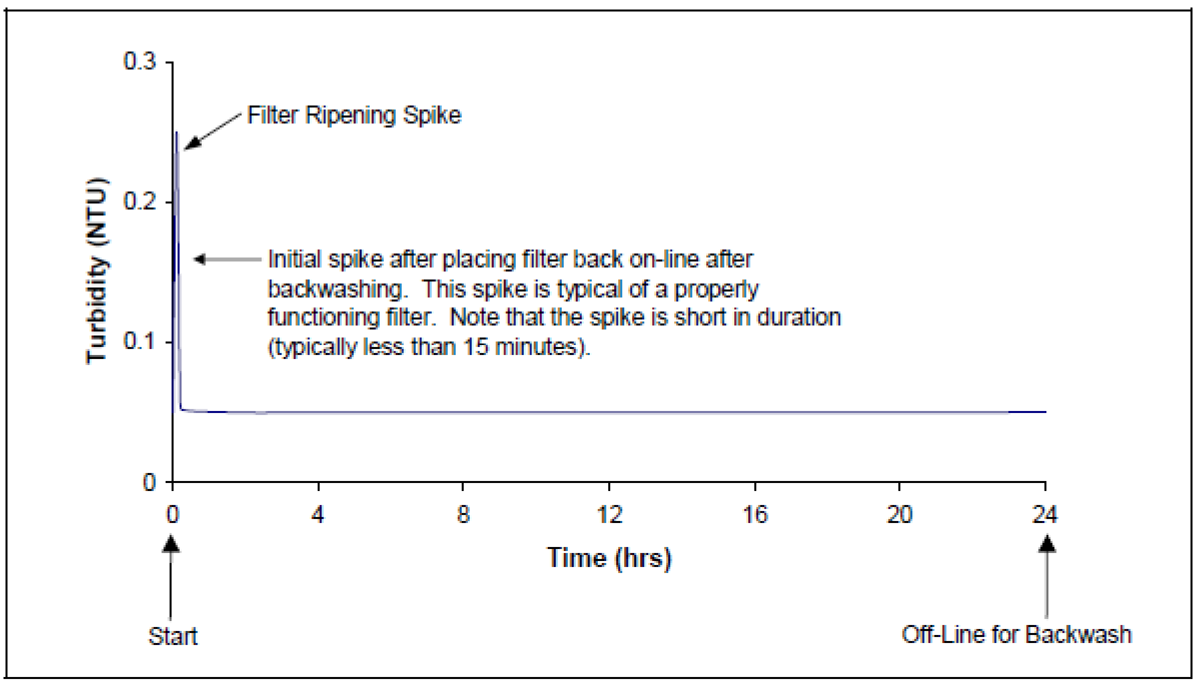


Figure 5-1. Example Filter Profile of Optimized Filter Performance

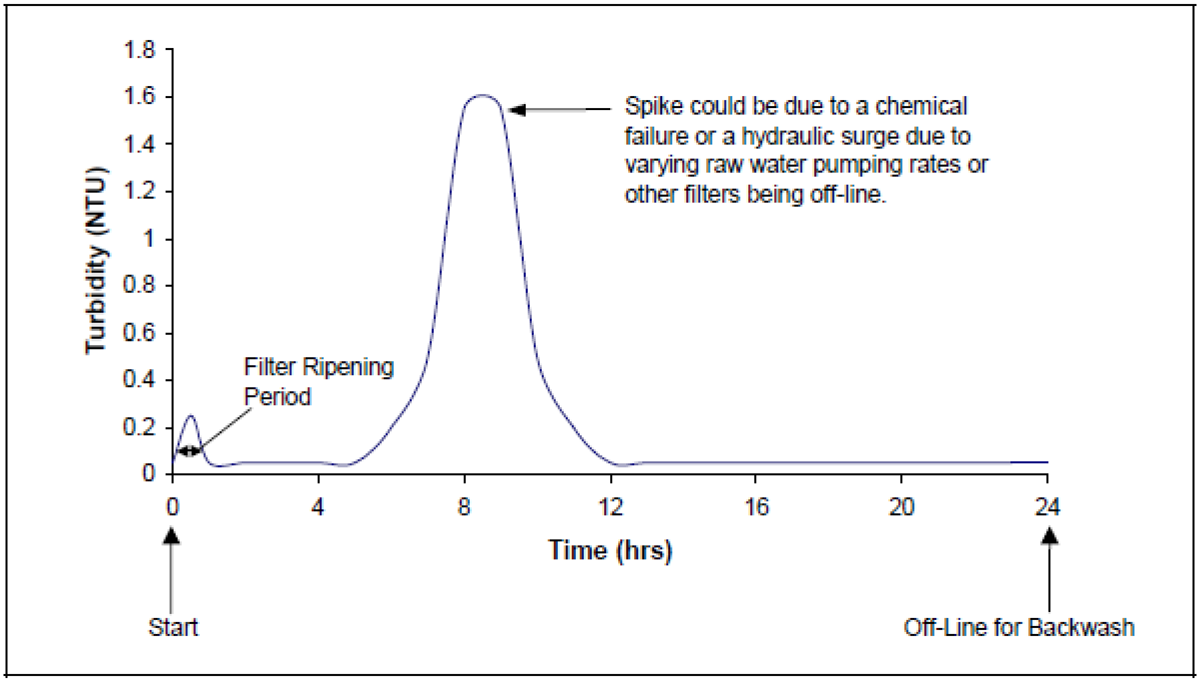


Figure 5-2. Example Filter Profile of Optimized Filter with Turbidity Spike During Filter Run

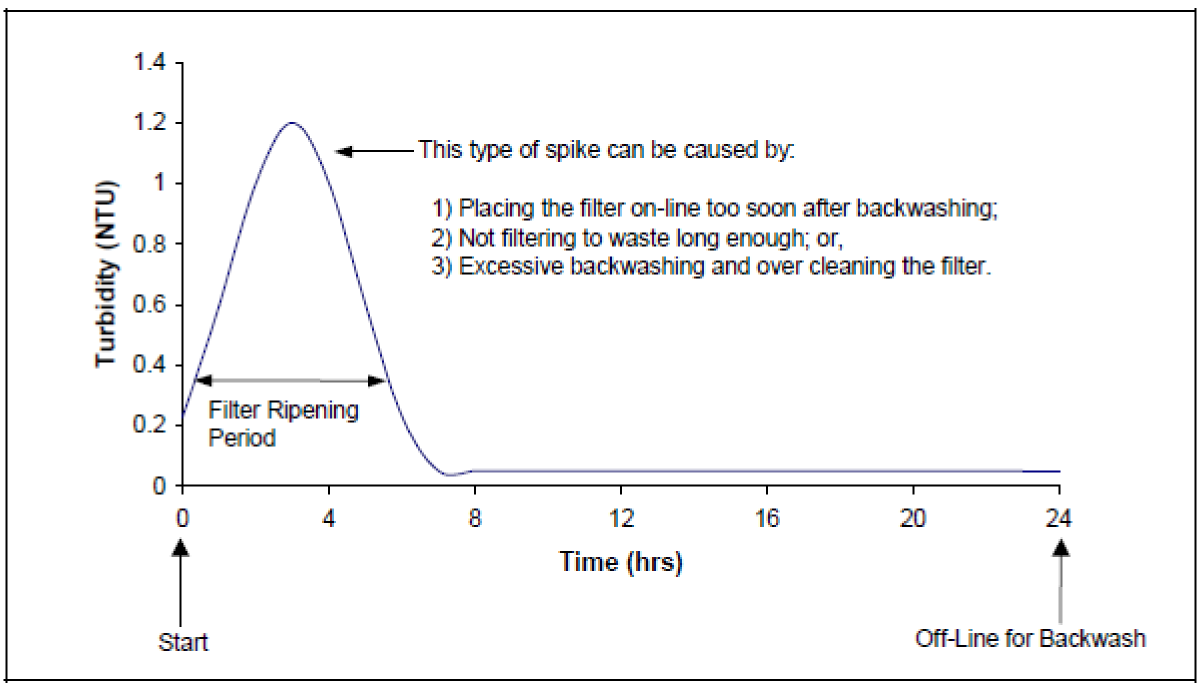


Figure 5-3. Example Filter Profile with Long and High Initial Spike

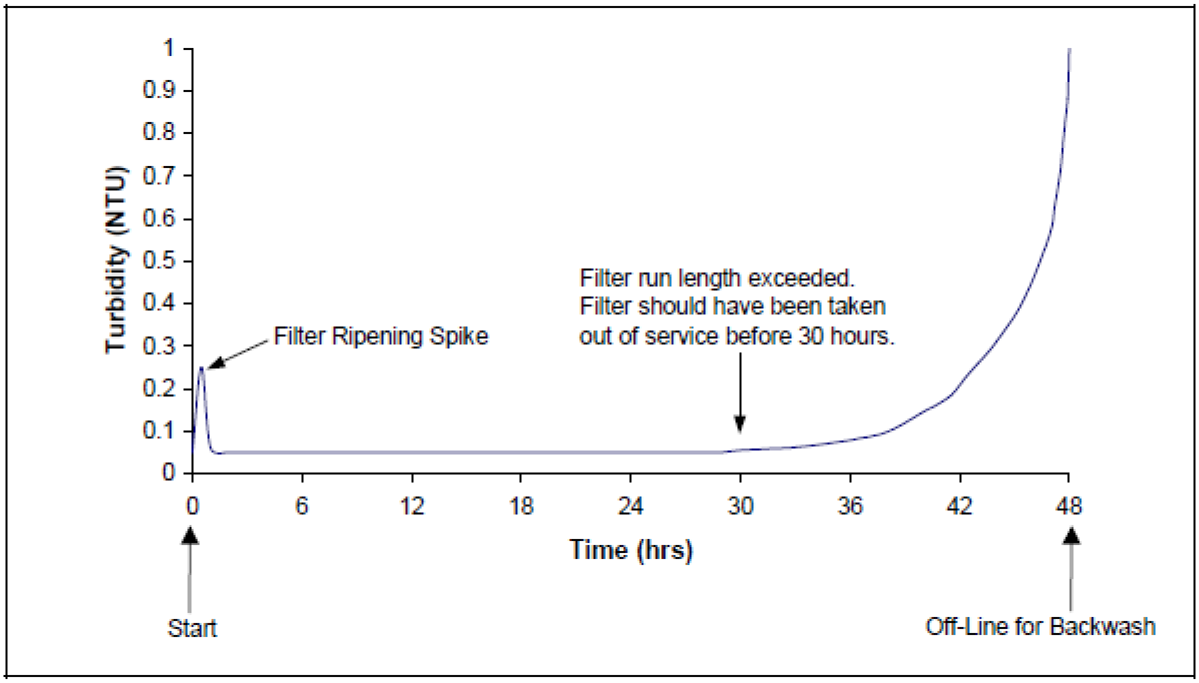


Figure 5-4. Example Filter Profile of Optimized Filter with Breakthrough at End of Filter Run

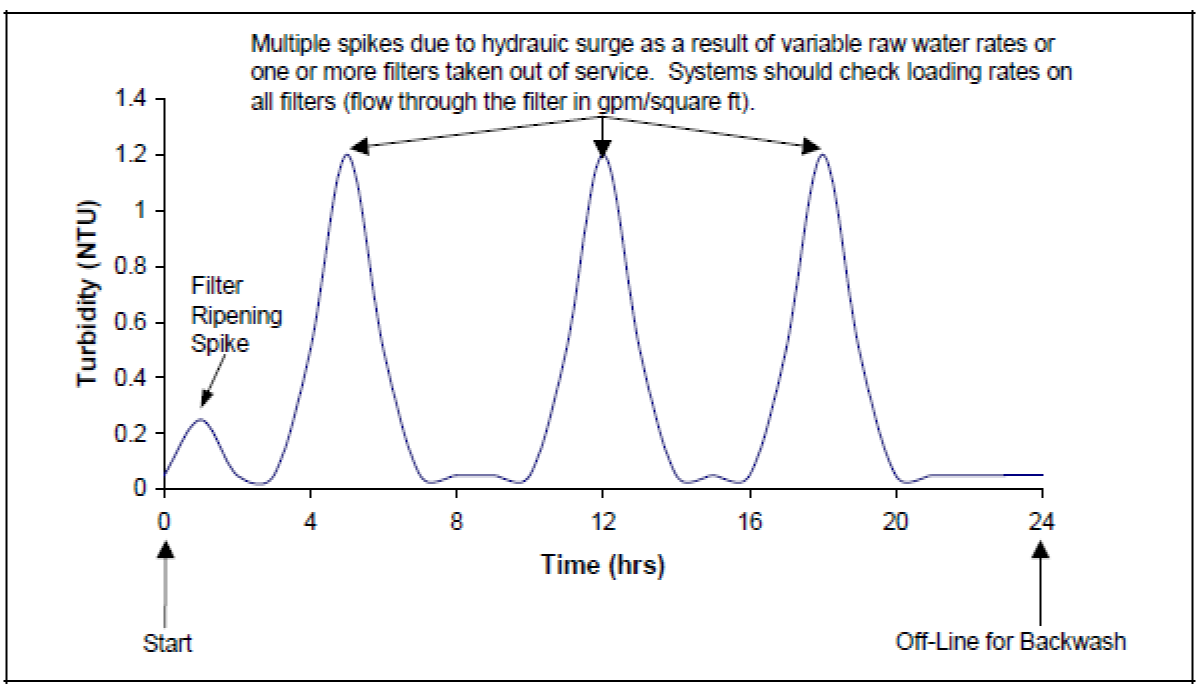


Figure 5-5. Example Filter Profile with Multiple Spikes

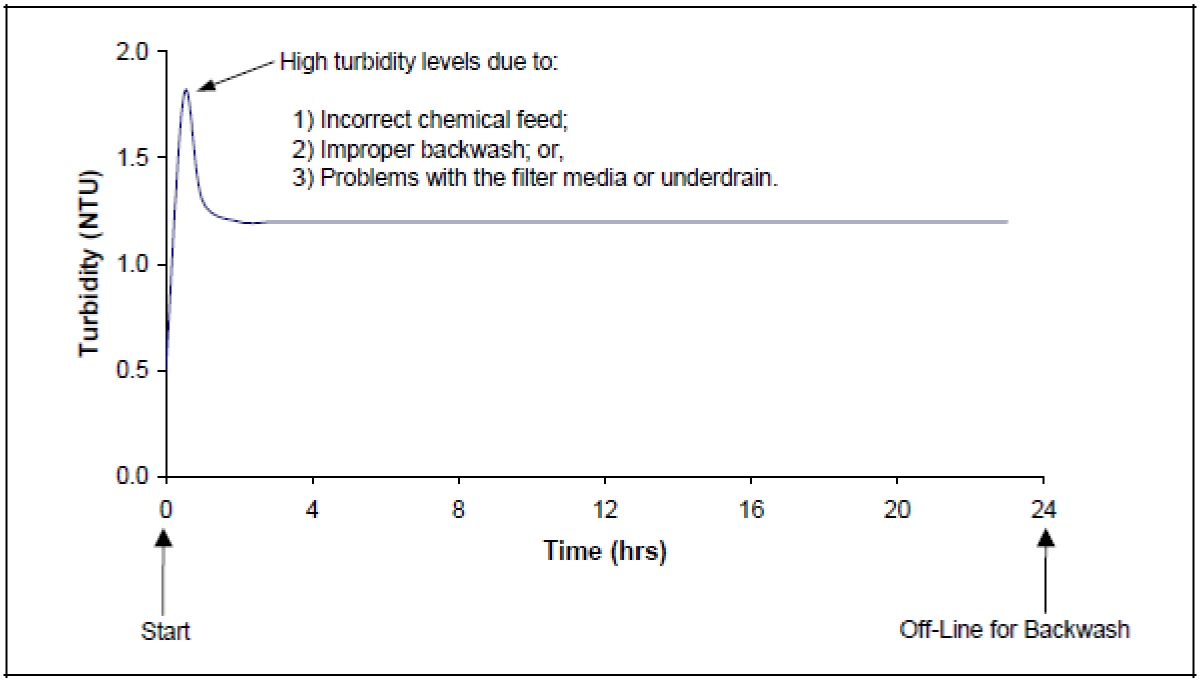


Figure 5-6. Example Filter Profile with High Initial Spike and Turbidity Levels Above 1.0 NTU

5.3 Assessing Hydraulic Loading Conditions of the Filter

Filters may operate poorly when peak loading rates exceed filter design or when hydraulic loading rates change suddenly. Table 5-3 presents a summary of industry standard loading rates for various filters. Filters may perform satisfactorily at loading rates other than those in Table 5-3; these values are general and provide a basis for evaluating excessive filter hydraulic loading. State requirements may differ from acceptable industry loading rates and should be considered during the assessment.

