CHAPTER 3

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
COAGULATION AND FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing chemical coagulation and filtration processes. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing coagulation and filtration equipment, within the structure provided by the Document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." This Equipment Verification Testing Plan is applicable only to granular media filtration processes that rely upon chemical coagulation to effectively condition the feed water for effective filtration.

In order to participate in the equipment verification process for coagulation and filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of Product-Specific Test Plan. The Procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modification made for adaptations to specific water treatment equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6.

2.0 INTRODUCTION

Various types of water treatment equipment employing processes of coagulation and filtration are used for a wide number of applications, including removal of turbidity from surface waters; removal of bacteria, viruses, *Giardia* and *Cryptosporidium;* removal of algae, and removal of color and other natural organic matter from surface waters. Some equipment process trains use only chemical coagulation, mixing, and granular media filtration. Others employ a solids separation or clarification step between coagulation and filtration. Clarification processes may include one of the following:

- sedimentation;
- sedimentation aided by tubes or plates;
- downflow contact clarification;
- upflow contact clarification;
- dissolved air flotation (DAF).

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing a coagulation and filtration process train which may include a clarification step before filtration. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Manufacturer to determine the optimum chemical pretreatment scheme at a specific geographical location. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions.

Verification Testing will be done for relatively short time intervals during one or more time periods when the source water or feed water quality is appropriate for testing the full range of water quality conditions that need to be evaluated. This will include cold water and water having high and low turbidity.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the coagulation and filtration Verification Testing program.

4.1 Task A: Characterization of Feed Water

The objective of this recommended Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for at least 320 hours during each testing period to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include pretreatment chemistry for coagulation, a listing of treatment processes used, and their operating conditions. Equipment performance includes rate of filter head loss gain, frequency and duration of filter washing, and need for cleaning of pretreatment clarifiers.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to estimate the capability of coagulation and filtration equipment to remove microorganisms by measuring turbidity and particle counts in feed water and filtered water, and to evaluate removal of microbiological contaminants during Verification Testing by measuring removal of microorganisms naturally present in the feed water or by measuring the removal of seeded microorganisms such as algae, bacteria, coliphage, or protozoa, or a combination of those types of microorganisms.

4.7 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during coagulation and filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more 320-hour periods, not including mobilization, start-up, and Initial Operations.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's objectives. For example this may include water having high and low turbidity and cold water. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 320-hour periods. The purposes of the 320-hour test period are to: 1) provide opportunity for treatment of feed water having variable quality; 2) provide a data base on multiple filter runs from start-up to backwash, so data can be subjected to statistical analysis (Data from multiple runs are needed for rate of head loss accumulation, total water production during a filter run, chemical consumption, and filtered water quality.); and 3) provide data demonstrating repeatability and dependability of the treatment process over time.

A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

Table 1. Generic Schedule for Verification Testing		
Test Period	Initial Operations, Estimated Time	Verification Testing, Required Time
1 (required)	1 – 6 weeks	320 hours
2 (optional)	1 – 3 weeks	320 hours
3 (optional)	1 – 3 weeks	320 hours
4 (optional)	1 – 3 weeks	320 hours

6.0 DEFINITIONS

Definitions that apply for coagulation and filtration processes and that were given in the Surface Water Treatment Rule, as published in the *Federal Register* on June 29, 1989, are:

6.1 Coagulation: A process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

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

6.3 Direct filtration: A series of processes including coagulation and filtration but excluding sedimentation resulting in substantial particulate removal.

6.4 Filtration: A process for removing particulate matter from water by passage through porous media.

6.5 Flocculation: 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.

6.6 Sedimentation: A process for removal of solids before filtration by gravity or separation.

Other definitions not included in the Surface Water Treatment Rule include:

6.7 Dissolved air flotation: A process in which coagulated, flocculated water is introduced into the bottom of a chamber, along with recycled water containing microscopic air bubbles. The bubbles rise to the water surface, carrying the floc up, while the clarified water leaves the chamber near the bottom.

6.8 Contact clarification: A process in which coagulated water is applied to a bed of coarse granular media. Flow may be downward from the top of the media bed to the bottom, or upward from the bottom of the media bed to the top. The bed of coarse media acts both as a flocculator by causing the division and recombination of flow streams of coagulated water, and as a clarifier, by trapping and removing some of the floc that forms as water flows through the bed. The coarse granular media may consist of natural mineral material or man-made materials such as plastic.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested.

7.3 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Water Temperature, pH, Turbidity, and Color
- Total Alkalinity, Calcium Hardness, Iron, and Manganese
- Total Coliform, *Bacillus* spores, and Algae
- Data on Aluminum, Total Nitrogen, Total Phosphorus, and Free Ammonia would be informative if such data are available

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a coagulation and filtration Verification Testing program.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment for the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures will be carried out during the initial test runs.

8.2 Objectives

The objective of these test runs is to determine the proper chemical pretreatment scheme for treatment of the feedwater during Verification Testing. The chemical pretreatment requirements may be different for feedwaters from different test sites or for the feedwater from the same site during testing periods when water quality has changed from the quality encountered during an earlier testing period. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Conducting jar tests often is a cost effective means of developing data on coagulant chemical dosages and pH that give effective coagulation. Use of jar tests is recommended before filtration testing is begun. The American Water Works Association's Manual M37, "Operational Control of Coagulation and Filtration Processes," contains a chapter that describes procedures for using jar tests to optimize coagulation. Exploration of use of both alum and iron as inorganic coagulants may be appropriate. Evaluation of the effect of polymers on coagulation, flocculation, and sedimentation could also be done in jar testing.

After jar tests have identified effective conditions for coagulation, several test runs may be needed to further refine appropriate chemical pretreatment conditions. If use of filter aid polymers is contemplated, they should be evaluated in filter runs rather than in jar tests, because jar tests cannot be used to demonstrate the increase of head loss during a filter run. At the end of these tests, an effective chemical pretreatment scheme should have been defined. During initial operations the filters should be operated for a period of 24 hours, or for filter run times as long as those anticipated during Verification Testing.

Filters will be operated until either terminal headloss is reached or effluent turbidity increases above 0.5 NTU or a value set by the Manufacturer.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the

schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the NSF will be conducting an initial on-site inspection of field operations, sampling activities, and on-site sample analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

Examples of performance objectives that might be included in the statement of performance objectives are presented in Table 2.

