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Environmental Technology Verification Protocol

Drinking Water Systems Center

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING OF VOLATILE ORGANIC CHEMICAL REMOVAL

Prepared by

NSF

NSF International

Under a Cooperative Agreement with
EPA U.S. Environmental Protection Agency

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EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING OF VOLATILE ORGANIC CHEMICAL REMOVAL

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Recommended by
the Steering Committee for the Verification of
Drinking Water Systems
on November 23, 1999
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U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the United States Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program---or ETV---to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and EPA regions with high quality data on the performance of new technologies. This encourages more rapid availability of approaches to better protect the environment.

ETV Drinking Water Systems Center

Concern about drinking water safety has accelerated in recent years due to much publicized outbreaks of waterborne disease and information linking ingestion of arsenic to cancer incidence. The EPA is authorized through the Safe Drinking Water Act (SDWA) to set numerical contaminant standards and treatment and monitoring requirements that will ensure the safety of public water supplies. However, small communities are often poorly equipped to comply with all of the requirements; less costly package treatment technologies may offer a solution. These package plants can be designed to deal with specific problems of a particular community; additionally, they may be installed on site more efficiently---requiring less start-up capital and time than traditionally constructed water treatment plants. The opportunity for the sales of such systems in other countries is also substantial.

The EPA has partnered with NSF International (NSF) to verify performance of small drinking water systems that serve small communities. It is expected that both the domestic and international markets for such systems are substantial. The EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, and states (issuers of permits), to assist in formulating consensus testing protocols. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment use is contemplated. NSF will meet this goal by working with equipment manufacturers and other agencies in planning and conducting equipment verification testing, evaluating data generated by such testing, and managing and disseminating information. The manufacturer is expected to secure the appropriate resources to support its part of the equipment verification process, including provision of equipment and technical support.

The verification process established by the EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process can help in moving small drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a Product Specific Test Plan (PSTP);
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;

4. Performance and cost factor (labor, chemicals, energy) verification; and
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development (ORD), National Risk Management Research Laboratory (NRMRL), Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. NSF's role is to provide technical and administrative leadership and support in conducting the testing. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Partnerships

The EPA and NSF cooperatively organized and developed the ETV Drinking Water Systems (DWS) Center to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators (ASDWA) have an understanding to assist each other in promoting and communicating the benefits and results of the project.

NSF INTERNATIONAL

Mission Statement

NSF, an independent, non-governmental organization, is dedicated to being the leading global provider of public health and safety-based risk management solutions while representing the interest of all stakeholders.

NSF Purpose and Organization

NSF is an independent not-for-profit organization. For more than 52 years, NSF has been in the business of developing consensus standards that promote and protect public health and the environment and providing testing and certification services to ensure manufacturers and users alike that products meet those standards. Today, millions of products bear the NSF Name, Logo and/or Mark, symbols upon which the public can rely for assurance that equipment and products meet strict public health and performance criteria and standards.

Limitations of use of NSF Documents

This protocol is subject to revision; contact NSF to confirm this revision is current. The testing against this protocol does not constitute an NSF Certification of the product tested.

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ORGANIZATION AND INTENDED USE OF PROTOCOL AND TEST PLANS

NSF encourages the user of this protocol to also read and understand the policies related to the verification and testing of drinking water treatment systems and equipment.

The first chapter of this document describes the protocol required in all studies verifying the performance of equipment or systems removing volatile organic contaminants (VOCs). The remaining chapters, or Technology Specific Test Plans (TSTPs), describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the protocol: the removal of VOCs.

Prior to the verification testing of drinking water treatment systems, plants, and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified Field Testing Organization (FTO). This designated FTO must write a PSTP to define the testing plan specific to the product. The equipment manufacturer and/or supplier will need this protocol and the TSTP(s) contained herein and possibly other ETV protocols and TSTPs to develop the PSTP, depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or TSTP may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified FTO that is selected by the manufacturer. Water quality analytical work to be completed as a part of a TSTP shall be contracted with a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. For information on a listing of NSF-qualified FTOs, contact NSF.