Table 5-3. General Guide to Acceptable Filter Hydraulic Loading Rates[1]

Filtration Type	Air Binding	Loading Rate
Sand Media	None	~2.0 gpm/ft^2
	Exists	~1.0 - 1.5 gpm/ft^2
Dual/Mixed Media	None	~4.0 gpm/ft^2
	Exists	~2.0 - 3.0 gpm/ft^2
Deep bed (anthracite > 60 in.)	None	~6.0 gpm/ft^2
	Exists	~3.0 - 4.5 gpm/ft^2

1. USEPA, 1998

Peak hydraulic loading rate should be calculated by dividing the peak flow to the filter (gpm) by the surface area of the filter (ft^2). Equation 5-1 demonstrates this method of calculating the peak hydraulic loading rate.

Equation 5-1

$$Peak\ hydraulic\ loading\ rate = \frac{Peak\ filter\ flow\ (\mathrm{gpm})}{Filter\ area\ (\mathrm{ft}^2)}$$

Since the filters can be most vulnerable during excessive loading rates, it is critical to determine the peak instantaneous flow that filters are experiencing and to minimize the occasions when filters are overloaded. The peak instantaneous operating flow rate can be identified by looking at operating records, operational practices, and flow control capability. However, review of plant flow records can be misleading in determining the peak instantaneous operating flow. The average daily flow rate can be calculated if the plant keeps track of total daily flow (total daily flow/minutes of plant operation) but it is difficult to calculate instantaneous flow with total daily flow information. The peak instantaneous operating conditions should be correctly identified when reviewing flow data. If pumps are used in multiple combinations throughout the operational day, care should be taken to determine the actual peak loading on the filters during the day. As seen in Example 5-1, the peak hydraulic loading rate to the filters did not occur during peak plant flows. More than one operating scenario may need to be examined to correctly identify peak filter hydraulic loading rate.

Example 5-1. Calculating Peak Hydraulic Loading Rate

A plant that operates 24 hours per day uses three 300-gpm pumps in various combinations throughout the year to meet system demand. The peak flow occurs for a 2-hour period each evening when all three pumps are used to fill on-site storage. Two pumps are used for the first hour and a half, while the third pump is used with the other two pumps only for the last 30 minutes of the 2-hour period. During that 30-minute period plant flow increases to 800 gpm. The peak instantaneous operating flow that goes onto the filters is 800 gpm. The plant has two dual media filters (each 100 ft^2) and would have a peak hydraulic loading rate of 4.0 gpm/ft^2 at the 800 gpm peak flow.

Using Equation 5-1:

Peak hydraulic loading rate = Peak flow (gpm)/Filter Surface Area (ft^2)

= 800 gpm / ((2 filters) X (100 ft^2/filter))

= 800 gpm / 200 ft^2

= 4.0 gpm/ft^2

This loading rate is within suggested rates. However, the PWS would want to avoid loading rates much higher than 4 gpm/ft^2 unless higher rates are allowed by design or recommended by the manufacturer and as long as the filtered water quality is acceptable.

For the same plant, the peak filter hydraulic loading rate could occur under a different set of circumstances. During the first hour and a half when the two pumps are on, one of the filters is taken off-line for backwashing. The peak flow is 540 gpm.

Peak hydraulic loading rate = 540 gpm / ((1 filter) X (100 ft^2/filter))

= 540 gpm / 100 ft^2

= 5.4 gpm/ft^2

This loading rate to the filter is higher than the loading rate realized during the peak flow and exceeds the suggested range.

Example 5-2 shows how the peak hydraulic loading rate can be affected for filters in service if adjustments are not made to plant flow while other filters are taken offline for backwashing.

Example 5-2. Peak Hydraulic Loading Rate Scenario

A plant with 8 dual media filters and a constant high service pumping rate of 8 MGD operates 24 hours per day and is unable to consistently meet the filter requirements. Each filter has 175 ft^2 of surface area and typically has a flow rate of 1 MGD. However, two filters are backwashed per day at the same time with no reduction in plant flow. During backwash the two filters are out of service for 40 minutes. During that 40-minute period the entire plant flow of 8 MGD is handled by just six filters. The peak instantaneous operating flow for each filter becomes 1.33 MGD. The hydraulic loading rate in gpm/ft^2 for each 175 ft^2 filter at this peak flow becomes 5.3 gpm/ft^2 (1.33 MGD converted to gpm divided by the filter surface area), which is at the upper end of the acceptable loading rates for a dual media filter and may be contributing to the unacceptable performance.

For more information on other indices to consider or use for calculating, including filter performance over time, unit filter run volume, and length/depth ratio, refer to the AWWA 2018 Filter Evaluation Procedures for Granular Media, Second Edition (Nix and Taylor, 2018).

5.4 Assessing Condition and Placement of Filter Media

Assessment of the condition and placement of the filter media is an integral step in identification of factors limiting performance of the filtration process. The presence of mudballs, surface cracking, or displaced media may often be attributed to excessive use of coagulant chemicals, inadequate backwashing, or a more serious problem related to the underdrain system. The assessment of the condition and placement of the filter media should include a physical inspection of the filter and the media, observation of the media placement, and media analyses. These are all discussed in more detail below.

5.4.1 Filter Inspection

The inspection of the filter should consist of the following steps:

1. The filter inspection should begin by draining the filter.

2. As the filter is drained, observe the filter surface carefully. Note areas where vortexing or ponding occurs. Areas of vortexing should be inspected for proper media and underdrain placement. Areas of ponding are a good indicator that the filter surface is not level.

3. The filter should be drained enough to allow for excavation of the media to assess the depths of each media type as well as each media interface (i.e., just below the anthracite/sand interface in a dual media filter). Deeper excavation of the filter may be warranted if evidence suggests disrupted support gravels or an inadequate underdrain system (see Section 5.5). Care should be taken not to disrupt the support gravel or media while coring or probing.

Anyone who enters a filter box needs to be aware of confined space entry and lockout/tagout issues. Confined spaces may present safety hazards. Check with the local Occupational Health and Safety Administration (OSHA) office for confined space entry requirements.

5.4.2 Media Inspection

Prior to getting in the filters, evaluators should place small pieces of plywood on the media to avoid sinking into the media. Filter media assessments may be conducted using a variety of coring devices (typically a 1½- to 2-inch thin-walled, galvanized pipe), a hand dig, a shovel, or if needed, a gross excavation technique. The gross excavation technique may be conducted using a plexiglass box like the ones shown in Figures 5-7 and 5-8. The box excavation consists of sinking a plexiglass box into the media and excavating inside the box down to the support media. The box excavation technique allows for visual observation of the media depths and interfaces after the excavation is completed.

Figure 5-7. Box Used for Excavation

Figure 5-8. Box Excavation Demonstration

If the filter is a pressure filter, coring the filter may be difficult or impossible. All necessary safety precautions should be taken when entering a pressure filter since it may well be considered a confined space. If the pressure filter has a viewing port the length of the filter media, the media should be viewed periodically to look for signs of cracking, mudballs, media segregation, or any other changes in the media.

5.4.3 Media Placement and Observations

Whatever media excavation technique is used, the evaluators should note the depth of each media type, (comparing this to the original specifications), the general condition of the media interface, whether mudballs are present (see Figure 5-9) or excess chemical has accumulated. After the excavation is completed, the excavation team should make certain that the media is placed back in the excavations in the same sequence that it was removed.

Figure 5-9. Mudball from a Filter

5.4.4 Media Analyses

Coring methods offer the advantage of being able to apply the floc retention analysis procedure (presented in Section 5.6.5). If media samples have been collected from the filter, the evaluators may want to consider having a sieve analysis conducted. A sieve analysis is recommended if it is suspected that the filter media size is wrong. The sieve analysis should be performed by a soils laboratory. The soils laboratory should determine the effective size and coefficient of uniformity for the different media; this will allow the evaluator to compare the laboratory results with filter media design specifications.

5.4.5 Completing the Inspection

Before placing the filter back on-line after an inspection:

- Make sure all the tools used to inspect the filter have been collected and removed from the filter. It is a good idea to make a list of tools that will be used before entering the filter to ensure all tools are removed upon exiting the filter.

- After completing the filter excavation, the filter should be backwashed prior to returning it to service. The backwash should be started very slowly to remove air. Disinfectant could be added to the filter prior to backwash. Filtering to waste after the inspection and before discharging to the clearwell is also an option.

5.5 Assessing Condition of Support Media/Underdrains

Maintaining the integrity of the support gravels and underdrains (see Figure 5-10) is extremely important to the performance of a rapid granular filter. Disrupted or unevenly placed support media can lead to rapid deterioration of the filtered water quality noticeable by quick turbidity breakthroughs and excessively short filter runs. Should disruption of the support media be significant, the impacted area of the filter may act as a "short-circuit" allowing particulates and any microbial pathogens which are present to pass directly into the clearwell. Filter support gravels can become disrupted by various means including sudden violent backwash, excessive backwashing flow rates, or uneven flow distribution during backwash. The number one cause of support gravel disruption is uncontrolled air. Also, air that accumulates during the filter run can disrupt gravel as it is released at the start of a backwash. This is why it is so important to start backwashes slowly at a low rate.

Figure 5-10. Underdrain System

The condition of the support gravel can be assessed in three steps:

- Step One – Visually inspect the filter during a backwash for the presence of excessive air boiling or noticeable vortexing as the filter is drained. Look for signs of pooling in low areas, which may indicate that the support gravel is not level.

- Step Two – "Map" the filter using a steel or solid probe. This is the most common method of assessing the placement of filter support media. The mapping procedure involves a systematic probing through the filter media down to the support gravels of a drained filter at various locations in a grid-like manner. At each probe location, the depth of penetration into the filter is measured against a fixed reference point such as the wash water troughs. The distance from the fixed reference point to the top of the support gravels should deviate less than 2 inches (USEPA, 1998). A grid map of the filter will help with tracking and recording measurements. See Example 5-3 for a completed grid. **Care should be taken during the filter probing not to disrupt the support gravel.**

- Step Three - Determine whether filter media has ever been found in the clearwell. This should be determined visually or by reviewing recent clearwell maintenance records. Clearwell inspections should be only be conducted following appropriate safety procedures while minimizing negative impacts on necessary plant operations. Clearwells containing a significant amount of filter media may indicate a greater problem than just disrupted support gravels. The problem may be attributed to a severe issue with the filter underdrain system. An in-depth assessment of the underdrains typically involves excavation of the entire filter bed.

PWSs should use best professional judgment and seek additional guidance if undertaking an underdrain assessment, as it is outside the scope of a typical filter self-assessment.

Example 5-3. Assessing Conditions of Support Media/Underdrains

Operators, while draining a poorly performing filter, observed vortexing occurring in a specific area of the filter. By probing through the media down to the support gravel, the operators were able to construct a grid of measurements, shown in Table 5-4. The 10-foot by 18-foot filter was probed every two feet using a 6-foot long aluminum rod that had been marked at 1-inch intervals. Using the probe, the operator measured the depth of probe penetration against the wash water trough. For this filter, the top of the support gravel should be approximately 41 inches below the wash water trough. Ideally, this depth should not vary by more than 2 inches throughout the filter (USEPA, 1998). However, as shown in Table 5-4, the support gravel was disrupted in one area of the filter (highlighted in yellow) with depths ranging from 37 inches (a 4-inch high mound) to 46.5 inches (a 5.5-inch depression). Therefore, the utility should inspect for filter media in the clearwell and consider further underdrain evaluation.

Table 5-4. Example Filter Support Gravel Placement Grid Depth of Filter Support Gravels (in inches) Measured from the Wash Water Trough

	2 ft	4 ft	6 ft	8 ft	10 ft
2 ft	41	40.75	41	41	41
4 ft	40.75	40.5	41	41	40.75
6 ft	41	41.25	40.75	41	41
8 ft	40.75	41	41	40.75	40.75
10 ft	41	41	40.5	40.5	40.75
12 ft	41	46	46.5	41	41
14 ft	40.75	46	46.25	39	40.75
16 ft	41	39	38.75	37	40.75
18 ft	40.75	41.25	40.75	41	41

5.6 Assessing Backwash Practices

Proper maintenance of filters is essential to preserve the integrity of the filter as constructed. Limitations of poor performing filters relating to filter media degradation or disruption of support gravel placement can often be attributed to inadequate backwashing or excessive backwashing rates. The duration of the backwash, if excessive, may also be detrimental. Different facilities have had different experiences in how clean the filters should be after backwashing. Consideration should be given to site-specific circumstances in the application of any recommendations regarding filter backwash procedures with the focus always being on filter effluent water quality. Table 5-5 summarizes guidelines for acceptable backwashing practices (AWWA and ASCE, 1990).

Table 5-5. Guidelines Regarding Acceptable Backwashing Practices

Area of Emphasis	Guideline
Basis for initiating backwash	Focus on filter performance (turbidity, particle counts) degradation versus head loss or time
Backwash flow	Slowly ramped to peak rate
Backwash flow rate	15 - 20 gpm/ft^2
Bed expansion during backwash	20 - 25 percent

The assessment of the filter backwash procedure should include the following:

- A collection of general information related to the backwash (such as when to initiate backwash and length of backwash);
- Reviewing the backwash SOP;
- A visual inspection of a filter during a backwash; and
- Determination of the backwash rate and expansion of the filter media during the wash.

The individual filter self-assessment worksheet (Table 5-1) can be used to collect general information regarding the backwash.

5.6.1 Initiation of Backwash

The backwash process is usually initiated when the head loss across the filter reaches a certain limit (established by the supplier or designer), when the filter effluent increases in turbidity or particle counts to an unacceptable level, or at a preset time limit determined by the PWS. It should be verified that the backwash is initiated in accordance with design specifications and established SOPs.

5.6.2 Backwash Sequence

The backwash process can consist of just backwashing with water, a combination of surface wash and backwash, ordinary air-scour, or simultaneous air and water wash. The backwash rate could also vary throughout the process. For example, the backwash rate could start at 10 gpm/ft^2 in combination with air scour or surface wash and then increase to 20 gpm/ft^2 after air scour or surface wash. With the air-scouring wash, the violent boiling action typically occurs in the top 6 to 8 inches of the filter. In this case, mudballs that are present below this depth are not broken and will remain in the filter. Surface washing is recommended during backwash whenever coagulants or polymer are used in the pretreatment process. Surface washing should be done first with backwash starting 2 to 3 minutes after surface washing begins (Kawamura, 2000). Operation of the surface wash during the backwash should be closely monitored because this can cause media loss in some filters, especially when the backwash rate is increased.

5.6.3 Identifying the Backwash Rate

Backwash rates are designed to provide adequate cleaning of the filter media without washing media into the collection troughs or causing disruption of the support gravels. Table 5-5. Guidelines Regarding Acceptable Backwashing Practices identifies backwash rates. These values are to be used as a guide when assessing adequacy of the backwash procedures. Backwash rates in gpm/ft^2 may be determined by a simple calculation if backwash pump rates or backwash flows are available and known to be accurate.

If pumping rates or flows are unavailable or suspect, backwash rates can be determined by performing a rise rate test of the filter. Periodic rise rate tests can also be used to verify the backwash flow measurement instruments. The rise rate test entails determining the amount of time it takes backwash water to rise a known distance in the filter bed. Typically, a metal rod marked at 1-inch intervals is fixed in the filter to enable measurement of the distance that water rises during the wash. The rise rate test should be conducted such that measurements are taken without the interferences of the wash water troughs in the rise volume calculation. Extreme care and great attention to safety should be followed while conducting the rise rate test. See Equations 5-2 and 5-3 and Example 5-4 for details on how to calculate the backwash flow using the rise rate test and backwash rate.

Equation 5-2. Backwash Flow Using Rise Rate Test

$$\textit{Backwash Flow}\ (\text{gpm}) = \frac{\textit{Filter Surface Area}\ (\text{ft}^2) \times \textit{Rise Distance}\ (\text{ft}) \times \textit{7.48 gal/ft}^3}{\textit{Rise Time}\ (\text{minutes})}$$

Equation 5-3. Backwash Rate

$$\textit{Backwash Rate}\ (\text{gpm/ft}^2) = \frac{\textit{Backwash Flow}\ (\text{gpm})}{\textit{Filter Surface Area}\ (\text{ft}^2)}$$

Example 5-4. Determining the Backwash Rate from the Rise Rate

A filter having a 150 ft^2 surface area has a wash water rise of 10.7 inches in 20 seconds during the rise rate test. You should calculate the backwash rate.

First, you should determine the backwash flow in the filter using Equation 5-3.

$$\textit{Backwash Flow}\text{ (gpm)} = \frac{150\text{ ft}^2 \text{ X } 10.7\text{ inches (1 ft/12 inches) X } 7.48\text{ gal/ft}^3}{20\text{ seconds (1 minute/60 seconds)}}$$
$$= 3{,}000\text{ gpm}$$

Second, you should determine the backwash rate using Equation 5-2.