Table 2. Examples of Filtration Performance Objectives

Characteristic	Definition	Criteria
Initial Turbidity	Filtered turbidity at 15 minutes into run	0.5 NTU or less
Length of Initial Improvement Period	Time to reach 0.2 NTU	0.5 hour or less.
Length of Initial Improvement Period	Time to reach 0.1 NTU	1.0 hour or less.
Operating Turbidity	Turbidity from matured filter	0.10 NTU or less.
All Turbidity Data	All data taken at equal, periodic time intervals from beginning to end of run	0.5 NTU or less in 95% of all turbidity samples analyzed or in all data from continuous turbidimeter at periodic time intervals
Time to Reach Turbidity Breakthrough	Time to reach turbidity over 0.20 NTU	8 hours minimum.
Time to Reach Terminal Head loss	Time to reach 5 ft increase in head loss	8 hours minimum.
Water Production	Volume of water filtered during a run	5000 gallons per square foot of filter area.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment employing coagulation and filtration shall be operated for Verification Testing purposes, with the approach to coagulation based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to meet the water quality goals and any other performance characteristics specified by the Manufacturer in the statement of performance objectives.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. One or more Verification Testing periods, each lasting for a minimum of 320 hours (13 full days plus one 8-hour shift), are anticipated for evaluating the performance of a treatment system. Verification Testing should be conducted to treat feed water having a range of quality consistent with the Manufacturer's statement of performance capability for the equipment. Testing of cold water having high turbidity and cold water having low turbidity is recommended. During each testing period, Tasks 1 through 5 shall be conducted simultaneously.

Operation under a wide variety of water quality conditions is recommended because of the differences in water quality that occur over time in many source waters. For coagulation and filtration treatment equipment, factors that can influence treatment performance include:

- cold water, encountered in winter or at high altitudes in mountainous regions of the country
- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis, such as in summer or fall
- natural organic matter, which may be higher in some waters in the fall
- pH, alkalinity, and hardness, which may vary over time

Among the above-listed factors that can influence coagulation and filtration performance, those that may be most commonly encountered are cold water with high turbidity and cold water with low turbidity. Coagulation and flocculation of water at temperatures of 5°C or lower seems to be especially difficult. It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the recommendation for testing during different times of the year or at different locations.

A minimum of three complete filter runs, ended either by turbidity breakthrough or by attaining terminal head loss, shall be performed, even if the time required for testing exceeds the minimum specified time stipulated in this section. If three complete filter runs are attained in less that the minimum time, filter operation must continue until the minimum time for Verification Testing has been fulfilled.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the SDWA primacy agency shall also be supplied to the NSF-qualified Testing Organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of 320 hours with interruptions in filtration as needed for backwashing of the filters or for other necessary equipment operations. Coagulation and filtration treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained, at which time the filter shall be washed and operation shall resume. Filter runs shall not be stopped before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption, because data on complete filter runs are needed to fulfill the objectives of Verification Testing. The duration of each filter run and the number of gallons of water produced per square foot of filter area shall be recorded in the operational results.

During routine equipment operation, the water treatment equipment should be operated in a manner appropriate for the needs of the water system.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 320 hour period, including time for filter washing and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 320 hours or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feedwater and filtered water as shown in Table 3, during Verification Testing. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the Field Testing Organization. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 3. The actual

water quality parameters selected for testing shall be stipulated in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives.

Table 3. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Frequency:
Temperature	Daily
pH	Daily
Total alkalinity	Daily
Hardness	Weekly
Total organic carbon	Weekly
UV_{254} absorbance	Weekly
Turbidity	Feed water turbidity collected at least once per 4 hours with grab samples, or continuous monitoring. Filtered water turbidity continuous monitoring. Daily at bench to check continuous turbidimeters
Particle Counts	Feed water particle counts collected at least once per 4 hours with grab samples, or continuous monitoring. Filtered water particle counts continuous monitoring.
Aluminum	Weekly if aluminum salt coagulant used
Iron	Weekly
Manganese	Weekly if present in concentration of 0.05 mg/L or greater
Algae, number and species	Weekly if no algae bloom Daily if algae bloom occurs
True color	Weekly
The schedule for collection of microbiological samples and for additional particle counting is presented in Task 4.	

10.3 Work Plan

The Field Testing Organization will be responsible for establishing the equipment operating parameters, on the basis of the Initial Operations testing. The filter shall be operated continuously until terminal headloss is attained, at which time it shall be backwashed.

Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Testing Organization (refer to Table 4). Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for coagulation and filtration treatment equipment, the feedwater (raw water) quality, filtered water quality, (and if applicable, the clarified water quality) shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (daily)
- total alkalinity (daily)
- hardness (weekly)
- total organic carbon (weekly)
- UV_{254} absorbance (weekly)
- turbidity (daily at bench to check continuous turbidimeters)
- aluminum (weekly if an aluminum salt coagulant is used)
- iron (weekly)
- manganese (weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly)
- true color (weekly)
- feed water turbidity and particle counts (at least once per 4 hours with grab samples, or continuous monitoring)
- filtered water turbidity and particle counts (continuous)

Table 4. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Reference Method	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total Alkalinity	Lab	2320 B	
Total Harness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
UV254 Absorbance	Lab	5910	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle Counts (electronic)	On-Site	Manufacturer	
Aluminum	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
True Color	On-Site	2120 B (Hach Company modification of SM 2120 measured in spectrophotometer at 455 nm)	
Total Coliform	Lab	9221 / 9222 / 9223	
E. Coli	Lab	9221 / 9222 / 9223 (Colilert)	
Micrococcus l.	Lab	AWWARF Surrogate Report by CSU	
Bacillus spores	Lab	Rice et al. 1996	
MS2 virus	Lab		EPA ICR Method for Coliphage Assay, 1996
Algae	Lab	AWWARF Surrogate Report by CSU	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	EPA 1622, EPA 1623

Notes:
1) *Standard Methods* Source: 20th Edition of *Standard Methods* for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Turbidity and particle counts in feed water samples may be measured on a batch or a continuous basis. If batch measurements are made, they shall be made at regular time intervals of four hours or less on each working day during Verification Testing. Filtered water analysis shall be done using continuous flow turbidimeters and flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and the quality of the filtered water. These data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to meeting the water quality objectives indicated by the Manufacturer.

Turbidity results shall be analyzed to determine the percentage of turbidity data in the range of 0.10 NTU or lower, the percentage in the range from 0.11 NTU up to 0.20 NTU, the percentage in the range from 0.21 NTU up to 0.34 NTU, the percentage from 0.35 NTU up to 0.54 NTU, and the percentage that were 0.55 NTU or greater. The percentage of filtered water turbidity results that exceed 1.0 NTU shall also be noted. In addition the frequency of occurrence in which the filter was placed into service after backwashing and subsequently produced filtered water turbidity exceeding 0.5 NTU after a four hour ripening period (i.e. the turbidity did not fall to below 0.5 NTU within four hours of starting the filter) shall be noted. The time intervals used for determining turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be between 5 and 15 minutes.

Particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and the 95th percentile log removal during that verification testing period. Uniform time intervals of between 1 hour and 4 hours shall be used to evaluate particle counting data for calculating log reduction of particles in all filter runs. Additional data analysis requirements for particle counting are given in Task 5.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of pretreatment chemistry for coagulation and of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain, frequency and duration of filter washing, and need for cleaning of pretreatment clarifiers.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

During each day of Verification Testing, treatment equipment operating parameters for both pretreatment and filtration will be monitored and recorded on a routine basis. This shall include a complete description of pretreatment chemistry; mixing and flocculation intensities, if applicable; operating parameters for clarification ahead of filtration; rate of flow; and filtration rate. Data on filter head loss and backwashing shall be collected. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on chemical dosages needed and on energy needed for operation of the process train being tested. Data shall be developed on the physical and chemical character of wastes or residues produced such as backwash water and sedimentation basin sludge. Data shall also be developed on the rates of waste production, expressed in terms of quantity of waste produced per thousand gallons of water filtered.

A complete description of each process shall be given, with data on volume and detention time of each process basin at rated flow. Data on the filter shall be provided and shall include the depth, effective size, and uniformity coefficient of each layer of filtering material and support material. The type of material used in each layer of filtering material and support material shall be stated. The location of each point for chemical or polymer addition shall be documented. System reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated.

11.4 Schedule

Table 5 presents the schedule for observing and recording coagulation and filtration equipment operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

Table 5. Equipment Operating Data	
Operating Data	Action
Chemicals Used	Record name of chemical, supplier, commercial strength, dilution used for stock solution to be fed (if diluted) for every chemical fed during treatment.
Chemical Feed Volume and Dosage	Check and record each 2 hours. Refill as needed and note volumes and times of refill.
RPM of Rapid Mix and Flocculator	Check once/day and record.
Feedwater Flow and Filter Flow	Check and record each two hours, adjust when >10% above or below goal. Record both before and after adjustment.
Filter Head Loss	Record initial clean bed total head loss at start of filter run and record total head loss each two hours.
Filtered Water Production	Record gallons of water produced per square foot of filter area, for each filter run. [This figure is the product of filtration rate (gpm/sf) and length of filter run in minutes for a filter run performed at constant rate.]
Filter Backwash	Record time and duration of each filter washing. Record water volume used to wash filter.
Clarifier/flocculator or other similar process ahead of filter	If clarifier/flocculator is backwashed separately from backwashing of filter, record the time of every backwash for this process, and volume of water used.
DAF scum removal	Record frequency of scum removal action each day.
DAF recycle flow	Record recycle water flow rate each 8 hours.
DAF saturator pressure	Record DAF saturator vessel pressure each 8 hours.
Electric Power	Record meter reading once per day
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day.
All parameters will be checked only during times when the equipment is staffed.	

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL (OPTIONAL)

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of coagulation and filtration treatment processes for microbial removal will be evaluated in this task. In this task, assessment of treatment efficacy will be made on the basis of removal of one or more microorganisms and on the basis of particle counting.

12.2 Experimental Objectives

The objective of this task is to evaluate removal of microbiological contaminants during Verification Testing by measuring the concentration of particles in feed water and filtered water or the density of microorganisms naturally present in the feed water and filtered water or by seeding the feed water with algae, bacteria, MS2 coliphage, or protozoa, or with a combination of those types of microorganisms, measuring the organism densities in the feed water and filtered water, and calculating the removal.

12.3 Work Plan

Task 4 shall be carried out during the Verification Testing runs being conducted in Task 1. The treatment equipment shall be operated using the chemical pretreatment conditions that provide effective clarification (if used) and filtration.

Microbiological testing may be performed by seeding one or more of the kinds of organisms listed in Table 7 into the feed water or by testing for ambient organisms in the feed water, and by analyzing for the organisms in question in the filtered water.

A minimum of three test runs shall be conducted to provide verifiable microorganism removal data that can be analyzed statistically as described in Task 5 of this Test Plan. Samples shall be collected from the feed water, clarifier (if used) effluent, and the filter effluent to determine microorganism removal through the system.

12.3.1 Bacteria Naturally Present

If sufficient numbers of bacteria are naturally present in the feed water so that 3-log removal can be calculated without seeding bacteria, treatment equipment shall be operated as usual in Verification Testing runs, and sampling shall be done as stipulated in the Analytical Schedule.

12.3.2 Seeded Microorganisms

Seeded organisms shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

For the protozoa challenges, sampling procedures and *Giardia* and *Cryptosporidium* enumeration procedures outlined in EPA Method 1622 or 1623 shall be employed.

For virus (coliphage) challenges water samples of at least 100 mL volume will be collected. Virus (coliphage) samples shall be shipped to a state-certified or third party- or EPA-accredited laboratory for analysis.

For testing in which algae are used as surrogate organisms, the sampling, preservation, and analytical procedures used in the CSU research (see AWWARF report) shall be used.

12.3.3 Organisms Employed for Challenge Tests

Table 6 presents the different microorganisms that may be used for microbial removal studies. These organisms represent a wide variety of types and sizes of microorganisms. Two algae, three bacteria, two protozoan cysts, and one virus are identified for use. Testing may be done with the microorganisms of interest or with surrogates. If surrogates are employed, particle counting and one or more surrogate organisms should be employed as surrogates, i.e., use multiple surrogates.

Table 6. Microorganisms and Surrogates for Coagulation and Filtration Testing

Microorganism	Surrogate (based on research results)	Source
Cryptosporidium parvum oocysts	*Giardia lamblia* cysts	seeded
	Chodatella quadriseta algae*	seeded
	Bacillus bacteria	ambient water or seeded
	E. coli bacteria	seeded
	MS2 coliphage	seeded
Giardia cysts	*Stichococcus subtilis* algae*	seeded
	Bacillus bacteria*	ambient water
	E. coli bacteria	seeded
	*Micrococcus l.** bacteria	seeded
	MS2 coliphage	seeded
Human Enteroviruses	MS2 coliphage	seeded

*recommended as surrogate in draft CSU report to AWWARF

Challenge testing with *Cryptosporidium parvum* or *Giardia lamblia*, or both, can be carried out, as numerous studies, including some cited in the list of references, have shown. The very high cost of testing with *Cryptosporidium* and *Giardia* makes this an unattractive and probably unaffordable option for verification of equipment performance. If studies are carried out with these organisms, it may not be possible in many cases to employ viable protozoan cysts and oocysts for seeding studies, depending upon where the equipment verification is being performed. In such a case, organisms fixed in no more than 5% formalin may be used.

MS2 bacterial virus was identified for use as the model virus for the optional virus challenge studies. MS2 virus is the virus of choice for challenge studies because it is similar in size (0.025 μm), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. This bacterial virus is the suggested organism to use in the SWTR Guidance Manual when conducting studies of microbial removal (USEPA, 1989). Furthermore, results from research at CSU (Table 6) suggests that MS2 removal results generally understate protozoan removal results, so it is considered a suitable surrogate for *Giardia* and *Cryptosporidium* as well.