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ACKNOWLEDGMENTS

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CHAPTER 1

EPA/NSF ETV PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR VOLATILE ORGANIC CHEMICAL REMOVAL

REQUIREMENTS FOR ALL STUDIES

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1.0 INTRODUCTION

This document is the protocol to be used for verification testing of equipment designed to achieve removal of volatile organic chemicals (VOCs). The equipment Field Testing Organization (FTO) is requested to adhere to the requirements of this protocol in developing a Product Specific Test Plan (PSTP).

The testing of new technologies and materials that are unfamiliar to NSF International (NSF) and/or the Environmental Protection Agency (EPA) will not be discouraged. It is recommended that resins or membranes or any other material or chemical in the equipment conform to NSF/American National Standards Institute (NSF/ANSI) Standard 60 and 61.

The final submission of the PSTP shall:

- Include the information requested in this protocol;
- Conform to the format identified herein; and
- Conform to the specific Environmental Technology Verification (ETV) Technology Specific Test Plan(s) [TSTP(s)] related to the manufacturer's statement(s) of performance capabilities that are to be verified.

The PSTP may incorporate the requirements of more than one TSTP. For example, testing might be undertaken to verify performance of a system employing aeration for removal of VOCs and for carbon dioxide removal to adjust pH.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the FTO may find useful in preparation of the PSTP. *The italicized text indicates specific protocol deliverables that are required of the FTO or of the manufacturer and that must be incorporated in the PSTP.*

The following glossary terms are presented here for subsequent reference in this protocol:

- Distribution System - A system of conduits by which a primary water supply is conveyed to consumers typically by a network of pipelines.

- EPA - The United States Environmental Protection Agency, its staff or authorized representatives.

- Equipment - Testing equipment for use in the verification test which may be defined as either a package plant or modular system.

- Field Testing Organization (FTO) - An organization qualified to conduct studies and testing of drinking water treatment systems in accordance with protocols and test plans. The role of the FTO is to ensure preparation of an acceptable PSTP; to enter into contracts with NSF, as discussed herein, arrange for or conduct the skilled operation of a system during the intense period of testing during the study, and to perform the tasks required by the protocol.

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- Manufacturer - A business that assembles and/or sells package plant equipment and/or modular systems. The role of the manufacturer is to provide the package plant and/or modular system and technical support for the verification testing and study. The manufacturer is also responsible for providing assistance to the FTO during operation and monitoring of the package plant or modular system during the verification testing and study.

- Modular System - A packaged functional assembly of components for use in a drinking water treatment system or package plant, that provides a limited form of treatment of the feedwater(s) and which is discharged to another module of the package plant or in the final step of treatment to the distribution system.

- NSF - NSF International, its staff, or other authorized representatives.

- Package Plant - A complete water treatment system including all components from connection to the raw water(s) through discharge to the distribution system.

- Plant Operator - The person working for a small water system who is responsible for operating water treatment equipment to produce treated drinking water. This person also may collect samples, record data and attend to the daily operations of equipment throughout the testing periods.

- Product Specific Test Plan (PSTP) - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV protocol(s) and TSTP(s) that apply to a specific make and model of a package plant/modular system.

- Protocol - A written document that clearly states the objectives, goals and scope of the study as well as the TSTP(s) for the conduct of the study. The protocol shall be used for reference during manufacturer participation in verification testing.

- Report - A written document that includes data, test results, findings, and any pertinent information collected in accordance with a protocol, analytical methods, procedures, etc., in the assessment of a product whether such information is preliminary, draft or final form.

- Technology Specific Test Plan (TSTP) - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the TSTP will include detailed instructions for sample and data collection, sample handling and sample preservation, precision, accuracy, reproducibility goals, and quality assurance/quality control (QA/QC) requirements.