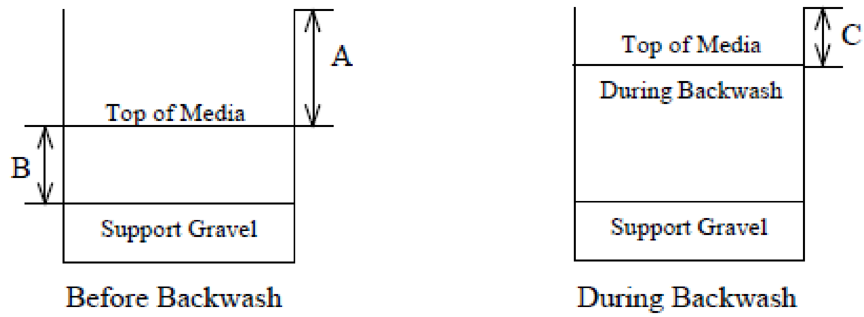
$$\textit{Backwash Rate}\text{ (gpm/ft}^2\text{)} = \frac{3{,}000\text{ gpm}}{150\text{ ft}^2} = 20\text{ gpm/ft}^2$$

5.6.4 Bed Expansion

It is also extremely important to expand the filter media during the wash to maximize the removal of particles held in the filter or by the media. However, care should be taken to ensure that none of the media is lost through over-expansion, air scour, or surface wash. Bed expansion may be determined by measuring the distance from the top of the unexpanded media to a reference point (e.g., top of the filter wall) and from the top of the expanded media to the same reference point. The difference between these two measurements is bed expansion.

Percent bed expansion may be determined by dividing the bed expansion by the total depth of expandable media (i.e., media depth less support gravels) and multiplied by 100 (see Equation 5-4 and Example 5-5). A proper backwash rate should expand the filter 20 to 25 percent, but expansion can be as high as 50 percent (AWWA and ASCE, 1990). The manufacturer should be contacted to determine the proper bed expansion for the media in the filters.

Equation 5-4. Percent Bed Expansion



A = Depth to media as measured from top of sidewall before backwash.*

B = Media depth (less support gravel).*

C = Depth to expanded media as measured from top of sidewall during backwash.*

$$\text{Percent Bed Expansion} = \frac{A - C}{B} \text{ X } 100$$

*Make sure all measurements have the same units.

Example 5-5. Evaluating Filter Backwash Bed Expansion using a Secchi Disk

The backwashing practices for a filter with 30 inches of anthracite and sand is being evaluated. While at rest, the distance from the top of the media to the concrete floor surrounding the top of the filter is measured to be 41 inches. After the backwash has been started and the maximum backwash rate is achieved, a probe containing a white disk (referred to as a Secchi disk) is slowly lowered into the filter bed until anthracite is observed on the disk. The distance from the expanded media to the concrete floor is measured to be 34 inches. The resultant percent bed expansion would be 23 percent.

Depth to media as measured from top of sidewall before backwash = A = 41 inches

Depth to expanded media as measured from top of sidewall during backwash = C = 34 inches

Depth of filter media = B = 30 inches

Percent Bed Expansion = (41 inches – 34 inches)/30 inches * 100% = 23%

A variety of tools can be used to measure bed expansion. One common apparatus is a metal shaft with a black and white disk (introduced in Example 5-5 and referred to as a “Secchi” disk) attached on one end as shown in Figure 5-11.

Figure 5-11. Examples of a Secchi Disk

The Secchi disk is used by placing the disk on the unexpanded media prior to backwash and recording the length of the metal rod to the reference point. The disk unit is then removed, and backwashing is initiated. After the backwash is allowed to reach its peak rate the disk is lowered slowly into the backwashing filter until media is observed on the disk. The measurement of the expanded media is then recorded, and percent bed expansion may then be determined. The media expansion should be measured at several locations to see if expansion occurs over the full surface area of the filter. Uneven bed expansion throughout the filter could indicate uneven distribution of backwash water or an underdrain or support gravel problem.

Another device used to measure bed expansion is a steel measuring tape fitted along the shaft to a metal pole with an attached collection of pipe segments of varying lengths each plugged at the bottom. The pipes are arranged like a set of church organ pipes with each pipe 1-inch longer than the next as shown in Figure 5-12.

Figure 5-12. “Pipe Organ” Expansion

The unit is solidly affixed, resting on the top of the media. During backwashing, the expanded media fills each successive piece of pipe until the rise stops. Care should be taken to affix the pipe organ apparatus such that it can easily be determined where bed expansion ended because during certain situations, all of the pipe segments will be filled with expanded media making it impossible to accurately determine media expansion. If this occurs, the apparatus should be emptied, affixed higher in the filter above the media, and the bed expansion test repeated. The key attribute of any method is that determination of the top of the expanded media be accurately characterized.

5.6.5 Backwash Effectiveness

A floc retention analysis procedure may be warranted if the filter is meeting backwash expansion and backwash rate guidelines, but still not achieving turbidity performance criteria (Kawamura, 2000). The floc retention analysis procedure (sometimes referred to as the sludge retention analysis procedure), can be used to determine the amount of particle retention occurring at each depth and area of the filter bed and the effectiveness of backwash procedures.

The floc retention analysis can be performed using the following steps:

1. Completely drain the filter at the end of a filter run and let stand for 2-1/2 hours.

2. Mark a one-gallon plastic bag (best to use a waterproof marker) for each depth interval and collect four to eight samples at representative sites in the filter bed at the following depths: 0-2, 2-6, 6-12, 12-18, 18-24, 24-30, and 30-36 inches. If the filter is more than 36 inches deep, collect additional core samples in increments of 6 inches. Place the composite media samples from each depth in the appropriate one-gallon plastic bag. The core samples can be obtained using a thin-walled 1½-inch galvanized pipe.

3. Prepare a 50 milliliter (mL) test sample from each of the sample bags by lightly tamping the core samples into a graduated cylinder. Transfer the 50-mL media sample to a large (500 mL) flask or beaker and add 100 mL of water. Swirl for 1 minute. Decant the turbid water from the sample into another beaker. Repeat this washing procedure with each sample four more times so that a total of 500 mL of water is used to wash out the sludge adhered to the media from each sample depth. Measure the turbidity of the 500 mL of

wash water. Multiply the recorded turbidity by two so that the final tabulations for each depth will list the turbidity for 100 mL of sample instead of the 50 mL sample used. Record the turbidity results for each depth of the media.

4. Start the backwash cycle very slowly to remove air.

5. After the backwash is done, drain the filter completely.

6. Repeat Steps 2 and 3 in the same locations.

7. Backwash the filter and place it back in service. Start the backwash very slowly to remove air.

8. The results should then be plotted to determine the floc retention before and after backwash.

An ideal floc retention profile should show linear results with more particle retention at the top of the filter than at the bottom of the filter. Figure 5-13 and Figure 5-14 show examples of floc retention analysis plots. Figure 5-13 indicates that most particles are captured in the upper media of the filter and the backwash effectively cleaned the media at all depths. Figure 5-14 indicates that most particles are retained in the upper media and at the sand/anthracite interface. In addition, the backwash was not effective in cleaning the sand/anthracite interface. Note also the increased particle retention at media interface).

Additional data on the filter media can be gathered, including effective size and uniformity coefficient of the media.

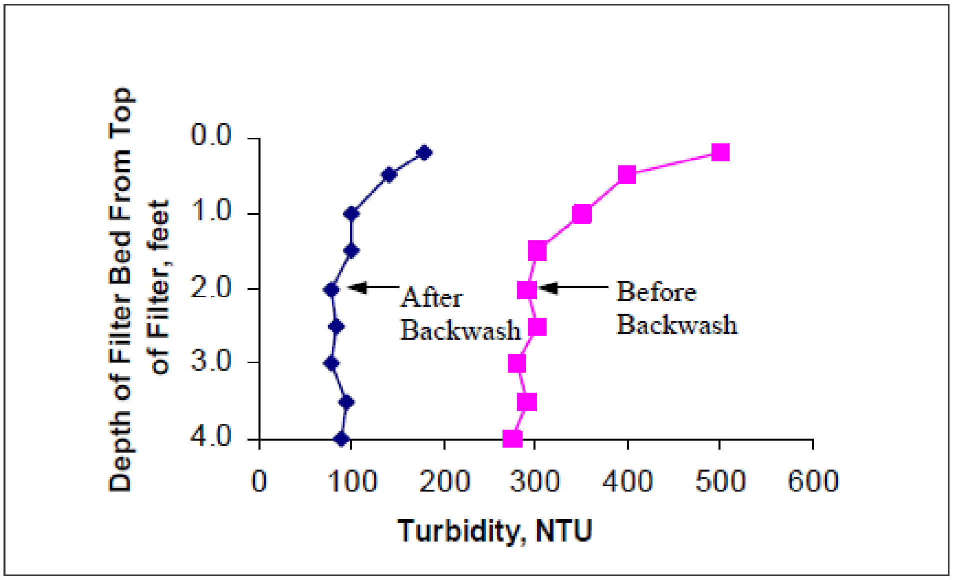


Figure 5-13. Example of Floc Retention Analysis Results for 4-foot Deep Mono Media Filter Bed

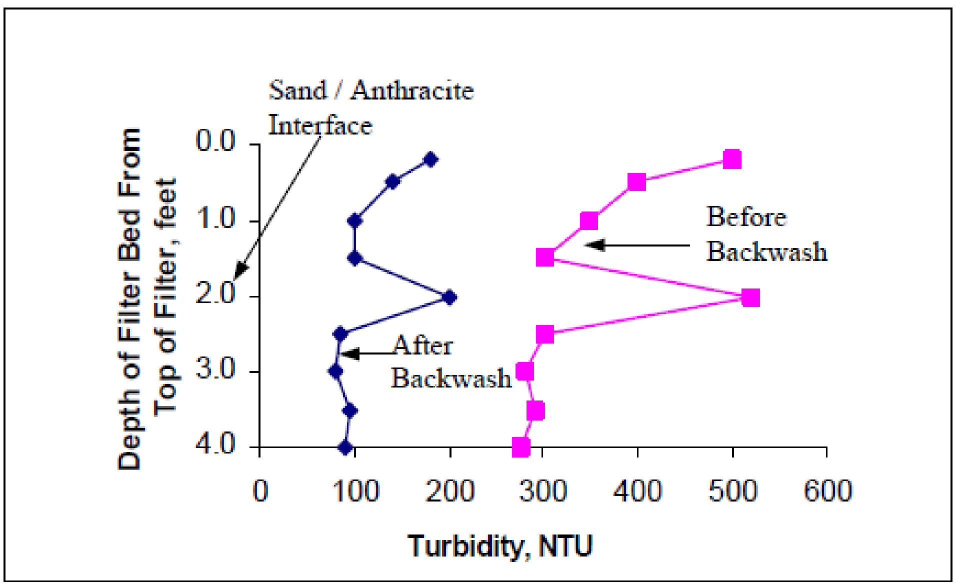


Figure 5-14. Example of Floc Retention Analysis Results for 4-foot Deep Dual Media Filter Bed

(Note increased particle retention at media interface).

5.6.6 Backwash Rate

PWSs may consider varying the backwash rate as the water temperature varies, because water properties vary with temperature. Cold water is more viscous than warm water. Therefore, the backwash rate for colder water should be decreased and the backwash rate for warmer water increased.

5.6.7 Terminating the Backwash

Criteria for terminating the backwash process should also be evaluated. Termination of the backwash should be based on measured turbidity in the backwash water. Backwash samples can be obtained every 30 seconds or every minute and analyzed using a benchtop turbidimeter. A suggested guideline is that the backwash process should be terminated if the backwash turbidity is 10 to 15 NTU (Kawamura, 2000). PWSs should watch the backwash and observe water quality routinely.

5.6.8 Backwash SOP

An adequate backwash SOP should describe specific steps regarding when to initiate backwash, how flows are ramped during the wash, when to start and stop surface wash or air scour, and duration of the wash. The SOP may help in training new operators and should improve operational consistency.

5.7 Assessment of Placing a Filter Back into Service

The methods used for placing a filter back into service after backwashing vary based on the design of the system and other factors. The following methods are used in some water treatment plants:

- Delayed start - The delayed start consists of letting the filter rest for a period of time after backwashing and before placing the filter back into service. This practice has been found to reduce filter ripening times. The length of this delay varies, so the rest period should be determined by doing a study.

- Slow start - The slow start technique involves a gradual increase of flow through the filter until the desired hydraulic loading rate is achieved. This practice can reduce initial turbidity spikes but may require a modification of the system or manual operation of the valve to control the feed rate to the filter.

- Filter-to-waste – Filter-to-waste is a common practice that allows filtered effluent to be sent to a part of the plant other than the clearwell after the filter goes back on-line. Once turbidity reaches an acceptable level, the filtered effluent is discharged to the clearwell. Make sure that no cross connection exists between the filter effluent and the waste location.

- Addition of a coagulant or filter aid during initial start-up of the filter or backwash – PWSs may consider feeding a coagulant or filter aid during the initial start-up of the filter or during the last part of the backwash process. This option has been shown to reduce initial turbidity spikes.

Some PWSs use a combination of the techniques above to minimize filter turbidity spikes.

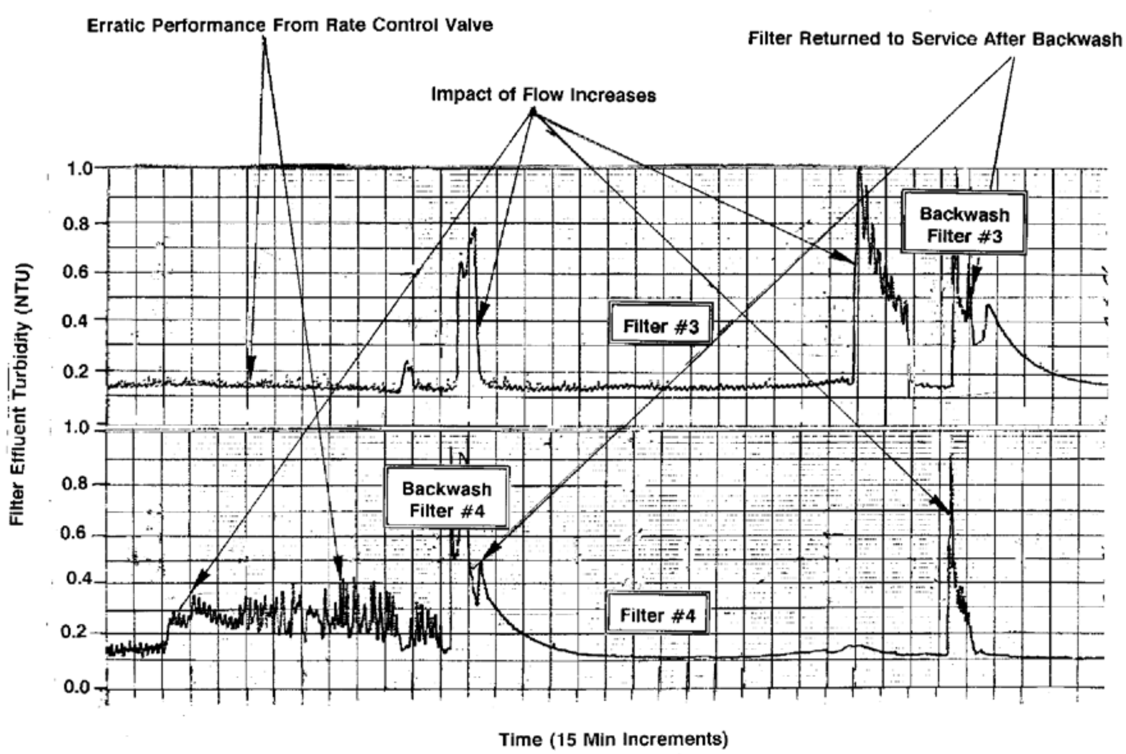
Placing a dirty filter (one that has not been backwashed) into service should be avoided. This practice can result in very high turbidities and has the potential to pass pathogens into the finished water.

5.8 Assessing Rate-Of-Flow Controllers and Filter Valve Infrastructure

The rate-of-flow controllers and ancillary valving related to the filter can have a significant impact on filter performance. Rapid hydraulic changes may cause filters to shed particles. Maintaining and calibrating or verifying the accuracy of rate-of-flow controllers is an important part of minimizing hydraulic changes through the filter. Improperly seated valves can leak and affect filter performance. All filter assessments should include an evaluation of all rate-of-flow controllers and filter valving. Example 5-6 illustrates performance problems due to an inoperable rate-of-flow controller.