Research conducted at Colorado State University developed data indicating that algae could be used as surrogates for protozoan cysts and oocysts. Algae must be cultured and identified by optical microscope. The analytical technique is, however, much less complicated than protozoan analysis. *Chodatella quadriseta*, an oval organism about 3 x 5 μm in size (Cushen et al., 1996) can be used as a surrogate for *Cryptosporidium*. *Stichococcus subtilis*, a rod-shaped organism about 3 x 7 μm in size (Cushen et al., 1996) can be used as a surrogate for *Giardia*. Details regarding procedures for growing and harvesting algae cells for use as surrogates in filtration testing will be found in the AWWA Research Foundation's report on the project "Biological Particle Surrogates for Filtration Performance Evaluation." (in press)

Bacteria can be used as surrogates for protozoan cysts and oocysts. Previous research at CSU (Al-Ani et al., 1986) identified total coliform bacteria as a potential surrogate for *Giardia* cysts. The recent work at CSU indicates that *Bacillus* bacteria can be used as a surrogate for *Giardia*, as can *Micrococcus l.* *Bacillus* has been evaluated as a surrogate for coagulation and filtration testing by Rice et al. (1996), who stated, "Monitoring for indigenous spores of aerobic sporeforming bacteria represents a viable method for determining treatment plant performance. Comparison of spore levels in source water and filter effluents provides an indication of biological particle removal efficiency." Rice et al. evaluated both naturally occurring *Bacillus* bacteria and cultured *Bacillus subtilis* spores purchased from a commercial laboratory. Analysis of the CSU data developed for AWWARF also indicates that *E. coli* could be a useful surrogate for protozoan cysts and oocysts. This finding could be anticipated from the work of Al-Ani et al., as *E. coli* is a part of the total coliform group.

12.4 Analytical Schedule

This schedule applies to the test runs (minimum of three) in which microbiological sampling and analysis are undertaken.

Turbidity and particle counts in feed water and filtered water shall be measured in conjunction with microbiological sampling in this task. This is in addition to turbidity and particle count analysis undertaken on a routine basis in Task 2.

Microbiological samples shall be collected from the plant influent (feed water after seeding, if organisms are seeded for challenge studies), clarifier effluent if a clarification step is employed ahead of filtration, and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the pretreatment process up to the filter. For microbiological sampling purposes, the time of operation when 3 pretreatment detention times have elapsed shall be considered time zero. Microbiological samples shall be collected at time zero and at 1, 3, and 6 hours past time zero (or samples shall be collected at a minimum of zero and one-half hour, 1, and 2 hours past time zero). Thereafter microbiological samples shall be collected once every 6 hours until the end of the filter run. In each of the filter runs

conducted to provide verifiable microorganism removal data (a minimum of three runs), one set of microbiological samples shall be collected after the filter has developed approximately 90 percent of terminal head loss, based on experience of prior runs. In addition, if a turbidity breakthrough episode occurs in the filter run, a set of microbiological samples shall be collected during the turbidity breakthrough episode. For purposes of Verification Testing for coagulation and filtration treatment equipment, turbidity breakthrough is defined as a circumstance in which turbidity rises to 0.5 NTU or higher. During each sampling event, four 1-liter samples (for organisms other than protozoa) will be collected. Whenever grab samples are collected for microorganisms, grab samples shall also be collected for turbidity. Particle counting data shall be obtained at the time of sample collection for microorganisms and turbidity and shall be treated (for purposes of statistical analysis described in Task 5) as if those particle counting data were grab sample data. The exact time of sampling will be recorded for each set of grab samples collected so the statistical analysis of grab sample data and particle counting data can be coordinated.

The Testing Organization shall then submit collected water samples to a state-certified or third party- or EPA-accredited laboratory for microbial testing.

12.5 Evaluation Criteria

When microbiological testing is conducted with protozoan cysts or oocysts or with surrogate microorganisms, the microbiological results will be compared to the Manufacturer's statement of performance objectives. Turbidity and particle counting data shall be evaluated as previously described in Task 2.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording of operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

13.3 Work Plan

13.3.1 Data Handling

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters

should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." Statistical analysis could be carried out for a large variety of testing conditions. For example, situations such as all test run data for optimized coagulation with a specified coagulant chemical and at a specified rate of flow for the treatment plant equipment, would provide a data base for which statistical analysis might

be appropriate. Two conditions that are specifically required to be analyzed statistically are:

- for runs involving microbiological sampling, all grab sample test data after the initial improvement period (filter ripening) and before turbidity breakthrough, analyzed separately for each filter run, to show the extent of performance variability during optimum operating conditions of each run, and;
- for runs involving microbiological sampling, all grab sample test data collected from the start of the run through the completion of the run, analyzed separately for each filter run, to show the extent of performance variability during each complete filter run.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in water quality variations for entire filter runs versus the quality produced during the optimized portions of the runs would be useful in evaluating appropriate procedures for starting and terminating filter runs.

14.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

14.1 Introduction

Quality assurance and quality control of the operation of the water treatment equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. Particular care will be taken to confirm that any chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications:

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- In-line turbidimeters flow rates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model

- Batch and in-line particle counters flow rates (verified volumetrically over a specific time period).

14.5 QA/QC Verifications Performed Every Two Weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications for Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+ or EPA Methods 150.1/150.2. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1^{o}C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1^o increments, would be appropriate for this work.)

14.7.3 Color

True color shall be measured with a spectrophotometer at 455 nm, using an adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass

bottles and analyzed as soon after collection as possible. If samples can not be analyzed immediately they shall be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

14.7.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be sued for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any subsequent modifications or enhancements made to monitoring instruments.

14.7.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples dial cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.4.2 In-line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate

readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.5 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.5.1 Bench-top Particle Counters. All particle counting shall be performed on site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated commercially-available particle standards or methods. This calibration should be verified at the beginning of each Verification Testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV testing, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will

also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by a triple PFW rinse. Sample beakers will then be stored inverted. Dedicated beakers will be used at all times for unfiltered water (raw, pre-oxidized, flocculated), diluted unfiltered water, filtered water, and PFW. When several samples are collected from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection. Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water. When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\ Particle\ Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

where MP is the measured particle concentration in the diluted sample, PF is the measured particle concentration in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04.The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.5.2 In-line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall verify the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.8.2 Microbial Parameters: Total Coliform, Viruses, Bacteria, Protozoa, and Algae

Samples for analysis of Total Coliforms (TC) shall be collected in bottles supplied by the

state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL.