- Testing Laboratory - An organization certified by a third-party independent organization, Federal agency, or a pertinent state regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of drinking water treatment systems is to analyze the water samples in accordance with the methods

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and meet the pertinent QA/QC requirements described in the protocol, TSTP, and PSTP.

- Verification - To establish the evidence on the range of performance of equipment and/or device such as a package plant or modular system under specific conditions following a predetermined protocol(s) and TSTP(s).

- Verification Statement - A written document that summarizes a final report reviewed and approved by NSF on behalf of the EPA or directly by the EPA.

- Water System - The water system that operates water treatment equipment to provide treated water to its customers.

1.1 Objectives

The specific objectives of verification testing may be different for each system, depending upon the statement of performance objectives of the specific equipment to be tested. The manufacturer's performance objectives are used to establish data quality objectives (DQOs) to develop the experimental design of the verification test. The broader the performance objectives, the more comprehensive the PSTP must be to achieve the DQOs. The objectives developed by each manufacturer shall be defined and described in detail in the PSTP developed for each piece of equipment. The objectives of the equipment verification testing may include but are not limited to the following:

- Generation of field data appropriate for verifying the performance of the equipment;
- Generation of operation and maintenance (O&M) information to assist users and potential operators of equipment; and
- Evaluation of new advances in equipment and equipment design.

An important aspect in the development of verification testing is to describe the procedures that will be used to verify the statement of performance objectives made for water treatment equipment. A PSTP document incorporates the QA/QC elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Although verification testing conducted at a single site may not represent every environmental situation, which may be acceptable for the equipment tested, it will provide data of sufficient quality to make a judgment about the application of the equipment under conditions similar to those encountered in the verification testing.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

1.2 Scope

This protocol outlines the verification process for equipment designed to remove VOCs. The scope of this protocol includes TSTPs for equipment employing air stripping, and for adsorptive

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media for removal of VOCs. This protocol is not an NSF or third-party consensus standard and it does not endorse the equipment or technologies described herein.

An overview of the verification process and the elements of the PSTP to be developed by the FTO are described in this protocol. Specifically, the PSTP shall define the following elements of the verification testing:

- Roles and responsibilities of verification testing participants;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation;
- Experimental design of the field operations procedures. The field operations procedures will identify recommended equipment maintenance and cleaning methods;
- QA/QC procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing; and
- Health and safety measures relating to biohazard (if present), electrical, mechanical and other safety codes.

***Content of PSTP*:**

The structure of the PSTP must conform to the outline below: The required components of the Document shall be described in greater detail in the sections below.

- *TITLE PAGE*
- *FOREWORD*
- *TABLE OF CONTENTS - The Table of Contents for the PSTP shall include the headings provided in this document although they may be modified as appropriate for a particular type of equipment to be tested.*
- *LIST OF DEFINITIONS - A list of key terms used in the PSTP should be provided.*
- *EXECUTIVE SUMMARY - The Executive Summary describes the contents of the PSTP (not to exceed two pages). A general description of the equipment and the statement of performance objectives which shall be verified during testing shall be included, as well as the testing locations, a schedule, and a list of participants.*
- *ABBREVIATIONS AND ACRONYMS - A list of the abbreviations and acronyms used in the PSTP shall be provided.*
- *EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES (described in the sections below)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (described in the sections below)*
- *EXPERIMENTAL DESIGN (described in the sections below)*
- *FIELD OPERATIONS PROCEDURES (described in the sections below)*
- *QUALITY ASSURANCE PROJECT PLAN (described in the sections below)*
- *DATA MANAGEMENT AND ANALYSIS (described in the sections below)*
- *SAFETY PLAN (described in the section below)*

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2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

The required content of the PSTP and the responsibilities of participants are listed at the end of each section. In the development of a PSTP, a manufacturer and its designated FTO shall provide a table which includes the name, affiliation, and mailing address of each participant, a point of contact, their role, and telephone, fax and E-mail address.