Example 5-6. Rate-of-flow Controller Problem

The figure below shows continuous turbidity measurements for two filters in a treatment plant. Each of the two filters had rate-of-flow controller problems that became more evident as head loss built up in the filters. Just prior to initiating backwash in Filter 4, the rate-of-flow controllers were opening and closing constantly “seeking” the correct position. This was first apparent to the filter evaluation team who observed constant turbidity fluctuations of the filter effluent during a filter performance review. Improperly seated valves can also have similar impacts on filter performance.



5.8.1 Leaking Valves

One way to check for leaking effluent valves is to close the filter influent and effluent valves and observe the water level change in the filter. If the water level continues to drop with the valves closed, there may be a leaking effluent valve. If the water continues to rise, then there may be a leaking influent valve. The filter profile may be useful in determining if a leaking valve exists. Also, listening to the valves can help detect problems.

5.8.2 Flow Meters

If IFE totalizers are available, total daily effluent volumes should be compared for each filter. This process may help identify which filter is operating too high or too low compared to other filters. The problem may be a poorly operating valve, a controller malfunction, or problems in the filter media.

5.9 Other Considerations

If any of the previously discussed areas do not seem to be causing the problem that triggered the filter self-assessment, the PWS should investigate other plant processes and data such as:

- **Chemical feed processes** and **coagulation** are important for proper floc formation. Poor floc formation can result in particles being passed through the filter. Chemical feed systems could be investigated to ensure the proper chemicals and feed rates are being used.

- A sudden change in **raw water quality** can cause particles to be passed through the filter, particularly if chemical feed rates cannot be adjusted in a timely manner. Raw water turbidity values could be checked to see if the turbidity spike was caused by a sudden increase in raw water turbidity.

- **Turbidimeters** can lose their accuracy over time and require calibration. Turbidimeters should be calibrated and verified to ensure they are properly recording filtered water turbidimeter values. Additional information on calibration is found in Section 3.4.5.

5.10 Assessment of Applicability of Corrections

After all the information on the filter has been collected on Table 5-1, the factors that caused the turbidity levels that triggered the filter self-assessment should be evaluated. One or more of the filter features or operating conditions may need to be modified to address the event that triggered the filter self-assessment. In more severe instances, system-wide modifications may be needed and these modifications would be identified through a Comprehensive Performance Evaluation (CPE) (See Chapter 6). Table 5-1 may help identify areas where filter modifications are necessary. The following are some examples of how corrections could be applied:

- Modify filter run times.

- Create or modify a backwash SOP.

- Extend the filter backwash period to a time that results in acceptable filter turbidity levels.

- Replace filter media if the filter media was determined to have reached its useful life.
- Add more filters if filter loading rates were determined to be too high and additional filters are needed.

Many combinations of filter modifications exist, and more than one modification may be needed to solve the problem.

5.11 Preparation of the Report

A PWS must prepare a report of the filter self-assessment if conducting the assessment in response to an IFE turbidity trigger [40 CFR 141.175(b)(3) and 141.563(b)] (see Section 2.2.3). PWSs should consult with their state on the proper format and state-specific reporting requirements. The report should include all the areas of the filter and filter operations that the PWS examined, and any modifications that resulted in acceptable turbidity levels. If the problem cannot be identified within the timeframe allowed for completion of the self-assessment, the report should specify the anomalies that were observed and explain whether any corrective actions have yielded improvements.

5.12 References

AWWA. 1998. How to Do a Complete Examination of Your Filters (Without Incurring the Wrath of the Filter Gods). Annual Conference Workshop Summary.

AWWA. 2011. Water Quality and Treatment. Sixth Edition. McGraw-Hill, Inc. New York, NY. AWWA and ASCE. 1990. Water Treatment Plant Design. Second Edition. McGraw-Hill, New York, NY.

Bender, J.H., R.C. Renner, B.A. Hegg, E.M. Bissonette, and R.J. Lieberman. 1995. Voluntary Treatment Plant Performance Improvement Program Self-Assessment Procedure. Partnership for Safe Water, USEPA, AWWA, AWWARF, Association of Metropolitan Water Agencies, Association of State Drinking Water Administrators, and National Association of Water Companies.

James M. Montgomery Consulting Engineers, Inc. 1985. Water Treatment Principles and Design. John Wiley & Sons, Inc.

Kawamura, S. 2000. Integrated Design of Water Treatment Facilities. John Wiley & Sons, Incorporated. New York, NY.

Nix, D.K., and J.S. Taylor. 2018. Filter Evaluation Procedures for Granular Media. Second Edition. AWWA, Denver, CO.

Peck, B., T. Tackman, and G. Crozes. No date specified. Testing the Sands - The Development of a Filter Surveillance Program.

Smith, J.F., A. Wilczak, and M. Swigert. No date specified. Practical Guide to Filtration Assessments: Tools and Techniques.

USEPA. 1998. Optimizing Water Treatment Plant Performance Using the Composite Correction Program. Cincinnati, OH.

Wolfe, T.A., and N.G. Pizzi. 1998. Optimizing Filter Performance.

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In this chapter:

- *Background of a CPE*
- *Components of a CPE*
- *Activities During a CPE*
- *QC Controls*
- *Next Steps*
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CHAPTER 6 – COMPREHENSIVE PERFORMANCE EVALUATION (CPE)

6.1 Introduction

Based on individual filter monitoring requirements in the IESWTR (USEPA, 1998a) and LT1ESWTR (USEPA, 2002), some PWSs may be required to arrange for a comprehensive performance evaluation (CPE). Specifically, PWSs must conduct a CPE if any individual filter has a measured effluent turbidity level of greater than 2.0 NTU in two consecutive measurements taken 15 minutes apart in two consecutive months. The PWS must report to the state by the 10th of the following month the filter number, the turbidity measurement, and the date(s) on which the exceedances occurred. The PWS shall contact the state or a third party approved by the state to conduct the CPE [40 CFR 141.175(b)(4) and 40 CFR 141.563(c)] (refer to Section 2.2.3).

A CPE is the evaluation phase of the larger composite correction program (CCP), as discussed previously in Section 4.2.1 of this document. Since 1988, the CCP has been developed and demonstrated as a method of optimizing surface water treatment plant performance with respect to protection from microbial pathogens. The CCP approach is based on establishing effective use of the available water treatment process barriers against passage of particles to the finished water. Specific performance goals are used by the CCP approach to define optimum performance for key treatment process barriers such as sedimentation, filtration, and disinfection. While there are CPE requirements in the IESWTR and LT1ESWTR, there are no federal requirements to perform the larger CCP.

The goals of this chapter are to present a fundamental discussion of CPE concepts and provide a general understanding of what a plant should expect when a CPE is completed. Detailed CPE procedures are not included in this guidance manual but can be found in EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998) which is available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents.

6.2 Background on the CPE

The CPE is a thorough review and analysis of a facility's design capabilities and associated administrative, operational, and maintenance practices as they relate to achieving optimum performance from the facility. It was originally developed as the evaluation phase in the CCP's two-step process to optimize performance at existing surface water treatment plants. A primary objective of a CPE is to determine if significant improvements in treatment performance can be achieved without major capital expenditures.

During a CPE, the historic performance of the plant is assessed with respect to pathogen removal and inactivation. The design, administration, and maintenance of the plant are completely reviewed to determine if they properly support a capable plant. If they are not supporting a capable plant, the root causes are identified as to how they are contributing to the performance problem(s). Operational practices are also reviewed to assess if operators have the necessary skills to achieve the required performance for compliance when provided with a capable plant.

It is important to understand that the CPE has applications in addition to achieving regulatory compliance and should be applied as appropriate for meeting desired performance needs. All CPE procedures are designed to focus a plant toward both meeting compliance requirements and achieving a PWS' performance goals. The original CCP goals for optimized performance, which are evaluated during the CPE and are included in the CCP Handbook, are presented in Table 6-1. Table 6-1 also compares the CCP goals with IESWTR and LT1ESWTR requirements and shows how some CCP goals exceed the regulatory requirements, some areas are not addressed by CCP goals but are addressed by IESWTR and LT1ESWTR requirements, and some CCP goals are the same as the IESWTR and LT1ESWTR requirements. Remember, there are no requirements in the IESWTR or LT1ESWTR to meet the CCP optimized performance goals. CCPEs, however, are required when individual filter effluent turbidity measurements indicate that a filter is performing poorly (see Section 6.1 for the IESWTR and LT1ESWTR CPE triggers).

Table 6-1. CPE Treatment Performance Goals[1]

	IESWTR and LT1ESWTR Compliance Requirements	CCP Optimized Performance Goals
Minimum Data Monitoring and/or Reporting Requirements	Continuous individual filter turbidity monitoring with values recorded at 15-minute intervals (conventional and direct filtration systems).	Daily raw water turbidity.
	Representative filtered/finished water effluent turbidity every 4 hours.	4-hour settled water turbidity from each sedimentation basin.
		Continuous turbidity from each filter.
Individual Sedimentation Basin Performance Criteria	Not applicable.	Settled water turbidity less than 1 NTU 95 percent of the time when raw water turbidity is less than or equal to 10 NTU.
		Settled water turbidity less 2 NTU 95 percent of the time when raw water turbidity is less than or equal to 20 NTU.
Individual Filter Performance Criteria	Maximum filtered water turbidity of 1 NTU in two consecutive measurements taken 15 minutes apart (conventional and direct filtration systems).	Filtered water is less than 0.1 NTU 95 percent of the time (excluding 15-minute period following backwashes) based on maximum values recorded during 4-hour increments.
	Maximum filtered water turbidity 4 hours following backwash of less than 0.5 NTU in two consecutive measurements taken 15 minutes apart (conventional and direct filtration systems).[2]	Maximum filtered turbidity measurement of 0.5 NTU.

	IESWTR and LT1ESWTR Compliance Requirements	CCP Optimized Performance Goals
		Maximum filtered water turbidity following backwash of less than 0.3 NTU.
		Maximum backwash recovery period of 15 minutes (e.g., return to less than 0.1 NTU).
		Maximum filtered water measurement of less than 10 total particles per milliliter (>3µm) of particle counts are available.
Combined Filtered Water Performance Criteria	Representative filtered/finished water turbidity less than 0.3 NTU 95 percent of the time based on 4-hour measurements (conventional and direct filtration systems).	
	Maximum filtered/finished water turbidity of 1 NTU based on 4-hour measurements (conventional and direct filtration systems).	
Disinfection Performance Criteria	CT values to achieve required log inactivation of *Giardia* and viruses.	CT values to achieve required log inactivation of *Giardia* and viruses.

1. USEPA, 1998b
2. This requirement only applies to systems serving 10,000 or more persons.

6.3 Components of a CPE

A CPE consists of the following five components:

- Performance assessment (evaluates historical plant performance);
- Major unit process evaluation (for assessing the physical plant capabilities);
- Factors limiting performance;
- Assessment of applicability of the follow-up phase; and
- Report of the results of the evaluation.

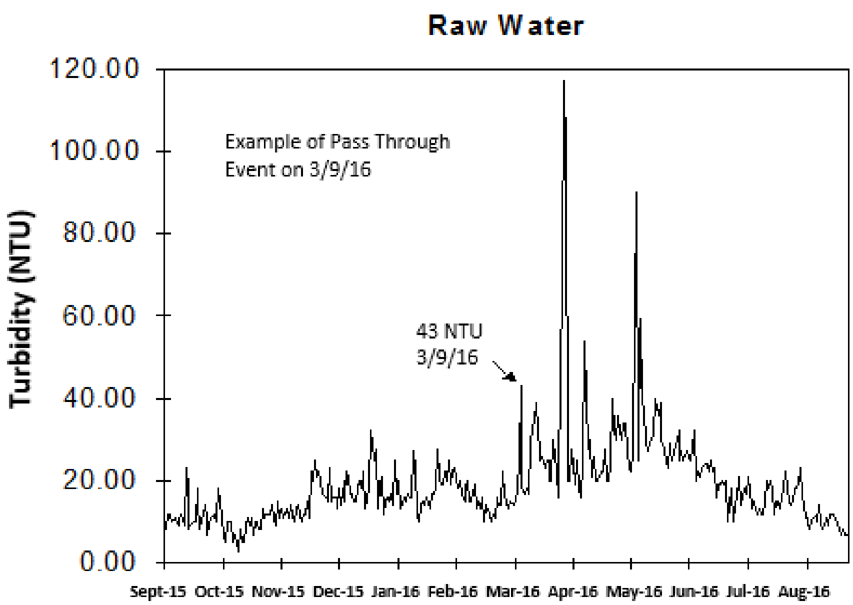
The following subsections discuss each of these components; more detailed procedures are provided in EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998b).

6.3.1 Performance Assessment

The performance assessment component of the CPE determines the status of a facility relative to achieving compliance requirements and performance goals and verifies the extent of any performance problems at the plant. This information also provides the CPE evaluators with some initial insights on possible causes of performance problems. These insights are then used to focus other activities during the CPE to better assess the design, operation, maintenance and administration of the plant.

To achieve desired performance levels (compliance or optimized), a water treatment plant should demonstrate that it can take a raw water source of variable quality and produce a consistent, high quality finished water. Further, the performance of each unit process should demonstrate its ability to act as a barrier to the passage of particles at all times. The performance assessment determines if major unit treatment processes consistently perform at optimum levels to provide maximum multiple barrier protection. If performance is not optimized, the assessment also provides valuable insights into possible causes of the performance problems and serves as the basis for other CPE findings.

During the performance assessment, historical turbidity data for the raw, settled, and finished water is collected from the plant records and trends are charted as shown in Figure 6-1. From this example data, the CPE evaluator can see that the plant treats a raw water source that varies moderately throughout the year. The settled and finished water performance indicates that this plant has a performance problem since turbidity levels produced for treatment processes are significantly above compliance requirements and performance goals as described in Table 6-1.



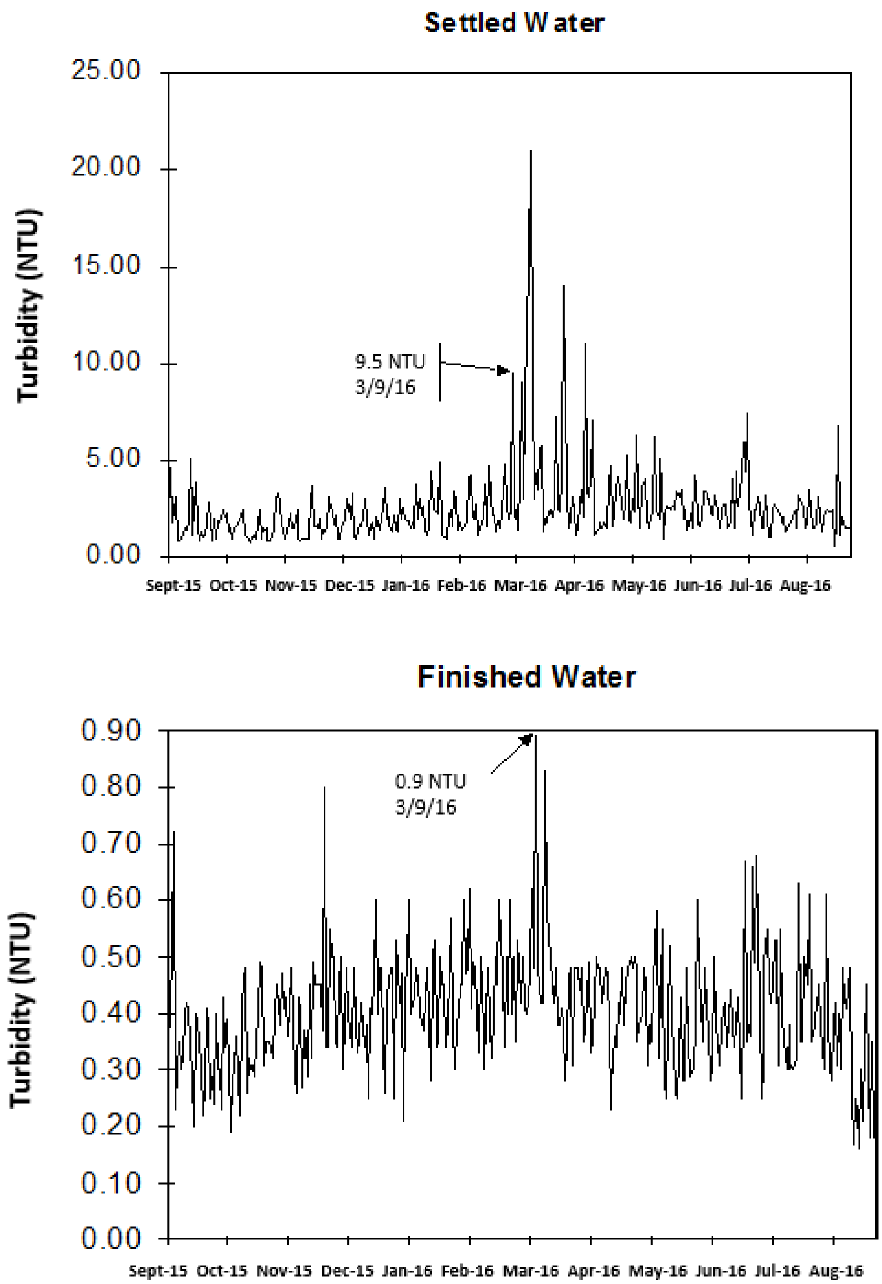


Figure 6-1. An Example of Performance Assessment Using Historical Data

Figure 6-1 also shows how the CPE evaluator can use the performance assessment to gain some insights into the causes of the poor performance. In reviewing this data, it is apparent that a spike in raw water turbidity on March 9th carried through the plant resulting in finished water turbidities close to 1 NTU. These pass-through variations and spikes provide some insight into the root cause of these performance problems that the CPE evaluators will use to direct the subsequent portions of the CPE. Typically, these types of performance problems are related to the process control skills of the plant staff, but other design and/or administrative issues or raw water events may also make a significant contribution to the problem. During their review of the design, operation and administration of the plant, the CPE evaluators will use these insights to focus the discussions they have with the plant staff. Information on the possible causes of this spike will be investigated until the evaluators are sure they understand the root cause.