Other microbiological samples shall be refrigerated at approximately 4°C immediately upon collection. Such samples shall be shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, aluminum, iron and manganese, shall be collected and preserved in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C. Samples shall be processed for analysis by a state-certified or third-party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for equipment employing coagulation and filtration.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- chemical feeders
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- filter vessels

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments -- how they should be made
- dilution of chemicals and polymers -- proper procedures

Mixers and flocculators:

- purpose
- changing intensity (RPM), if available

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter washing:

- end of filter run
- use of auxiliary water scour (surface wash) or air scour
- start of backwash
- appropriate backwash rates
- conclusion of filter washing
- return of filter to service

Monitoring and observing operation:

- observation of floc
- pretreated water turbidity, if appropriate
- filtered water turbidity
- filter head loss
- what to do if turbidity breakthrough occurs

Coagulant dose selection:
Strongly recommend that Manufacturer include a copy of AWWA Manual M37, "Operational Control of Coagulation and Filtration Processes" with each coagulation and filtration system, as an AWWA committee of experts has prepared an excellent manual that would be very helpful to plant operators.

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feed water) flow to plant
- poor raw water quality (raw water quality falls outside the performance range of the

equipment)

- can't control rate of flow of water through equipment
- no chemical feed
- mixer or flocculator will not operate (won't rotate)
- filter can't be backwashed or backwash rate of flow can't change
- no reading on turbidimeter or streaming current monitor
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- filter head loss builds up excessively rapidly
- no head loss readings
- valve stuck or won't operate
- no electric power

It is also recommended that the Manufacturer add a toll free number to the O&M manual for technical assistance on operation and maintenance of the equipment.

The following are recommendations regarding operability aspects of equipment employing coagulation and filtration. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- fluctuation of chemical feed rate from desired value -- the time interval at which re-setting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with chemical dosage selection:
- streaming current monitor provided?
- influent and filtered water continuous turbidimeters provided?
- pilot filter provided?
- can backwash be done automatically?
- if automatic backwash provided, could it be initiated by:
- reaching a set value for head loss?
- reaching a set value for filtered water turbidity?
- does remote notification to operator occur when backwash happens?
- can operator observe filter backwash?
- how can plant operator check on condition and depth of filter media?
- can flocculation energy be varied?
- does plant have multiple feed points for chemicals:
- for pH adjustment?
- for coagulant chemical feed?
- for polymer feed?
- is head loss measurement provided?
- is rate of flow of raw water measured?
- is chemical feed paced with raw water flow?
- is backwash rate of flow measured and variable?
- is backwash duration (time) variable?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Operating Conditions and Treatment Equipment Performance, in the Coagulation and Filtration Test Plan.

16.0 REFERENCES

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APPENDIX 3A

OPTIONAL EXTRA TASK FOR EVALUATING REDUCTION OF TRIHALOMETHANE FORMATION POTENTIAL BY COAGULATION AND FILTRATION

Introduction

Coagulation and filtration processes have been shown to be capable of reducing the organic precursor materials that form trihalomethanes (THMs) and haloacetic acids (HAAs) in a wide variety of waters. Each feed water may be somewhat different from other feed waters, but evaluation of the capability for removal of DBP precursor at sites where coagulation and filtration testing is done for control of particulate and microbiological contaminants could be advantageous in terms of obtaining data related to other water quality concerns at a relatively nominal cost.

Objective

This optional task, if carried out, is done to assess removal of organic materials that can form DBPs upon chlorination. Removal of DBP precursors is variable, depending on the nature of the organics in the source water or feed water. Data on DBP precursor removal shall be obtained by evaluating THM precursor removal and by evaluating HAA precursor removal.

Work Plan

During the verification testing runs in coagulation and filtration testing, water samples shall be collected and THM formation potential and HAA formation potential testing of both feed water and filtered water shall be performed. NOTE: This task shall not be undertaken if a disinfectant other than ozone is used prior to filtration. Samples collected for evaluation of DBP precursor removal shall be set up according to Method 5710B, Trihalomethane Formation Potential, in *Standard Methods*. The incubation conditions and other requirements of Method 5701B shall be followed without deviation. Unless the NSF-qualified testing organization has laboratory capabilities for doing this work, these samples should be collected and shipped in suitably prepared glass bottles to an analytical laboratory where sample set-up and incubation and THM analysis HAA analysis can be performed.

Water treatment practice can influence removal of DBP precursor. Treatment plant operating data that shall be collected in conjunction with sampling for DBP formation potential determination include:

- pH of coagulated water
- alkalinity of feed water and filtered water
- type of coagulant chemical used, and dosage
- temperature during treatment
- TOC of feed water and filtered water

Analytical Schedule

During each verification testing period, on four different days on which verification testing runs are being carried out, one sample of feed water and one sample of filtered water shall be obtained and set up for THM and HAA formation potential, or shall be shipped to a state-certified or third party- or EPA-accredited laboratory for set-up. At the end of the specified incubation time, the samples shall

be analyzed for THMs and HAAs.

Evaluation Criteria

The concentrations of DBPs that form in water distribution systems (where regulatory compliance samples must be obtained by water systems) are influenced by many factors beyond the control of the treatment plant operator and the coagulation and filtration process. Therefore data analysis shall consist only of calculation of the mean reduction of THM formation potential and HAA formation potential by coagulation and filtration for each period of testing. No minimum percentage of reduction is specified for comparison purposes. The report shall simply state the extent to which THM formation potential could be reduced by coagulation and filtration, along with the coagulant chemical, dosage used, and pH of coagulation when the test results were obtained. The report shall also state the extent to which HAA formation potential could be reduced under the same conditions of coagulant chemical type, dosage used, and coagulation pH for which THM formation potential reduction was reported.

APPENDIX 3B

USE OF SURROGATES FOR ESTIMATING MICROORGANISM REMOVAL IN COAGULATION AND FILTRATION TESTING

Microorganism Removal -- Direct Evaluation versus Surrogates

Evaluation of coagulation and filtration treatment processes for microbiological contaminant removal can be done directly by measurement of microorganisms of concern in the feed water and in the filtered water. This approach provides a direct assessment of the removal capability of a water treatment process train, but its use is limited to natural waters (feed waters) having sufficiently high densities of microorganisms that comparison of feed water and filtered water densities can be used to calculate percentage reductions or log removals. It is desirable to have sufficient numbers of organisms in feed water such that if no organisms are detected in filtered water, 3-log or 4-log removal (99.9% or 99.99% removal) could be calculated. Many natural waters do not have the high densities of protozoan organisms necessary to show the true removal capability of treatment processes. It is of little value to be able to state that based on the numbers of organisms found in feed water and with none found in filtered water, the removal exceeded 90% when in fact if sufficient numbers of organisms had been present removal might have exceeded 99% or 99.9%.

One approach to evaluating removal of viruses or protozoa would be to measure feed water and filtered water organism densities at existing treatment plants using equipment, providing the feed water had sufficiently high numbers of viruses or protozoa. This approach would also require that no disinfectant was applied to the water before filtration, so that the entire reduction of microorganisms could be attributed to physical removal. An existing treatment plant that provided drinking water to a community would not be an appropriate facility for spiking or seeding viruses or protozoa, because of public health concerns.