2.2 Organization

The organizational structure for the verification testing showing lines of communication shall be provided by the FTO in its application on behalf of the manufacturer.

2.3 Verification Testing Site Name and Location

This section discusses background information on the verification testing site(s), with emphasis on the quality of the feedwater. The PSTP must provide the site names and locations at which the equipment will be tested. In most cases, the equipment may be demonstrated at more than one site. Depending upon the verification testing requirements stipulated in the TSTP employed, testing of the equipment may be required under different conditions of feedwater quality (or source water quality) that allow evaluation of system performance over a range of seasonal climate and weather conditions.

2.4 Site Characteristics

The PSTP shall include an area location map showing access from major streets and highways and a site layout drawing with equipment footprints and dimensions. The drawing should indicate the location of the existing facilities, the source of the feedwater, and where the treated water will be discharged and the waste streams disposed. The PSTP shall also indicate if any facilities other than the equipment would be required to perform the test such as additional trailers or temporary structures for sample collection and preparation, electrical power, concrete pads, drainage, easements, etc. The location of the VOC waste stream treatment, disposal and discharge facility, or method of removal shall be clearly identified in the site plan. The PSTP must include a description of the test site. This shall include a description of where the equipment will be located. If the feedwater to the equipment is the source water for an existing water treatment plant, describe:

- The raw water intake;
- The opportunity to obtain raw water without the addition of any chemicals; and
- The operational pattern of raw water pumping at the full-scale facility (is it continuous or intermittent?).

The source water characteristics shall be described and documented. The PSTP shall also describe facilities to be used for handling the treated water and wastes (i.e., residuals) produced during the verification test. The PSTP will state whether the required water flows and waste

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flows produced are dealt with in an acceptable way, and whether any water pollution discharge permits are needed.

2.5 Responsibilities

The PSTP shall identify the organizations involved in the testing and describes the primary responsibilities of each organization. The responsibilities of the manufacturer may vary depending on the type of verification testing. Multiple manufacturers testing at one time is also an option. However, at a minimum, the manufacturer shall be responsible for:

- Providing the equipment to be evaluated during verification testing. The equipment must be in complete working order at delivery to the test site;
- Providing logistical and technical support, as required; and
- Providing equipment that explicitly meets all requirements of the Occupational Safety and Health Administration (OSHA), National Electrical Manufacturers Association (NEMA), Underwriters Laboratory Inc. (UL), NSF, and other appropriate agencies to ensure operator safety during verification testing.

In brief, the FTO shall be responsible for:

- Preparation of the PSTP;
- Providing needed logistical support, establishing a communication network, and scheduling and coordinating the activities of all verification testing participants;
- Ensuring that locations selected as test sites have feedwater quality consistent with the objectives of the verification testing (manufacturer may recommend a verification testing site(s));
- Managing, evaluating, interpreting, and reporting on data generated by the verification testing; and
- Evaluating and reporting on the performance of the technologies.

***Content of PSTP Regarding Verification Testing Responsibilities*:**

The FTO, shall be responsible for including the following elements in the PSTP:

- *Definition of the roles and responsibilities of appropriate verification testing participants;*
- *A table which includes the name, affiliation, and mailing address of each participant, a point of contact, their role, and telephone, fax and email address;*
- *Organization of operational and analytical support;*
- *List of the site name(s) and location(s); and*
- *Description of the test site(s), the site characteristics and identification of where the equipment shall be located.*

The manufacturer shall be responsible for:

- *Provision of complete, field-ready equipment for verification testing;*

- *Provision of logistical, and technical support, as required;*
- *Provision of assistance to the qualified FTO during operation and monitoring of the equipment during the verification testing;*
- *Reviewing the PSTP; and*
- *Reviewing the verification report.*

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities

The manufacturer and its designated FTO must identify the water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the verification testing. The PSTP must state the treated water quality objectives of the equipment to be tested. Statements should also be made regarding the applications of the equipment, what advantages it provides over existing equipment, and the known limitations of the equipment. The statement of performance objectives must be specific and be verifiable by a statistical analysis of the data. An example of a satisfactory statement of performance objectives would be:

> "This system is capable of reducing the concentration of 1,1,2-trichloroethylene or other VOC with a value of Henry's Law Constant greater than 1,1,2-trichloroethylene in water by at least an order of magnitude from a feedwater concentration of 40 µg/L to less than 5 µg/L in the treated water."