Supplemental data may be collected during the CPE to confirm the historical performance data, further assess the performance of individual treatment processes, and confirm insights on possible causes of poor performance. Typically, this type of data is collected through actions during an onsite evaluation and includes:

- Verification of filtered turbidity results by independently comparing a PWS's measurements with measurements from a turbidimeter brought by the CPE evaluators. If the plant is not already individually measuring turbidity from each filter, the CPE team can select the filter which the operators believe has the most problems and collect individual filter data on that filter.

- Filter inspections for media depth and media condition. See Section 5 and AWWA 2018 Filter Evaluations Procedures for Granular Media, 2^{nd} Edition.

- Filter media expansion during backwash. See Section 5 and AWWA 2018 Filter Evaluations Procedures for Granular Media, 2^{nd} Edition (Nix and Taylor, 2018).

- Verification of chemical dosages to be sure plant staff are actually adding the amount of chemicals they are intending to add. See Section 4 and AWWA M37 on jar testing.

- Verification of the benchtop turbidimeter in the plant laboratory with a unit brought by the CPE evaluators. See Standard Methods or another appropriate resource for handheld units.

Depending on the needs of the CPE evaluators, supplemental data on the performance of individual sedimentation basins may also be collected (USEPA, 1998b). Continuous monitoring of individual filters during the CPE allows for an in-depth assessment of the filter performance during critical periods of startup, backwash, and/or changes in plant flow rates. Figure 6-2 shows the performance of a filter during a CPE immediately after start-up following a backwash. Backwash spikes of this magnitude also indicate a possible problem with the plant's process control procedures.

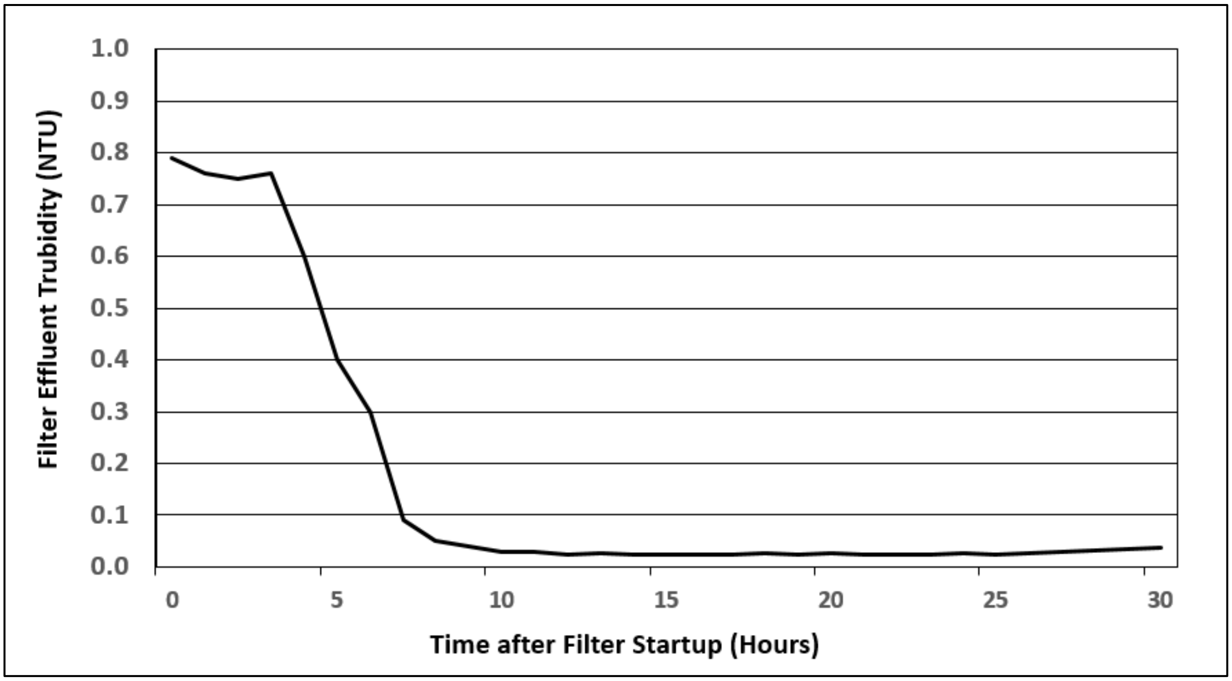


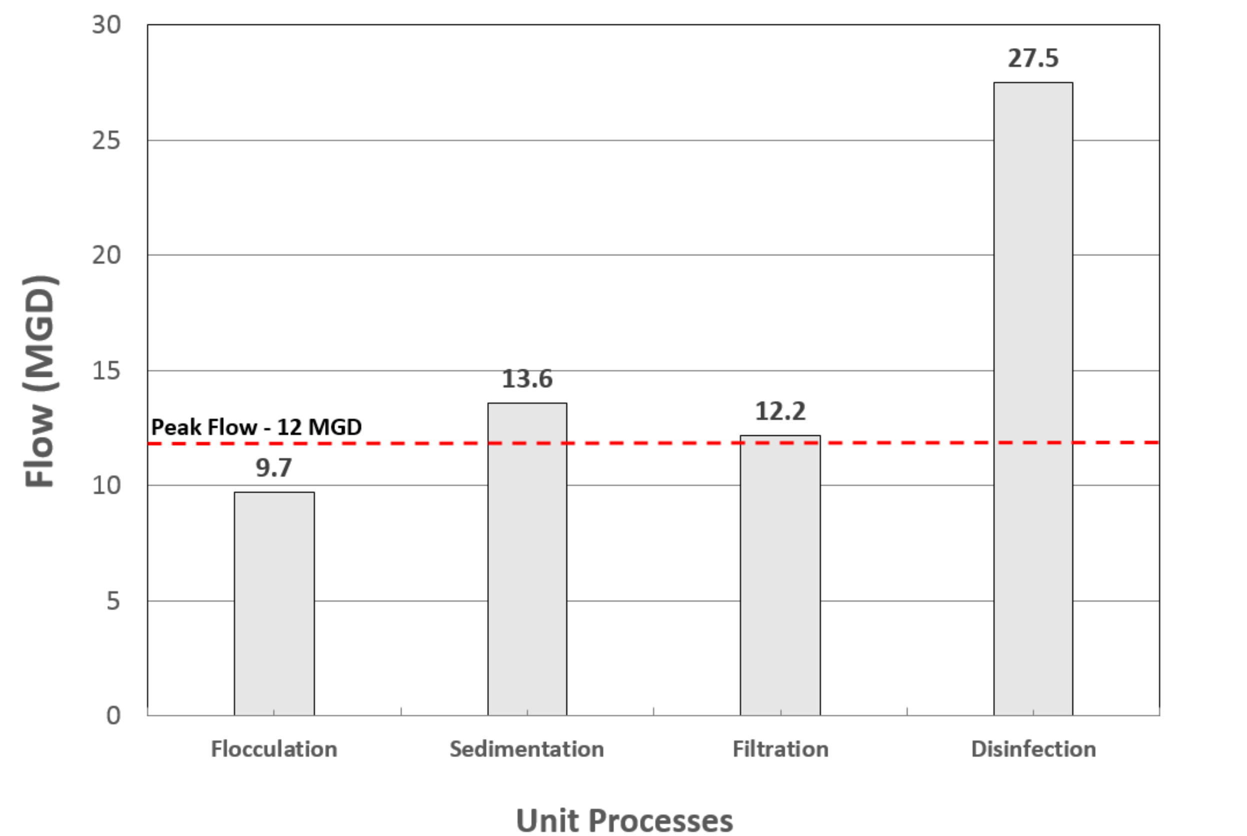
Figure 6-2. An Example of Individual Filter Data Collected During a CPE

6.3.2 Major Unit Process Evaluation

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 the performance goals at the plant's current peak instantaneous operating flows. If the evaluation indicates that the major unit processes are of adequate size, then the opportunity for the existing facility to achieve compliance by addressing operational, maintenance or administrative limitations is available. If, on the other hand, the evaluation shows that major unit processes are too small, then construction of new or additional processes may be required to obtain compliance or optimize performance.

The major unit process evaluation only considers if the existing treatment processes are of adequate size to treat current peak instantaneous operating flows and to meet the desired performance levels. The intent is to assess whether existing facilities, in terms of concrete and steel, are adequate. This evaluation does not review the adequacy or condition of existing mechanical equipment. The evaluation assumes that if the concrete and steel are not of adequate size then major construction may be warranted, and the pursuit of purely operational approaches to achieve performance may not be prudent. The condition of the mechanical equipment around the treatment processes is an important issue, but in this part of the CPE it is assumed that the potential exists to repair and/or replace this equipment without the disruption of the plant inherent to a major construction project. These types of issues are addressed in the factors limiting performance component of the CPE. It is also presumed in the major unit process evaluation that the necessary process control procedures are in place and practiced to meet performance goals. By assuming that the equipment limitations can be addressed and that operational practices are optimum, the evaluator can project the performance potential or capability of a unit process to achieve performance goals.

During the CPE, a performance potential graph similar to that shown in Figure 6-4 is developed. The four treatment processes included in this major unit process evaluation are flocculation, sedimentation, filtration and disinfection. The CPE evaluators determine the peak instantaneous operating flow that the plant has seen over the last year and collect data on the sizes of the various basins. To prepare the performance potential graph, the CPE evaluators should select loadings for each process that they consider adequate for the plant to achieve the performance goals. The assumptions and loadings used in this example are shown at the bottom of the graph. Based on these loadings a projected capacity is calculated and shown as a bar on the performance potential graph. Bars above the dashed line in Figure 6-3 represent unit processes that have the capacity to treat the peak instantaneous flow. Bars below the dashed line indicate processes where major or minor changes may be necessary.



Flocculation criteria: Hydraulic detention time = 30 minutes; total volume = 202,500 gal; single stage, tapered flocculation
Sedimentation criteria: Surface loading rate = 0.7 gallons per minute (gpm)/ft^2; total surface area = 13,440 ft^2; swd=15 ft
Filtration criteria; Surface loading rate = 4 gpm/ft^2; 6 filters in service; 30 inches mixed media
Disinfection criteria; Total *Giardia* inactivation = 3 log, 0.5 log required by disinfection; available volume = 900,000 gallons @ depth = 10 ft; pH = 7.5; temp = 0.5 C; chlorine residual = 1.5 mg/L; T_{10}/T = 0.7

Figure 6-3. Example Performance Potential Graph

6.3.3 Factors Limiting Performance

The last and most significant component of a CPE is the identification of factors that limit the filtration plant's performance. CPE evaluators review all the collected information and work to identify and prioritize the root causes of any performance problems. This step is critical in defining the future activities that the plant will need to focus on to achieve the compliance or optimize performance goals.

To assist in factor identification, a list of 50 different factors and definitions that could potentially limit water treatment plant performance is provided in EPA's *Handbook: Optimizing Water Treatment Plant*

Performance Using the Composite Correction Program (USEPA, 1998b). These factors are divided into the four broad categories of administration, design, operation, and maintenance. This list and the corresponding definitions are based on the results of more than 70 water treatment plant CPEs. Definitions are provided for the convenience of the user as a reference to promote consistency in the use of factors from plant to plant and to assist others in interpreting the CPE results.

While the definitions for the administrative, operation, and maintenance factors adequately explain when these factors are identified, plant staff may find several of the design factors confusing when reviewing the CPE findings. Design factors are included for each of the treatment processes in the major unit process evaluation. If any of the treatment processes in the major unit process evaluation were classified as marginal or inadequate, they would be identified in the CPE findings as a factor limiting the plant's performance. Treatment processes that were identified as adequate in the major unit process evaluation can also be identified as a factor when there are equipment-related problems that are limiting performance. This would occur when key equipment (e.g., filter rate-of-flow control valves) needs to be repaired and/or replaced before desired performance can be achieved.

A CPE is intended to be a performance-based evaluation and therefore factors should be identified only if they impact water quality performance. A proper CPE does not contain factors that are primarily observations that a utility does not meet a particular "industry standard" (e.g., utility does not practice good housekeeping), unless a clear link is made between the practice and the identified performance problem.

The major challenge in identifying a plant's unique list of factors is making sure that the root causes are identified. This is difficult because the actual problems in a plant are often masked. This concept is illustrated in Example 6-1.

Example 6-1. Identifying Performance Problems through a CPE

A review of plant records revealed that a conventional water treatment plant was periodically producing finished water with a turbidity greater than 0.5 NTU. The utility, assuming that the plant was operating beyond its capability, was beginning to make plans to expand both the sedimentation and filtration unit processes. Field evaluations conducted as part of a CPE revealed that settled water and finished water turbidities averaged about 5 NTU and 0.6 NTU, respectively. Filtered water turbidities peaked at 1.2 NTU for short periods following a filter backwash.

Conceivably, the plant's sedimentation and filtration facilities were inadequately sized. The major unit process evaluation, however, showed that these processes were capable to handle the plant's current peak flows.

A review of the plant's operation procedures revealed that the poor performance was caused by the operator adding coagulants at excessive dosages, leading to formation of a pin floc that was difficult to settle and filter. The operators did not have an adequate process control program or equipment to allow them to identify and set the proper chemical doses. Additionally, the plant was being operated at its peak capacity for only 8 hours each day, further aggravating the washout of solids from the sedimentation basins.

The CPE evaluators assessed that by implementing proper process control of the plant (e.g., jar testing for coagulant control, calibration and proper adjustment of chemical feed) and operating the plant at a lower flow rate for a longer time period would allow the plant to continuously achieve the desired performance.

When the operator and administration were questioned about the reasons that the plant was not operated for longer periods of time, it was identified that it was an administrative decision to limit the plant staffing to one person. This limitation made additional daily operating time as well as weekend coverage difficult.

The CPE evaluators concluded that three major factors were contributing to the poor performance of the plant:

1. Application of Concepts and Testing to Process Control: Inadequate operator knowledge led to improper coagulant doses and incorrect settings on the chemical feed pumps which then applied the incorrect chemical dose.

2. Administrative Policies: A restrictive administrative policy prohibited hiring an additional operator to allow increased plant operating time at a reduced plant flow rate.

3. Process Control Testing: Inadequate test equipment and an inadequate sampling program to provide process control information.

In this example, pursuing the perceived limitation regarding the need for additional sedimentation and filtration capacity would have led to improper corrective actions. Completing a plant expansion without correction of the operation and administrative factors probably would not have solved the performance problems. The limitations in process control would have remained even with a new plant. Administrative policies that led to insufficient staffing of the old plant could have remained with a new plant. The CPE, however, indicated that addressing the identified operational and administrative factors would allow the plant to achieve the desired performance on a continuous basis without major expenditures for construction. The funds that initially were directed towards construction could then be directed towards other factors that truly are limiting the plant's performance.

This example illustrates that a comprehensive analysis of a performance problem is essential in identifying the actual performance limiting factors. The CPE emphasis of assessing factors in the broad categories of administration, design, operation, and maintenance helps to ensure the identification of root causes of performance limitations.

6.4 Activities During a CPE

There are several activities a PWS should expect to occur during a CPE as a CPE involves numerous activities conducted within a structured framework. In general, if all the following activities do not occur, the plant should question whether the evaluators are following the procedures of EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998b). A schematic of CPE activities is shown in Figure 6-4.