A different approach might be taken at a water treatment facility that had been installed solely for verification of performance capability. At an installation where no drinking water is produced, seeding viruses or protozoa into feed water might be feasible, depending on the feed water flow, the desired density of organisms in the feed water, and the cost of this undertaking.

Another technique for assessing the potential for removal of microorganisms is through the use of surrogates in place of viruses and protozoa. Analyzing water samples for human enteric viruses, *Cryptosporidium* oocysts, and *Giardia* cysts is complex and expensive. In the case of *Cryptosporidium*, the analytical method is acknowledged to have many uncertainties, including poor recovery of oocysts from the water that was sampled. As a result of the uncertainties associated with analytical data for human enteroviruses and protozoa, use of less-expensive surrogate measurements may reveal as much as or more than measuring the microorganisms of actual concern.

A number of surrogate indicators of filtration performance for coagulation and filtration treatment trains have been used by researchers. The simplest is turbidity, which does not involve analysis for any microorganisms. Somewhat more complicated, but still avoiding microbiological analysis, is use of particle counting, either by using electronic particle counters or by counting a particular type of particle that was seeded into the feed water. Use of biological surrogates involves analysis for natural organisms or seeded organisms that are simpler and easier to detect than the protozoa and viruses. Each of the surrogate techniques mentioned above is described in the paragraphs below.

Use of multiple surrogates is recommended to compensate for the problem that no surrogate perfectly reproduces the behavior of the protozoan organisms. Even though particle counting is conservative with regard to removal of microorganisms, use of particle counting is a recommended technique because particle counters can be operated continuously to permit detailed observation of filtered water quality and temporary, short-term changes in that quality. Use of one or more microorganisms as a surrogate is also recommended to ascertain a better estimate of actual biological particle removal than can be determined by particle counting.

Turbidity as a Surrogate

Relationships between turbidity removal and microorganism removal have been noted by some investigators but not others. Hibler and Hancock (1990) reported on a data base of 20 conventional treatment plants in which turbidity reductions of about 85% or greater resulted in *Giardia* cyst reductions exceeding 90% in 18 of the 20 plants, but they did not provide information on the filtered water turbidity. In an extensive filtration research project, turbidity removal did not correlate well with removal of *Giardia* or *Cryptosporidium*, because turbidity was removed to a much lesser extent than those microorganisms (Patania et al. (1995). Al-Ani et al. (1986) combined the concepts of turbidity removal and filtered water turbidity, reporting, "...if turbidity removal exceeded 70 percent and if filtered water turbidity was lower than 0.10 NTU, the probability was 0.85 (37/44) that the removal of *Giardia* cysts would equal or exceed 99 percent. The work of Al-Ani et al. was done with feed water having turbidity of 1 NTU or less.

The association of low filtered water turbidity with high removal of various microorganisms and particles has been made for over three decades by various researchers who have studied coagulation and filtration. Turbidity measurement is based upon scattered light, and it is not a direct measure of particles in water, nor can it give any information on particle size; nevertheless, general relationships for filtered water turbidity and filter performance have been developed over the past three or four decades. Robeck et al. (1962) studied removal of seeded poliovirus and found the best removals (greater than 99.7% for conventional treatment) were associated with turbidities around 0.1 turbidity unit. DeWalle et al. (1984) at the University of Washington found that attaining low filtered water turbidity (about 0.1 NTU) was related to removal of 97% to 99.9% of *Giardia* cysts. Logsdon and Symons (1977) reported that removal of amphibole asbestos fibers, which were larger than viruses but smaller than bacteria, was better when filtered water turbidity was less than 0.2 NTU than when the turbidity was above that value. Patania et al. (1995) attained a median removal of 4.2 log (slightly over 99.99%) for both *Giardia* and *Cryptosporidium* in 105 observations of raw and filtered water samples. Filtered water samples having turbidity between 0.1 and 0.3 NTU, as compared to those with turbidity less than 0.1, were associated with lower removals of organisms, by as much as 1.0 log. Although concentrations of microorganisms in coagulated and filtered water can not be predicted based upon filtered water turbidity, attaining filtered water turbidity of 0.1 NTU or lower has been associated with very effective removal of viruses and protozoan cysts. The same concept held for very small inorganic particles (asbestos fibers) counted by an electron microscope. Attaining very low filtered water turbidity thus is an effective indicator of attaining very good removal of microbes or small particles.

Particle Counting as a Surrogate

Use of particle counting as a surrogate for removal of microorganisms was proposed in EPA's Surface Water Treatment Rule Guidance Manual. Electronic particle counters are much more sensitive to changes in water quality than turbidimeters, and they have the additional advantage of

being able to provide data on sizes of particles in water, which turbidimeters can not do. Particle counters also are able to detect water quality changes in low turbidity waters for which turbidimeters have approached or reached the detection limit for low turbidity. In the turbidity range of 0.02 to 0.10 NTU the magnitude of turbidity variation is much less than the magnitude of particle counts that could be detected.

Users need to be aware of the limitations of particle counting, however. A coagulated and filtered water having between 1 and 10 particles/mL (1000 to 10,000 particles/L) would be considered to have a low particle count. In contrast, the EPA has suggested that one option for controlling *Cryptosporidium* might be to require up to 6-log reduction for raw waters containing more than 100 oocysts/100 L (1 oocyst/L). Based on the performance capability of coagulation and filtration, the use of particle counting to indicate directly that *Giardia* and *Cryptosporidium* are not present in finished waters at concentrations that could cause problems appears to be impossible at present.

A second difficulty with use of particle counting as a surrogate is that all particle counters have some lower size limit for particles, and below that limit particles in water are not counted. Particles in feed water that are too small to be counted before coagulation can be agglomerated together after coagulation and then may form particles large enough to be counted. Flocculation can increase the number of large particles by combining many smaller particles. Finally filtration removes particles, but in a granular media filter attached floc and particles can be sloughed off of the media and can flow out of the filter bed during the filtration process. Because of all of these factors it is highly unlikely that the specific particles in the feed water in a specified size range, such as 3 to 6 μm, are also the 3 to 6 μm particles seen in the filtered water. By coagulation and flocculation, many of the 3 to 6 μm particles counted in the feed water would subsequently be flocculated into larger particles, some of which would be removed in filtration and a few of which might pass through the filter. The myriad changes occurring between feed water and filtered water make it difficult to determine the fate of any given particle in the feed water. The possibility for incorporating smaller sized particles into larger ones introduces uncertainty into calculations of log reduction of particles, particularly in the smaller size ranges. Smaller particles that apparently were removed as indicated by reductions in their concentration in fact may have been incorporated into larger particles that passed through the filter and were counted.