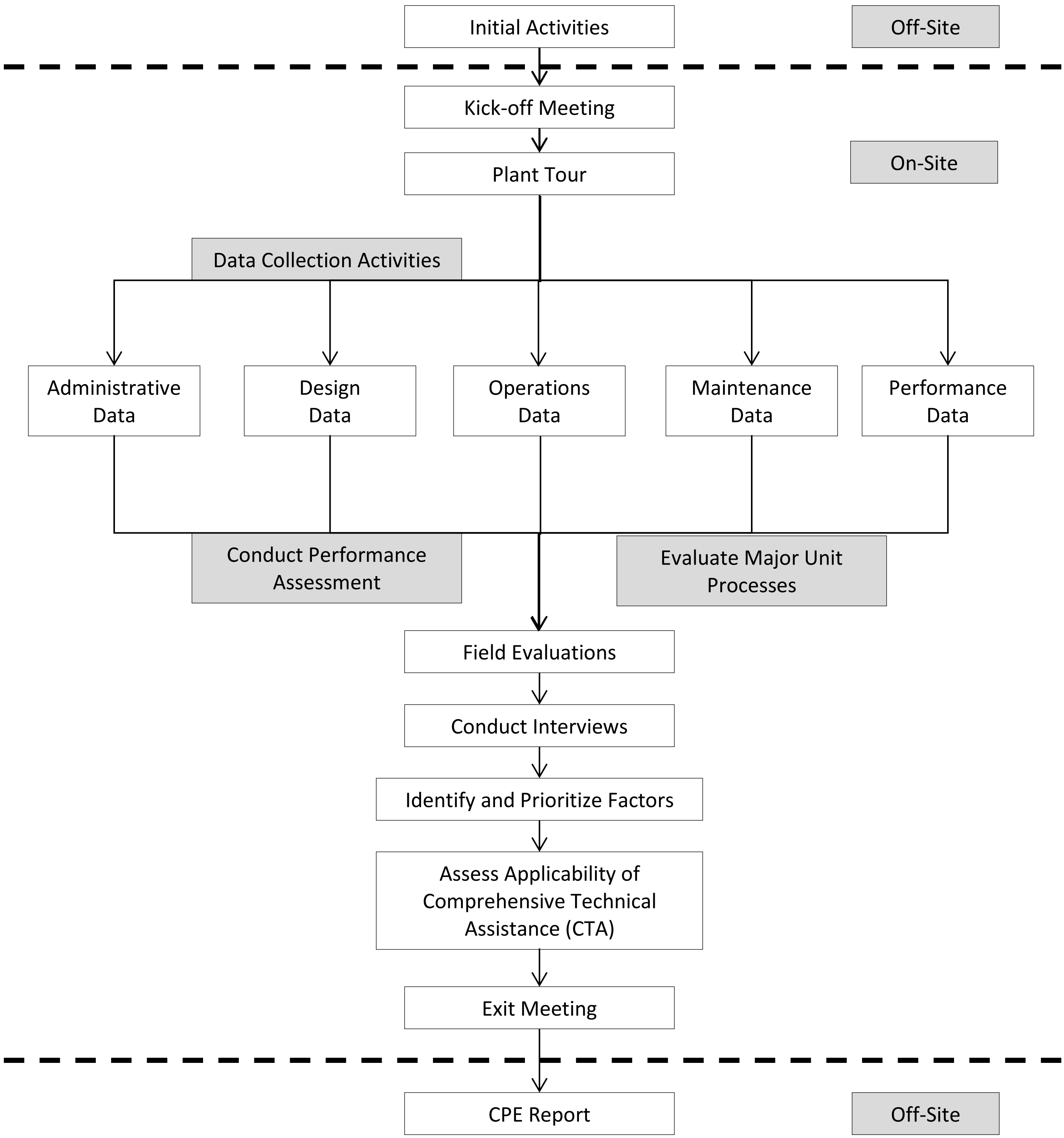


Figure 6-4. Activities During a CPE.

A detailed description of the activities performed during a CPE is as follows:

- **Initial activities** are conducted prior to on-site efforts and involve notifying appropriate plant personnel to ensure that they, as well as other necessary resources, will be available during the CPE.

- The **kick-off meeting**, conducted on site, allows the evaluators to describe forthcoming activities, to coordinate schedules, and to assess availability of required materials.

- Following the kick-off meeting, the superintendent or process control supervisor **conducts a plant tour**. During the tour, the evaluators ask questions regarding the plant and observe areas that may require additional attention during data collection activities. For example, an evaluator might make a mental note to investigate more thoroughly the flow splitting arrangement prior to flocculation basins if one basin appeared to receive more flow than the other units (e.g., flooding).

- Following the plant tour, **data collection activities** begin. Depending on team size, the evaluators split into groups to facilitate simultaneous collection of the **administrative, design, operations, maintenance, and performance data**. Appropriate forms are provided in Appendix F of the EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998b) to facilitate the data collection activities. After data are collected, the CPE evaluators will **conduct a performance assessment** and **evaluate major unit processes** are conducted. It is noted that often the utility can provide the performance data prior to the site visit. In this case the performance graphs can be completed prior to the on-site activities. However, it is important to verify the sources of the samples and quality of the data during field efforts.

- CPE evaluators will then **conduct field evaluations** to continue to gather additional information regarding actual plant performance and confirm potential factors. This activity typically includes a special study focusing on an individual filter or filters.

- Once all of this information is collected, CPE evaluators should **conduct a series of interviews** with the plant staff and administrators. Initiating all the previous activities prior to the interviews provides the evaluators with an understanding of current plant performance and plant unit process capability, which allows interview questions to be more focused on potential factors.

- After all information is collected, the evaluation team meets at a location isolated from the utility personnel to review findings and **identify and prioritize limiting factors**. The CPE team will compile and copy the list of factors, performance data, field evaluation results, and major unit process evaluation data to use as handouts during the exit meeting.

- The CPE team **assesses whether Comprehensive Technical Assistance (CTA) is applicable** for the plant. The CTA is the second phase of the CCP and may be used to improve performance in a more formal and structured setting. During the CTA phase, the system, with assistance from the state, identifies and systematically addresses plant-specific factors. The CTA is a combination of utilizing CPE results as a basis for follow-up, implementing process control priority-setting techniques, and maintaining long-term involvement to systematically train staff and administrators.

- An **exit meeting** is held with appropriate operations and administration personnel where all evaluation findings are presented, and the plant staff are given the opportunity to ask questions.

The evaluation team answers clarifying questions during the exit meeting but does not make recommendations or offer solutions to the identified factors.

- CPE providers will then generate **a CPE report** which formally documents the information presented in the exit meeting**. All CPE findings** should be presented in the exit meeting and it is critical that the report not present any additional findings. The CPE provider should not withhold any controversial findings and present them for the first time in the report.

A CPE is typically conducted over a three to five-day period by a team consisting of at least two personnel. A team approach is necessary to allow a facility to be evaluated in a reasonable time frame, and for evaluation personnel to jointly develop findings on topics requiring professional judgment. Professional judgment is critical when evaluating subjective information obtained during the on-site CPE activities. For example, assessing administrative versus operational performance limiting factors often involves the evaluators' interpretation of interview results. The synergistic effect of two people making this determination is a key part of the CPE process.

Because of the wide range of areas that are evaluated during a CPE, the evaluation team needs to have a broad range of available skills. This broad skills range is another reason to use a team approach in conducting CPEs. Specifically, persons should have capability in the areas shown in Table 6-2.

Table 6-2. Evaluation Team Capabilities

Technical Skills/Knowledge	Leadership Skills
Water treatment plant design	Communication (presenting, listening, interviewing)
Water treatment operations and process control	Organization (scheduling, prioritizing)
Regulatory requirements	Motivation (involving people, recognizing staff abilities)
Maintenance	Decisiveness (completing CPE within time frame allowed)
Utility management (rates, budgeting, planning)	Interpretation (assessing multiple inputs, making judgments)

Regulatory agency personnel with experience in evaluating water treatment facilities, consulting engineers who routinely work with plant evaluation, design and start-up, and utility personnel with design and operations experience represent the types of personnel with appropriate backgrounds to conduct CPEs. Other combinations of personnel can be used if they meet the minimum experience requirements outlined above. Although teams composed of utility management and operations personnel associated with the CPE facility can be established, it is often difficult for an internal team to objectively assess administrative and operational factors. The strength of the CPE is best represented by an objective third-party review.

6.5 CPE Quality Control (QC)

It is important for CPE providers and recipients of CPEs to ensure that a CPE being carried out under IESWTR or LT1ESWTR is properly executed and adheres to CCP concepts and expectations. While a CCP itself is not required by the IESWTR or LT1ESWTR, a CPE that is conducted in response to an IESWTR or LT1ESWTR turbidity threshold trigger should closely follow the CPE protocols described in EPA's *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA, 1998b). The CPE providers should maintain the integrity of the program and the recipients should make sure they receive the full benefit of the CPE. However, to assure effective and consistent CPE results, QC considerations have been developed.

Table 6-3 presents a checklist for CPE providers and recipients to assess the adequacy of a CPE relative to the guidance provided in the CCP Handbook. The following discusses some of the key areas of concern in more detail.

Table 6-3. QC Checklist for Completed CPEs

Checklist
• Findings demonstrate emphasis on achievement of compliance and/or optimized performance goals (i.e., performance emphasis is evident in the discussion of why prioritized factors were identified).
• Lack of bias associated with the provider's background in the factors identified (e.g., all design factors identified by a provider with a design background or lack of operations or administrative factors identified by the utility personnel conducting a CPE).
• Emphasis in the CPE results to maximize the use of existing facility capability.
• All components of the CPE completed and documented in a report (i.e., performance assessment, major unit process evaluation, identification and prioritization of factors, and assessment of CTA application).
• Fewer than 15 factors limiting performance identified (i.e., excessive factors indicate lack of focus for the utility).
• Specific recommendations are not presented in the CPE report, but rather, clear examples that support the identification of the factors are summarized.
• Identified limitations of operations staff or lack of site-specific guidelines instead of a need for a third party-prepared operation and maintenance manual.
• Findings address administrative, design, operation and maintenance factors (i.e., results demonstrate provider's willingness to identify/present all pertinent factors).

A challenging area for the CPE provider is to maintain the focus of the evaluation on performance and public health protection. Often, a provider will identify limitations in a multitude of areas which may not be related to the performance criteria (e.g., poor plant housekeeping practices, lack of preventive maintenance, or lack of an operation and maintenance manual). Limitations in these areas are easily observed and do not challenge the capability of the operations staff. While they demonstrate a thoroughness by the provider to identify all issues, their identification may cause the PWS to focus resources on these areas while ignoring areas more critical to achievement of performance goals. The evaluator should be aware that a utility may take the CPE results and only address those factors that are considered relatively easy to correct without consideration of priority or the inter-relatedness of the factors.

Another significant challenge in conducting an effective CPE is the tendency for providers to identify limitations that are non-controversial rather than real factors that may challenge the plant personnel's roles and responsibilities. For example, it is often easy to identify a design limitation, since the utility could not be expected to achieve desired performance with inadequate facilities. It is much more difficult to identify “lack of administrative support” or an operator’s “inability to apply process control concepts" as the causes of poor performance. This may be especially problematic when the CPE findings tend to criticize the administrators that have hired the CPE providers.

Failing to appropriately identify these difficult factors is a disservice to all parties involved. **A common result of this situation is the utility addressing a design limitation without addressing existing administrative or operational issues.** Ultimately, these administrative and operational issues remain and impact the utility’s ability to achieve desired performance. Understanding this concept allows the CPE provider to present the true factors, even though they may not be well received at the exit meeting. CPE recipients should be suspicious when a plant has a performance problem and no operations or administrative factors are identified.

A final consideration when implementing a CPE is to understand the importance that specific recommendations involving plant modifications or day-to-day operational practices should not be made by the CPE provider or accepted without question by the recipient. For example, direction on changing coagulants or chemical dosages is not appropriate during the CPE. These types of changes should be evaluated to determine if they are truly appropriate for the specific plant. A coagulant that worked for the CPE provider at one plant may not work for the plant being evaluated; causing unnecessary costs and/or poor performance. There is a strong bias for providers to give specific recommendations and for recipients to want specific checklists to implement. CPE providers should focus their observations during the evaluation on two key areas:

1. Identification of factors limiting the facility from achieving desired performance goals (compliance or optimized); and

2. Providing specific examples to support these factors.

Recipients should, also, not request specific guidance from the providers and, if this guidance is provided, they should make sure that the information provided is truly appropriate to their plant.

6.6 Next Steps

The results of the CPE provide PWSs and states with a thorough evaluation of processes at a treatment plant. CPE results identify factors which may be limiting the performance of the treatment plant and subsequently causing compliance problems. The CPE affords PWSs the opportunity to achieve improvements largely through administrative and operational changes. Most PWSs can implement any necessary changes through a self-improvement program, but if assistance is necessary facilities should work closely with EPA, their state, and technical assistance programs geared towards improving treatment plant performance.

6.7 References

AWWA. 2011. M37 Operational Control of Coagulation and Filtration Processes, Third Edition. Denver, CO.

Nix, D.K., and J.S. Taylor. 2018. Filter Evaluation Procedures for Granular Media. Second Edition. AWWA, Denver, CO.

USEPA. 1998a. National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule; Final Rule. 63 FR 69478. December 16, 1998. Available at: http://www.gpo.gov/fdsys/pkg/FR-1998-12-16/pdf/98-32888.pdf.

USEPA. 1998b. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA/625/6-91/027. Available at: https://www.epa.gov/dwreginfo/interim-enhanced-surface-water-treatment-rule-documents.

USEPA. 2002. National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule; Final Rule. 67 FR 1811. January 14, 2002. Available at: https://www.gpo.gov/fdsys/pkg/FR-2002-01-14/pdf/02-409.pdf.

APPENDIX A- GLOSSARY

A.1 Glossary

accuracy. How closely an instrument measures the true or actual value of the process variable being measured or sensed.

activated carbon. Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble organic materials from water.

air binding. A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

algae. Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. They are food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

alkalinity. The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

analog. The readout of an instrument by a pointer (or other indicating means) against a dial or scale.

Association of Boards of Certification (ABC). An international organization representing over 150 boards which certify the operators of waterworks and waste water facilities. For information on ABC publications regarding the preparation of, and how to study for operator certification examinations, contact ABC at: 4261/2 Fifth Street, P.O. Box 786, Ames, Iowa 50010-0786.

backwashing. The process of reversing the flow of water back through the filter media to remove the entrapped solids.

bacteria. Singular: bacterium. Microscopic living organisms usually consisting of a single cell. Some bacteria in soil, water or air may cause human, animal and plant health problems.

baffle. A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry).

bias. An inadequacy in experimental design that leads to results or conclusions not representative of the population under study.

breakthrough. A situation in which particles are able to pass through the filter media. This will cause an increase in filter effluent turbidity. A breakthrough can occur: 1) when a filter is first placed in service; 2) when the effluent valve suddenly opens or closes; and, 3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

calcium carbonate ($CACO_3$) equivalent. An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

calibration. A procedure which checks or adjusts an instrument's accuracy by comparison with a standard or reference.

capital costs. Costs (usually long-term debt) of financing construction and equipment. Capital costs are usually fixed, one-time expenses which are independent of the amount of water produced.

carcinogen. Any substance which tends to produce cancer in an organism.

clarifier. A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. Clarifiers are also called settling basins and sedimentation basins.

coagulant aid. Any chemical or substance used to assist or modify coagulation.

coagulants. Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

coagulation. Coagulation means a process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

colloids. Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long-time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

combined sewer. A sewer that transports surface runoff and human domestic wastes (sewage), and sometimes industrial wastes. Wastewater and runoff in a combined sewer may occur in excess of the sewer capacity and cannot be treated immediately. The excess is frequently discharged directly to a receiving stream without treatment, or to a holding basin for subsequent treatment and disposal.

community water system (CWS). A PWS which serves at least 15 service connections used by year-round residents or regularly serves at least 25 persons year-round.

complete treatment. A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, flocculation, sedimentation, and filtration. Also called conventional filtration.

continuous sample. A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

conventional filtration. Means a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal. Also called complete treatment. Also see **direct filtration** and **in-line filtration.**

conventional filtration treatment. A series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

cross connection. Any actual or potential connection between a drinking (potable) water system and an unapproved water supply or other source of contamination.

CT or CTcalc. The product of "residual disinfectant concentration" (C) in mg/l determined before or at the first customer, and the corresponding "disinfectant contact time" (T) in minutes, i.e., "C" x "T". If a public water system applies disinfectants at more than one point prior to the first customer, it must determine the CT of each disinfectant sequence before or at the first customer to determine the total percent inactivation or "total inactivation ratio." In determining the total inactivation ratio, the public water system must determine the residual disinfectant concentration of each disinfection sequence and corresponding contact time before any subsequent disinfection application point(s). "CT99.9" is the CT value required for 99.9 Percent (3-log) inactivation of *Giardia lamblia* cysts. CT99.9 a variety of disinfectants and conditions appear in Tables 1. l- 1.6, 2.1, and 3.1 of CFR section 141.74(b)(3). CT99.9 is the inactivation ratio. The sum of the inactivation ratios, or total inactivation ratio shown as E = (CT calc) / (CT99.9) is calculated by adding together the inactivation ratio for each disinfection sequence. A total inactivation ratio equal to or greater than 1.0 is assumed to provide a 3-log inactivation of *Giardia lamblia* cysts.

degasification. A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

degradation. Chemical or biological breakdown of a complex compound into simpler compounds.

diatomaceous earth filtration (DE filtration). Means a process resulting in substantial particulate removal in which (1) a precoat cake of diatomaceous earth filter media is deposited on a support membrane (septum), and (2) while the water is filtered by passing through the cake on the septum, additional filter media known as body feed is continuously added to the feed water to maintain the permeability of the filter cake.

direct filtration. means a series of processes including coagulation and filtration but excluding sedimentation resulting in substantial particulate removal. Also see **conventional filtration** and **in-line filtration**.

effective range. That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see **range**.

effective size (ES). The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. ES is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The ES is also approximately the average size of the grains.

effluent. Water or some other liquid-raw, partially or completely treated-flowing from a reservoir, basin, treatment process or treatment plant.

end point. Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

enteric. Of intestinal origin, especially applied to wastes, bacteria, or viruses.

enteric virus. A group of viruses found in the intestinal tract of humans and animals**.**

entrain. To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

filtration. A process for removing particulate matter from water by passage through porous media.

finished water. Water that is introduced into the distribution system of PWS and is intended for distribution and consumption without further treatment, except as treatment necessary to maintain water quality in the distribution system (e.g., booster disinfection, addition of corrosion control chemicals).

floc. Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

flocculation. Means a process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

garnet. A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

gastroenteritis. An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.

***Giardia lamblia*.** Flagellate protozoan which is shed during its cyst stage into the feces of man and animals. When water containing these cysts is ingested, the protozoan causes a severe gastrointestinal disease called giardiasis.

giardiasis. Intestinal disease caused by an infestation of Giardia flagellates.

grab sample. A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

ground water under the direct influence (GWUDI) of surface water. Any water beneath the surface of the ground with: 1) significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as *Giardia lamblia*; or, 2) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the state. The state determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.

hardness, water. A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

head. The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

head loss. The head, pressure, or energy lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, or restrictions caused by fittings. Water flowing in a pipe loses head, pressure, or energy as a result of friction losses.

influent. Water or other liquid-raw or partially flowing INTO a reservoir, basin, treatment process or treatment plant.

in-line filtration. The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installations. Also see **conventional filtration** and **direct filtration**.

inorganic. Inorganic materials are chemical substances of mineral origin.

jar test. A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to estimate the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals are added to each jar, and the settling of solids is observed. The dose of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time. When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

legionella. A genus of bacteria, some species of which have caused a type of pneumonia called Legionnaires Disease.

linearity. How closely an instrument measures actual values of a variable through its effective range; a measure used to determine the accuracy of an instrument.

micrograms per liter (µg/L). One microgram of a substance dissolved in each liter of water. This unit is equal to parts per billion (ppb) since one liter of water is equal in weight to one billion micrograms.

micron. A unit of length. One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

microorganisms. Living organisms that can be seen individually only with the aid of a microscope.

milligrams per liter (mg/L). A measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each liter of water. For practical purposes, this unit is equal to ppm since one liter of water is equal in weight to one million milligrams. Thus, a liter of water containing 10 milligrams of calcium has 10 parts of calcium per one million parts of water, or 10 parts per million (10 ppm).

mudballs. Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

nephelometric. A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

nephelometric turbidity unit (NTU). The unit of measure for turbidity.

non-transient non-community water system (NTNCWS). A PWS that regularly serves at least 25 of the same nonresident persons per day for more than six months per year.

non-community water system (NCWS). A PWS that is not a CWS. A NCWS is either a transient non-community water system (TWS) or a NTNCWS.

operation and maintenance costs. The ongoing, repetitive costs of operating a water system including for example, employee wages, costs for treatment chemicals, and periodic equipment repairs.

organic. Substances that come from animal or plant sources. Organic substances always contain carbon.

organics. 1) A term used to refer to chemical compounds made from carbon molecules including natural materials (such as animal or plant sources) or man-made materials (such as synthetic organics); and, 2) any form of animal or plant life.

overflow rate. One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Overflow Rate (GPD/sq. ft) = Flow (GPD)/Surface Area (sq. ft)

particle count. The results of a microscopic examination of treated water with a special "particle counter" which classifies suspended particles by number and size.

particulate. A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

pathogens. Microorganisms that can cause disease in other organisms or in humans, animals, and plants. They may be bacteria, viruses, or parasites and are found in sewage in runoff from animal farms or rural areas populated with domestic and/or wild animals, and in water used for swimming. Fish and shellfish contaminated by pathogens, or the contaminated water itself, can cause serious illnesses.

performance evaluation sample. A reference sample provided to a laboratory for the purpose of demonstrating that the laboratory can successfully analyze the sample within limits of performance specified by the EPA. The true value of the concentration of the reference material is unknown to the laboratory at the time of the analysis.

pH. pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration, [H+]. pH = Log (1/H+) The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

plug flow. A type of flow that occurs in tanks, pipes, basins, or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

polymer. A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

pore. A very small open space in a rock or granular material.

precision. The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results.

public water system (PWS). PWS means a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any "special irrigation district." A PWS is either a CWS or a NCWS.

range. The spread from minimum to maximum values that an instrument is designed to measure. Also see **effective range**.

reservoir. Any natural or artificial holding area used to store, regulate, or control water.

reverse osmosis. The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). The liquid produced is a demineralized water.

Safe Drinking Water Act (SDWA). SDWA was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells.

sand. Soil particles between 0.05 and 2 .0 mm in diameter.

sand filters. Devices that remove suspended solids from water during treatment using a filter bed made up of sand. Sand filters may be used for conventional, direct, or slow sand filtration processes.

sedimentation. A process for removal of solids before filtration by gravity or separation.

slow sand filtration. A process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms.

standard. A physical or chemical quantity whose value is known exactly and is used to calibrate or standardize instruments.

Standard Methods for the Examination of Water and Wastewater. A joint publication of the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation which outlines the procedures used to analyze the impurities in water and wastewater.

standardize. To compare with a standard. 1) In wet chemistry, to find out the exact strength of a solution by comparing it with a standard of known strength. 2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

state. The agency of the state or Tribal government which has jurisdiction over PWSs. During any period when a state or Tribal government does not have primary enforcement responsibility pursuant to Section 1413 of the SDWA, the term "state" means the Regional Administrator of the U.S. EPA.

surface water. Is all water which is open to the atmosphere and subject to surface runoff.

surfactant. Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

suspended solids. 1) Solids that either float on the surface or are suspended in water or other liquids and which are largely removable by laboratory filtering; or 2) the quantity of material removed from water in a laboratory test, as prescribed in *Standard Methods for The Examination of Water and Wastewater*.

total inactivation ratio. The residual disinfectant concentration of each disinfection sequence and corresponding CT before any subsequent disinfection application point(s). Also called total percent inactivation.

transient water system (TWS). TWS means a NCWS that does not regularly serve at least 25 of the same persons over six months per year.

tube settler. A device that uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular. As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

turbid. Having a cloudy or muddy appearance.

turbidimeter. A device that measures the amount of suspended solids in a liquid.

turbidity. The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

urban runoff. Stormwater from city streets and adjacent domestic or commercial properties that may carry pollutants of various kinds into the sewer systems and/or receiving waters.

waterborne disease outbreak. The significant occurrence of acute infectious illness, epidemiologically associated with the ingestion of water from a PWS that is deficient in treatment, as determined by the appropriate local or state agency.

water supplier. A person who owns or operates a PWS.

water supply system. The collection, treatment, storage, and distribution of potable water from source to consumer.

zeta potential. In coagulation and flocculation procedures, the difference in the electrical charge between the dense layer of ions surrounding the particle and the charge of the bulk of the suspended fluid surrounding this particle. The zeta potential is usually measured in millivolts.

A.2 References

Calabrese, E.J., C.E. Gilbert, and H. Pastides, Eds. 1988. *Safe Drinking Water Act Amendments, Regulations and Standards*. Lewis Publishers. Chelsea, MI.

California State University. 1988. *Water Treatment Plant Operation*. School of Engineering, Applied Research and Design Center, Sacramento, CA.

Dzurik, A.A., Rowman, and Littlefield. 1990. *Water Resources Planning*. Savage, MD.

USEPA. *Code of Federal Regulations*, Title 40, Chapter I, Section 141.2. July 1. Accessed on-line on December 27, 2013.

von Huben, H. 1991. Surface Water Treatment: The New Rules. AWWA.

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APPENDIX B - BASIC TURBIDIMETER DESIGN AND CONCEPTS

B.1 Introduction

Turbidity is described in the *Standard Methods for the Examination of Water and Wastewater* Method 2130B (EPA Method 180.1) for turbidity measurement as, “an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample” (Standard Methods, 1995). This appendix includes a detailed summary of the various types of instruments used to measure turbidity and includes descriptions of the physical properties associated with the measurements of turbidity and design configurations.

As shown in Figure B-1, modern turbidimeters use the technique of nephelometry, which measures the amount of light scattered at right angles to an incident light beam by particles present in a fluid sample. In general, all modern turbidimeters utilize the nephelometric measurement principals, but instrument manufacturers have developed several different meter designs and measurement configurations.

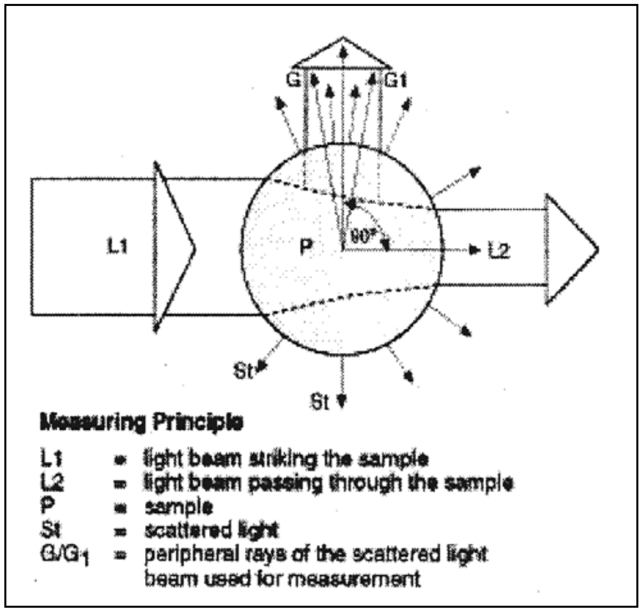

Figure B-1. Scattered Light at 90° Degrees (Source: GLI, undated)

B.2 Turbidimeter Measuring Principles

As light passes through ‘absolutely pure’ water, the light beams travel along relatively undisturbed paths. However, some distortion occurs as light is scattered by molecules present in the pure fluid. As shown in Figure B-1, when light passes through a fluid containing suspended solids, the light beam interacts with the particles, and the particles absorb the light energy and re-radiate light in all directions.

Particle size, configuration, color, and refractive index determine the spatial distribution of the scattered light intensity around the particle. As shown in Figure B-2, particles much smaller than the wavelength of the incident light, which is typically expressed in nanometers (nm), scatter light of approximately equal intensity in all directions. However, particles larger than the wavelength of the incident light, form a spectral pattern that results in greater light scattering in the forward direction (away from the incident light) than in the other directions. This scattering pattern and intensity of the light beam transmitted through the sample can also be affected by the particles absorbing certain wavelengths of the transmitted light (Sadar, 1996).

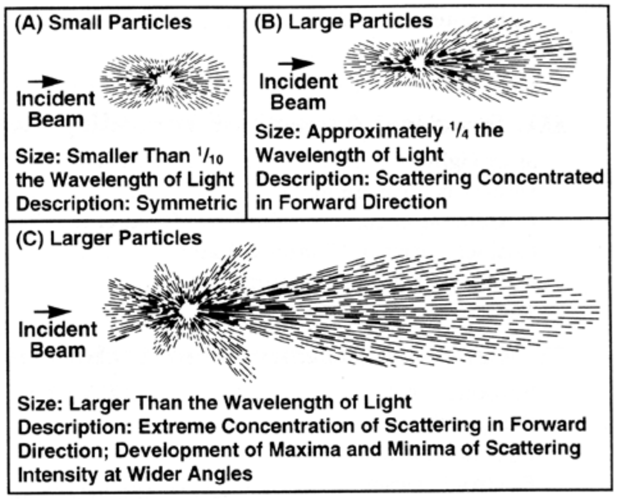

Figure B-2. Patterns of Scattered Light from Particles of Different Sizes (Source: Sadar, 1996)

Since the light scattered in the forward direction is variable depending on particle size, the measurement of the light transmitted through the sample yields variable results. In addition, the change in transmitted light is very slight and difficult to distinguish from electronic noise when measuring low turbidities. High turbidity samples are also difficult to measure using transmitted light due to multiple scatter of the light by many particles in the fluid. To solve these problems, turbidimeters primarily measure the scatter of light at a 90-degree angle to the incident beam and relate this reading to turbidity. This angle is considered very sensitive to light scatter by particles in the sample. As described in Section B.3, additional light sensors are also sometimes added to detect light scattered at other angles in order to improve the instrument range and remove errors introduced by natural colors and lamp variability.

B.2.1 Light Source

The basic turbidimeter instrument contains a light source, sample container or cell, and photodetectors to sense the scattered light. The most common light source used is the tungsten filament lamp. The spectral output (band of wavelength light produced) of these lamps is generally characterized by “color temperature,” which is the temperature that a black body radiator must be operated to produce a certain color. The tungsten filament lamps are incandescent lamps and are termed “polychromatic,” since they have a fairly wide spectral band that includes many different wavelengths of light, or colors. The presence of the various wavelengths can cause interference in the turbidity measurements as natural color and natural organic matter (NOM) in the sample can absorb some specific wavelengths of light and reduce the intensity of the scattered light (King, 1991).

The tungsten filament lamp is also highly dependent on the voltage of the lamp power supply. The voltage applied to the lamp determines the spectral output characteristics produced, making a stable power supplies a necessity. In addition, as with any incandescent lamp, the output from the lamp decays with time as the lamp slowly “burns out,” making recalibration of the instrument a frequent and necessary requirement.

To overcome some of the incandescent lamp limitations, some turbidimeter designs utilize monochromatic light sources, such as light emitting diodes (LEDs), lasers, mercury lamps, and various lamp filter combinations. Monochromatic light has a very narrow band of light wavelengths (only a few colors). By selecting light wavelengths that are not normally absorbed by organic matter, the monochromatic light source can be less susceptible to interference by sample color. However, some of these alternate light sources respond differently to particle size, and are not as sensitive to small sized particles as the tungsten filament lamp.

B.2.2 Sample Volume

Grab samples are typically introduced into bench top turbidimeter instruments through a transparent sample cell made of glass. These samples cells, or cuvettes, are usually about 30 milliliters in capacity. Some continuous turbidimeters utilize the glass sample cell, but most designs use a flow-through chamber with the light source located outside the sample. Sample chambers in continuous turbidimeters range from 30 milliliters to over two liters.

B.2.3 Photodetector

In turbidimeters, photodetectors detect the light produced from the interaction of the incident light and the sample volume and produce an electronic signal that is then converted to a turbidity value. These detectors can be located in a variety of configurations depending on the design of the instrument. The four types of detectors commonly used include photomultiplier tubes, vacuum photodiodes, silicon photodiodes, and cadmium sulfide photoconductors (Sadar, 1992).

Each of the four types of detectors vary in their response to certain wavelengths of light. Therefore, if a polychromatic light source is used, the spectral output of the light source has a direct bearing on the type and design of photodetector selected for an instrument. The specification of the photodetector is not nearly as critical when a monochromatic light source is used. In general, with the polychromatic tungsten filament lamp as a light source, the photomultiplier tube and the vacuum photodiode are more sensitive to the shorter wavelength light in the source, making them more sensitive to the detection of smaller particles. Conversely, the silicon photodiode is more sensitive to longer wavelengths in the light source, making it more suited for sensing larger particles. The sensitivity of the cadmium sulfide photoconductor is between the sensitivity of the photomultiplier tube and the silicon photodiode.