Patania et al. (1995) conducted a very large study of coagulation and filtration for *Giardia* and *Cryptosporidium* removal, and included particle counting in filtration testing. They reported, "Removal of particles in size ranges of 1-2, 2-5, 5-15, and 1-25 μm did not correlate well with removal of either *Cryptosporidium* or *Giardia*. Further, a one-to-one relationship between particle removal and *Cryptosporidium* or *Giardia* removal was not observed, with particle removal consistently lower than organism removal. Use of particle removal as a surrogate for cyst (and oocyst) removal, as is presently recommended in the SWTR Guidance Manual (USEPA 1989), can therefore considerably underestimate cyst and oocyst removal under some conditions, such as the relatively high organism concentrations and relatively low turbidity and particle concentrations occurring in this study." In an attempt to determine the upper limits for filtration performance, very high numbers of cysts and oocysts were seeded into the natural waters used in the Patania et al. pilot study conducted with four different source waters in California, Oregon, and Washington.

Particle counting was also undertaken in a study at Colorado State University sponsored by the AWWA Research Foundation (Hendricks et al., 1996). An analysis of the CSU data was done as a part of the NSF project for Verification Testing. This analysis is presented later in the section on microbiological surrogates, where comparisons are made between particle removal and microbe

removal.

The results of testing by Patania et al. and by Hendricks et al. suggest that straightforward comparisons of *Giardia* or *Cryptosporidium* removal and particle removal can not be made because the reduction of the protozoan organisms often is considerably greater than the reduction of particles.

In spite of the drawbacks, particle counting offers much more information about filtration performance than turbidity measurement, and so it has become a favored means of filter evaluation among many in the field.

Microbiological Surrogates

Numerous researchers have used or recommended using microorganisms as surrogates for other microorganisms in water treatment. Examples include use of *G. muris* as a surrogate for *G. lamblia* in water filtration studies, use of coliphage MS2 as a surrogate for human enteroviruses, and use of total coliform bacteria as a surrogate for *Giardia* cysts.

Successful use of microorganisms as surrogates requires knowledge of the characteristics of both the target organism and the surrogate. Resistance to disinfectants varies from organism to organism, so use of microbiological surrogates in filtration studies is most appropriate when no disinfectant chemical will be employed until after the filtration process is completed. This eliminates disinfectant resistance as a variable in testing.

Using microorganisms as surrogates has the advantage of working with particles that have negative surface electrical charge (i.e., have negative zeta potential) and have a density close to that of water. According to currently-held theories of how microscopic particles are removed by coagulation and deep bed filtration, both surface charge and density are factors that are related to particle removal. *Giardia* cysts have a density of about 1.05 g/cm^3 (Hibler and Hancock, 1990), and the density of *Cryptosporidium* is similar, because the same gradient centrifugation technique can be used for analysis of both cysts and oocysts. The specific gravity of bacteria is approximately 1 (Gainey and Lord, 1952), and they are 80% water by weight. From the perspective of specific gravity, bacteria and protozoan cysts or oocysts are similar. The zeta potential, or apparent electrical charge close to the surface of particles in water, is negative at neutral pH values for bacteria, protozoan cysts and oocysts, and by inference, for viruses (Cushen, Kugrens, and Hendricks, 1996; Fox and Lytle, 1996). The zeta potential for clay particles and for the great majority of particles found in water is also negative; therefore, using cationic polymers or metal coagulants based on iron or aluminum is the correct approach for lowering or neutralizing the zeta potential of all of the above types of small particles so that they can be agglomerated into larger floc particles or so the small particles will adhere to granular filter media in the filtration process.

Appropriate particle sizes can be selected by using viral surrogates or surrogates in the size range of bacteria or protozoan cysts. Filtration theory and experimental results suggest that 1 μm particles should be more difficult to remove than either larger particles or smaller particles. On this basis, bacteria removal should be as difficult as cyst removal, or more difficult, and bacteria should be a good surrogate for protozoan cysts in coagulation and filtration processes. Studies by Al-Ani et al. (1986) showed that percent removal of total coliform bacteria is a good indicator of percent removal of *Giardia* cysts. In 7 of 52 pairs of samples *Giardia* removal exceeded total coliform removal, ranging from 87 to 93% when total coliform removal was 95% or greater; in 8 of 52 pairs, *Giardia* removal was 96% or greater but total coliform was 80% or lower; and in 36 of 52 samples both

Giardia and total coliform removal were 95% or greater. Thus in only about 14% of the sample pairs was the total coliform removal greater than *Giardia* cyst removal. These results suggest that total coliform bacteria may be a useful surrogate for *Giardia* cysts.

The AWWA Research Foundation funded an evaluation of potential surrogate organisms at Colorado State University (Hendricks et al., 1996). Coagulation and filtration pilot plant tests were undertaken with *Giardia* and *Cryptosporidium* plus a number of algae, bacteria, and coliphages as possible surrogates.

The CSU draft report to AWWARF indicated that log removals of the algae *Chodatella quadriseta* could be used to estimate log removals of *Cryptosporidium* with an adjustment factor of 1.06 applied to the algae log removal. The draft report also noted that log removals of the algae *Stichococcus subtilis* could be used directly to estimate log removals of *Giardia*. Both algae species were reported to be easy to culture and to have a distinct appearance under the microscope when water samples were examined to enumerate the algae in feed water or filtered water.

Bacteria could be used as a surrogate for *Giardia* removal. By applying a factor of 1.19 to the log removal of *Bacillus stearotheromophillus*, the log removal for *Giardia* could be estimated. *Micrococcus l.* could be used directly, without a multiplicative factor, to evaluate *Giardia* removal. The draft report also noted that use of bacteria as surrogates may be more practical than using algae since utilities have to monitor for bacteria, but the algae would have to be cultured.

For coagulation and filtration test runs performed at CSU, in which both *Giardia* and *Cryptosporidium* were seeded, and some or all of three potential surrogates (*Bacillus st.*, *E. coli*, coliphage MS2) were included in testing, data are given in Table B-1. These are actual data or calculated results from the individual test runs, which are identified by date. An analysis of log reduction in total particle count is included as well. All of the comments and opinions expressed in this document that are based on Table B-1 are the result of this work and are not to be considered as conclusions of CSU.

Several preliminary conclusions can be drawn from Table B-1.

- Turbidity of the feed water was low, varying from 1 to 3 NTU.

- Except for the run on October 30, the range of log removals for particle count data was narrow, from 1.79 to 2.85 logs.

- Log removals for *Cryptosporidium* were higher than log removals of *Giardia* in 15 of 18 runs when both were seeded. During optimum treatment *Cryptosporidium* removals ranged from 2.46 log to 4.95 log whereas *Giardia* removals ranged from 2.85 log to 4.55 log.

- During non-optimum treatment with inadequate alum doses (runs of Jan 15 and Feb 5) removals of *Giardia* cysts, *Bacillus*, *E. coli*, and MS2 were lower than during the runs with adequate alum doses. (Unfortunately no particle counting data are available for these runs.) In these runs the 2.6-log removals observed for *Cryptosporidium* were similar to the 2.5-log removals observed during two runs with optimum alum doses. Only in those four runs, however, was *Cryptosporidium* log removal less than 3.0.