B.3 Turbidimeter Design Configurations

Several instrument design standards have been developed by various organizations to attempt to standardize instrument designs and achieve test results that are accurate and repeatable. These standards govern the design of the various turbidimeter configurations available today, which include the single beam design, modulated four beam design, surface scatter design, and transmittance design. Only the single beam design, ratio design, and modulated four beam design are approved by the United States Environmental Protection Agency (EPA).

B.3.1 Design Standards

The requirements stated in *Standard Methods* 2130B are similar to the requirements of EPA Method 180.1. The EPA Method 180.1 lists the following design requirements for turbidimeters:

- "Light Source: Tungsten-filament lamp operated at a color temperature between 2200 and 3000 K.
- Distance traversed by incident light and scattered light within the sample tube not to exceed 10 cm.

- Angle of light acceptance by detector: Centered at 90 degrees to the incident light path and not to exceed +/- 30 degrees from 90 degrees. The detector, and filter system if used, shall have a spectral property between 400 and 600 nm (Standard Methods, 1995)."

EPA has recognized two additional standards for turbidimeter design called GLI Method 2 and Hach FilterTrak Method 10133. Like EPA Method 180.1, these standards are applicable for turbidities in the 0 to 40 nephelometric turbidity units (NTU) range, but may be used for higher turbidities by diluting the sample. The GLI Method 2 standard requires that instruments utilize basic nephelometric concepts, but unlike other methods (EPA Method 180.1 and Hach FilterTrak Method 10133), this method requires the use of two light sources with a photodetector located at 90-degrees from each source. This concept, which is often called a modulated four beam design, pulses the two light sources on and off and utilizes a portion of the scattered light as a reference signal to arithmetically cancel errors. A full description of the modulated four beam design is discussed in Section B.3.4.

B.3.2 Single Beam Design

The single beam design configuration, shown in Figure B-3, is the most basic turbidimeter design using only one light source and one photodetector located at 90 degrees from the incident light. The single beam design is the oldest of the modern nephelometers and typically is used with a polychromatic tungsten filament lamp. The design is still in wide used today and yields accurate results for turbidity under 40 NTU, provided that samples have little natural color. In fact, many continuous turbidimeters in use today still utilize the single beam design.

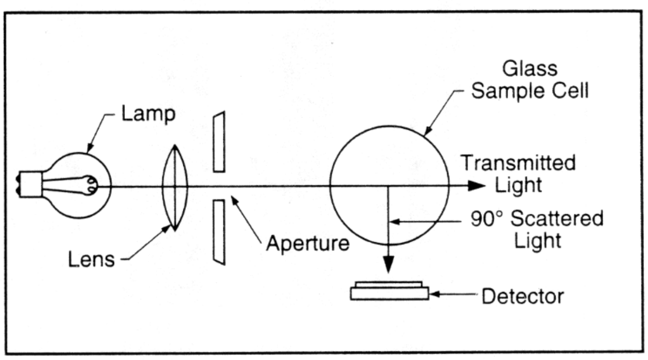

Figure B-3. Basic Nephelometer (Source: Sadar, 1996)

The single beam design does, however, have limited accuracy at higher turbidities. As turbidity increases and the amount of scattered light increases, multiple scattering can occur when light strikes more than one particle as it reacts with the sample fluid. The resulting scattered light intensity reaching the 90-degree detector can diminish as the instrument effectively "goes blind." For this reason, a single beam design conforming strictly to EPA 180.1 does not typically demonstrate stable measurement capability at high turbidities and is generally only applicable for turbidity readings from 0 to 40 NTU.

The design of the single beam instrument is also limited by the need for frequent recalibration of the instrument due to the decay of the incandescent light source. Because of the polychromatic nature of the light source, these instruments also can demonstrate poor performance with samples containing natural color. Since most treated water samples have low or no color, use of the single beam design is appropriate.

B.3.3 Ratio Design

The ratio turbidimeter design expands upon the single beam concept, but includes additional photodetectors located at other angles than 90 degrees from the incident light. As shown in Figure B-4, the ratio design utilizes a forward scatter detector, a transmitted light detector, and for very high turbidity applications, a back-scatter detector. The signals from each of these detectors are mathematically combined to calculate the turbidity of the sample. A typical ratio mathematical algorithm is as follows (Standard Methods, 1995):

$$T = I_{90} / (d_0 * I_t + d_1 * I_{fs} + d_2 * I_{bs} + d_3 * I_{90})$$

Where:

T = Turbidity in NTU

d_0, d_1, d_2, d_3 = Calibration Coefficients

I_{90} = 90 Degree Detector Current

I_t = Transmitted Detector Current

I_{fs} = Forward Scatter Detector Current

I_{bs} = Back Scatter Detector Current

The use of multiple photodetectors and the ratio algorithm gives the instrument much better performance with colored samples. The transmitted light and the 90-degree scattered light are affected almost equally by the color of the sample because they travel nearly the same distance through the sample volume. When the ratio of the two readings is taken, the effects of color absorption on the two readings tend to cancel mathematically.

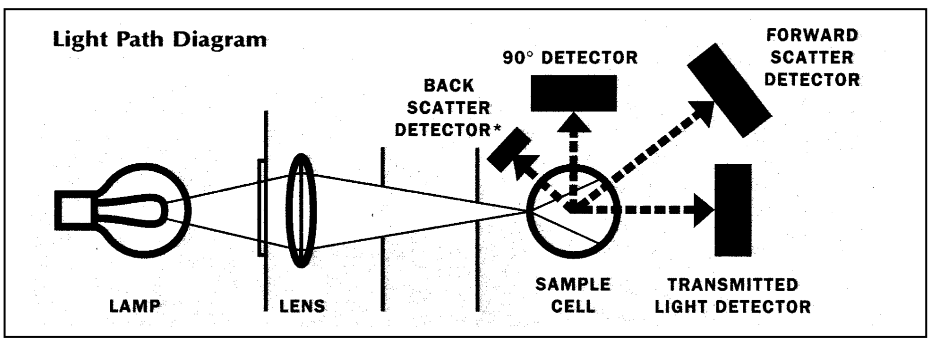

Figure B-4. Ratio Turbidimeter (Source: Sadar, 1996)

B.3.4 Modulated Four-Beam Design

Unlike the single beam and ratio turbidimeters, the modulated four-beam instrument design utilizes two light sources and two photo detectors. The two sources and the two detectors are used to the implement theory of ratio measurements to cancel errors. As shown in Figure B-5, the light sources and detectors are located at 90 degrees around the sample volume (Great Lakes Instruments, undated).

This design takes two measurements every 0.5 seconds. In the first phase, light from source #1 is pulsed directly into photodetector #2. Simultaneously, photodetector #1 measures the light scattered from this pulse at a 90-degree angle. In the second phase, light from source #2 is pulsed directly into photodetector #1. Simultaneously, photodetector #2 measures the light scattered from this pulse at a 90-degree angle. In both phases, the signal from the photodetector receiving the direct light signal is the active signal, while the signal from photodetector measuring scattered light is called the reference signal. The two-phase measurements provide four measurements from two light sources: two reference signals and two active signals.

The turbidity of the sample is calculated from the four independent measurements taken from the two light sources using a mathematical algorithm similar to the algorithm used by the ratio instrument design. The result is that errors resulting from sample color appear in both the numerator and denominator of the mathematical algorithm, and the errors are mathematically canceled.

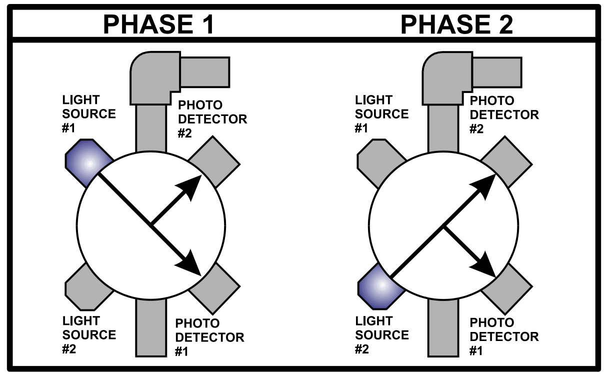

Figure B-5. Modulated Four-Beam Turbidimeter (Source: GLI, undated)

Like the ratio design, the mathematical algorithm used in the four-beam design allows for more sensitivity in highly turbid samples and extends the range of the instrument to about 100 NTU. The error cancellation achieved by the ratio algorithm also makes the instrument very accurate in the 0 to 1 NTU range.

B.3.5 Surface Scatter Design

As turbidity increases, light scattering intensifies and multiple scattering can occur as light strikes more than one particle as it interacts with the fluid. Light absorption by particles can also significantly increase. When particle concentration exceeds a certain point, the amount of transmitted and scattered light decreases significantly due to multiple scattering and absorption. This point is known as the optical limit of an instrument.

The surface scatter design utilizes a light beam focused on the sample surface at an acute angle. As shown in Figure B-6, light strikes particles in the sample and is scattered toward a photodetector that is also located above the sample surface. As turbidity increases, the light beam penetrates less of the sample, thus shortening the light path and compensating for interference from multiple scattering. The reported range of surface scatter instruments is about 0 to 9999 NTU, although these instruments are best suited for measuring high turbidities such as are present in raw water and recycle streams (Hach Corporation, 1995). These designs are not approved by EPA.

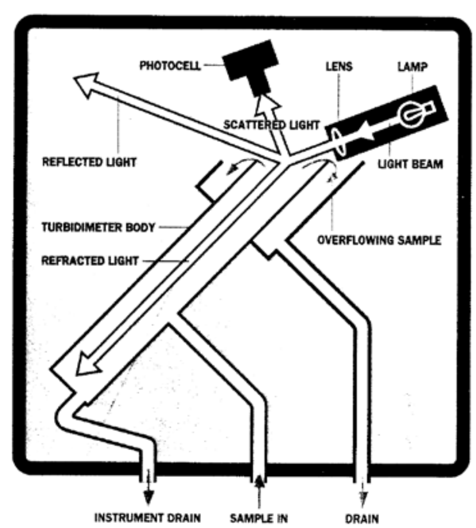

Figure B-6. Surface Scatter Turbidimeter (Source: Hach Corporation, 1995)

B.3.6 Transmittance Design

Instruments utilizing a transmittance design are often referred to as turbidimeters, but these instruments do not measure true turbidity of water in NTUs. These instruments are better termed “absorptometers” as they measure the amount of light transmitted through a sample rather than the amount of light scattered by a sample. Light transmittance is measured by introducing a light source to a sample volume and measuring the relative amount of light transmitted through the sample volume to a photodetector located opposite the light source. Transmittance values are reported as 0 to 100 percent of the incident light source transmitted through the sample. The use of absorptometers in water treatment has generally been restricted to monitoring spent filter backwash water to determine relative cleanliness of the filter media (Hach Corporation, 1995). These designs are not approved by EPA.

B.4 Types of Turbidimeters

There are three common types of turbidimeters employed today. These are referred to as bench top, portable, and continuous instruments. Bench top and portable turbidimeters are used to analyze grab samples. Bench top units are typically used as stationary laboratory instruments and are not intended to be portable. Continuous instruments are typically installed in the field and continuously analyze a sample stream spilt off from a unit process. Measurement with these units requires strict adherence to the manufacturer’s sampling procedure to reduce errors from dirty glassware, air bubbles in the sample, and particle settling.

B.4.1 Bench Top Turbidimeters

Most bench top turbidimeters are designed for broad applications and have the capability to measure highly colored samples as well as samples with high turbidities. The most popular bench top turbidimeters used today utilize the ratio design, but may have options for back scatter detectors or monochromatic light sources. Many ratio bench top instruments also have the capability to turn off the ratio calculation so that measurements can be made using the single beam design. Older bench top instruments may be of the single beam design, and some have analog rather than digital displays. Bench top units are used exclusively for grab samples and require the use of glass cuvettes for holding the sample volume. Figure B-7 is an example of a bench top turbidimeter.

Figure B-7. Bench Top Turbidimeter (Source: Hach Corporation, 1995)

B.4.2 Portable Turbidimeters

Portable turbidimeters are similar to the bench top units, except that they are designed for portable use and are battery operated. Portable turbidimeters are available in a variety of designs, including the single beam and ratio designs. The accuracy of portable instruments is comparable to the bench top units, but the resolution of low turbidity reading may only be 0.01 NTU as compared to the 0.001 NTU resolution of bench top units (Hach Corporation, 1995). Figure B-8 is an example of a portable turbidimeter.

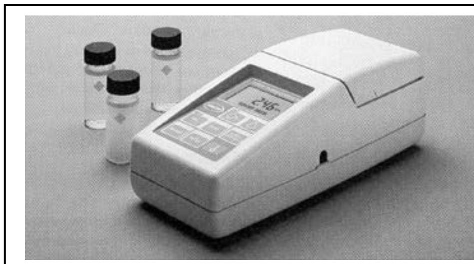

Figure B-8. Portable Turbidimeter (Source: Hach Corporation, 1995)

Portable turbidimeters are designed for use in the field with grab samples. These instruments are designed to be rugged and capable of withstanding the effects of moving the instrument as well as variable field conditions. However, since these instruments are inherently susceptible to damage or disturbance from dropping, abuse, or environmental conditions such as dust, these units are not appropriate for the process monitoring and reporting tasks normally accomplished by bench top units or continuous turbidimeters.

However, portable instruments are useful for measuring turbidity at remote locations such as at sampling points in the watershed upstream of a water treatment plant, or at a remote raw water intake location. Portable instruments are also useful for conducting special process studies, such as backwash recycle characterization or distribution system analysis that may be accomplished more readily and accurately in the field rather than conducting analysis after transporting a sample to a laboratory.

B.4.3 Continuous Turbidimeters

The continuous instruments used in the water treatment industry typically utilize the single beam or modulated four beam design. Continuous ratio turbidimeters are also available, but their use has not been as extensive as the single beam and modulated four beam designs. Continuous surface scatter turbidimeters are often used for raw water monitoring and transmittance-type absorptometers have been used for filter backwash monitoring. Figure B-9 is an example of an continuous turbidimeter.

Figure B-9. Continuous Turbidimeter (Source: GLI, undated)

Continuous instruments typically sample a side stream split off from the treatment process. The sample flows through the continuous instrument for measurement and then is wasted to a drain or recycled through the treatment process. Supervisory Control and Data Acquisition (SCADA) instrumentation and remote telemetry can also be connected to continuous instruments to collect data for trending analysis or to control automated treatment actions based on the turbidities measured. The use of SCADA with turbidity measurement is discussed in Chapter 3.

Typical sample flow rates through continuous instruments range from about 0.1 to 1.0 liter per minute. Some single beam continuous turbidimeters do not contain a glass sample container. The light source is located above the sample volume, which has an optically flat surface as it flows over a weir. The photodetector is submerged within the sample volume and requires frequent cleaning to prevent fouling. Most continuous four beam instruments used in the water industry contain a sealed flow-through sample volume with windows at each of the light sources and photodetectors. These surfaces must also be cleaned frequently to prevent fouling.

Most continuous instruments contain bubble traps to eliminate air bubbles from the sample that might interfere with the turbidity readings. Bubble traps are typically baffled chambers that allow air bubbles to rise to the sample surface prior to the sample entering the measurement chamber. The volume of the sample chamber varies significantly between the single beam and four beam design due mostly to the design of the bubble trap. Single beam devices typically include a bubble trap within the sample chamber, making the sample volume in excess of two liters. Several other continuous instruments use sample volumes as small as 30 milliliters.

B.5 References

California Department of Health Services (CDHS). 1996. *Particle Counting Guidelines*. CDHS.

GLI (Great Lakes Instruments). undated. *Technical Bulletin Number T1 – Turbidity Measurement.* Rev. 2-193, Great Lakes Instruments.

Hach Corporation. 1995. *Excellence in Turbidity Measurement.* Hach Corporation.

International Organization for Standards (ISO). 1990. *International Standard ISO 7027 – Water Quality – Determination or Turbidity.* ISO.

King, K. 1991. *Four-Beam Turbidimeters for Low NTU Waters.* Great Lakes Instruments.

Lex, D. 1994. Turbidity Technology Turns on the High Beams. *Intech Engineer's Notebook.* 41(6):36

Sadar, M.J. 1996. *Understanding Turbidity Science*. Technical Information Series – Booklet No. 11. Hach Company.

Standard Methods. 1995. *Standard Methods for the Examination of Water and Wastewater,* nineteenth edition. America Public Health Association, AWWA, Water Environment Federation. Franson, M.H., A.D. Eaton, L.S. Clesceri, and A.E. Greenberg (editors). American Public Health Association, AWWA, and Water Environment Federation. Port City Press, Baltimore, MD.

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