- Log removals of *Bacillus* and *E. coli* were similar to log removals for coliphage MS2, even

though MS2 is about 1/50 the size of the bacteria.

Concerning use of microorganisms as surrogates for protozoans, with respect to log removals:

- Removal of *Bacillus* was less than removal of *Cryptosporidium* in 5 of 8 tests. Removal of *Bacillus* exceeded removal of *Cryptosporidium* in 3 of 8 tests, by 0.2, 0.2, and 0.3 log.

- Removal of *Bacillus* was less than removal of *Giardia* in 7 of 8 tests. Removal of *Bacillus* exceeded removal of *Giardia* in 1 test by 0.4 log.

- Removal of *E. coli* was less than removal of *Cryptosporidium* in 7 of 8 tests. Removal of *E. coli* exceeded removal of *Cryptosporidium* in 1 test by 0.1 log.

- Removal of *E. coli* was less than removal of *Giardia* in 6 of 8 tests. Removal of *E. coli* exceeded removal of *Giardia* in 2 tests by 0.1 and 0.2 log.

- Removal of MS2 coliphage was less than removal of *Cryptosporidium* in 8 of 10 tests. Removal of MS2 exceeded removal of *Cryptosporidium* in 2 tests by 0.4 and 0.7 log.

- Removal of MS2 coliphage was less than removal of *Giardia* in 9 of 10 tests. Removal of MS2 exceeded removal of *Giardia* in 1 test by 0.4 log.

Concerning the removal of particles as a surrogate for removal of microorganisms:

- Particle removal was less than *Cryptosporidium* removal in 15 of 16 tests.

  - Particle removal was less than *Giardia* removal in 16 of 16 tests.

- Particle removal was less than *Bacillus* removal in 7 of 8 tests and exceeded *Bacillus* removal in 1 test by 0.6 log.

- Particle removal was less than *E. coli* removal in 5 of 7 tests and exceeded *E. coli* removal in 2 tests by 0.2 log and 0.6 log.

- Particle removal was less than MS2 removal in 10 of 10 tests, with a maximum difference of 1.0 log.

Particle removal tends to underestimate the removal of viruses, bacteria, and protozoa when used to evaluate results of coagulation and filtration. The surrogate evaluation data developed by Colorado State University indicate that using biological surrogates for protozoan removal may provide closer estimates of protozoan removal than particle counting. This may be the result of the changes that particle size distributions undergo as a result of coagulation and flocculation. Although particle counting can be used to evaluate coagulation and filtration process train performance without parallel use of biological surrogates, use of biological surrogates together with particle counting is recommended as a means of diversifying the surrogates for evaluation of treatment. On the basis of the CSU data, use of coliphage MS2 as a surrogate for enteroviruses and as a surrogate for protozoan removal is appropriate. This organism could be used in seeding studies. In seeding studies, use of *E. coli* in settled domestic sewage could be considered, but this should not be done at a drinking water treatment plant. In circumstances where a treatment system is being used to treat drinking water for

a small water system, if chlorination is not practiced until after filtration, and if the feed water has sufficient numbers of *Bacillus* bacteria, use of *Bacillus* as a surrogate to supplement particle counting is recommended.

Table B-1. AWWARF Surrogate Removal Pilot Plant Data
Coagulation and Filtration Results (CSU, 1996)

Date/ Pilot Plant Mode	Alum Dose, mg/L	Turbidity, NTU		Log Removals of Organisms and Particles (> 2 μm)					
		Raw	Filt. (Avg.)	Crypto	Giardia	Bacillus	E.Coli	MS2	Particles
Oct 23/I	26	3.27	0.10	3.50	4.50	--	--	--	2.44
Oct 30/I	26	3.23	0.10	--	--	--	--	2.51	0.62
Nov 10/I	26	1.16	0.08	3.20	--	--	--	--	1.91
Nov 29/I	26	1.22	0.08	--	--	2.45	--	--	1.79
Dec 5/I	26	1.07	0.07	3.81	2.92	--	--	2.81	1.84
Dec 12/I	26	1.00	0.08	3.72	3.15	--	--	--	2.04
Dec 19/I	26	1.25	0.08	4.32	3.70	--	--	--	1.89
Jan 15/I	13	1.18	0.53	2.61	1.48	--	--	0.93	--
Feb 5/I	13	1.27	1.08	2.61	1.76	0.58	1.47	--	--
Feb 26/C	26	1.29	0.10	4.22	3.40	--	--	2.23	--
Mar 5/C	26	1.29	0.11	4.34	3.20	--	--	--	2.15
Mar 19/C	26	1.49	0.16	4.34	3.84	2.25	2.91	--	1.83
Apr 2/I	26	1.52	0.09	3.90	3.54	2.55	--	--	2.02
Apr 9/C	26	1.42	0.09	4.95	4.55	--	--	2.73	2.41
May 7/C	26	1.73	0.09	4.19	4.25	--	--	3.50	2.60
May 16/I	26	2.17	0.06	--	--	--	--	3.08	2.61
May 24/I	26	2.29	0.06	4.00	3.86	2.89	2.28	--	2.52
May 28/I	26	2.47	0.07	2.46	2.89	2.69	1.77	3.36	2.40
Jun 4/I	26	2.54	0.07	4.30	3.58	--	3.09	2.81	2.85
Jun 11/I	26	2.64	0.08	3.00	2.85	3.23	2.99	2.79	2.71
Jun 25/I	26	2.72	0.09	3.33	3.14	2.08	3.32	3.01	2.73
Jun 29/I	26	2.71	0.09	2.47	2.86	2.75	2.56	2.85	2.58

NOTES: I = in-line filtration; C = conventional filtration; -- = no data; Jan 15 and Feb 5 runs used suboptimum coagulation; alum used as coagulant; particle count data are for all particles > 2 μm in size

APPENDIX 3C
STATE-SPECIFIC VERIFICATION TESTING REQUIREMENTS

California:

- The coefficient of variation for turbidity of an individual filter run should be restricted to below 15%, to ensure consistent performance between the individual filter runs, and indication of good process control.

Ohio:

- Additional site specific pilot testing may be necessary where seasonal turnover of reservoirs and lakes due to thermal destratification (spring and fall) impacts the chemical and colloidal nature of the turbidity. Non-seasonal testing may not be able to characterize the system's ability to deal with algae blooms.

- Total hardness should be measured at least daily rather than weekly, as specified in this test plan (Table 3).

Virginia:

- Additional site-specific pilot testing will be required whenever the ETV testing does not adequately address seasonal source water quality issues. This is especially likely for verifications based on a single season of testing.
- Measurements of pH and alkalinity should be taken hourly for at least 2 hours following any change in coagulant dose.