A statement of performance objectives such as: "This system will provide lower VOC levels than required by the Safe Drinking Water Act (SDWA) on a consistent and dependable basis," would not be acceptable.

The statement of performance objectives shall indicate the range of water quality with which the equipment can be challenged while successfully treating the feedwater. Statements of performance objectives that are too easily met may not be of interest to the potential user, while performance objectives that are overstated may not be achievable. The statement of performance objectives forms the basis of the entire equipment verification testing and must be chosen appropriately. Therefore, the design of the PSTP shall include a sufficient range of feedwater quality to permit verification of the statement of performance objectives.

3.2 Equipment Description

Description of the equipment for verification testing shall be included in the PSTP. Data plates shall be permanent and securely attached to each production unit. The data plate shall be easy to read in English or the language of the intended user, located on the equipment where it is readily accessible, and contain at least the following information:

- Equipment Name;
- Model Number;
- Manufacturer's name and address;

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- Electrical requirements - volts, amps, and Hertz;
- Equipment size and weight;
- Shipping requirements and special handling precautions;
- Equipment maintenance requirements;
- Serial Number;
- Warning and Caution statements in legible and easily discernible print size; and
- Capacity or output rate (if applicable).

In addition, the manufacturer must provide the equipment with all OSHA required safety devices (if applicable).

Content of PSTP Regarding Equipment Capabilities and Description:

The PSTP shall include the following elements:

- *Description of the equipment to be demonstrated including photographs from relevant angle or perspective;*
- *Brief introduction and discussion of the engineering and scientific concepts on which the water treatment equipment is based;*
- *Description of the treatment train and each unit process included in the equipment including all relevant schematics;*
- *Brief description of the physical construction/components of the equipment, including the general environmental requirements and limitations, weight, transportability, ruggedness, power and other consumables needed, etc.;*
- *Statement of typical rates of consumption of chemicals, a description of the physical and chemical nature of wastes, and rates of waste production; concentrates, residues, etc.;*
- *Definition of the performance range of the equipment;*
- *Identification of any special licensing requirements associated with the operation of the equipment;*
- *Description of the applications of the equipment and the removal capabilities of the treatment system relative to existing equipment by providing comparisons in such areas as: treatment capabilities, requirements for chemicals and materials, power, labor requirements, suitability for process monitoring and operation from remote locations, ability to be managed by part-time operators; and*
- *Discussion of the known limitations of the equipment by including such items as the range of feedwater quality suitable for treatment with the equipment, the upper limits for concentrations of regulated contaminants that can be removed to concentrations below the manufacturer's objectives, level of operator skill required to successfully use the equipment.*

4.0 EXPERIMENTAL DESIGN

This section discusses the objectives of the verification testing, factors that must be considered to meet the performance objectives, and the statistical and other means that the FTO should use to evaluate the results of the verification testing.

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4.1 Objectives

The objectives of this verification testing are to evaluate equipment in the following areas:

- Performance relative to manufacturer's stated range of equipment objectives;
- The impacts of variations in feedwater quality (such as VOC concentrations and temperature) on its performance;
- The logistical, human, and economic resources necessary to operate the equipment; and
- The reliability, ruggedness, cost factors, range of usefulness, and ease of operation.

The PSTP shall include those treatment tests listed in TSTPs that are most appropriate to challenge the equipment. For example, if the equipment is only intended for removal of vinyl chloride, there would be no need to conduct testing to evaluate the removal of benzene or toluene.

4.2 Equipment Characteristics

This section discusses factors that shall be considered in the design and implementation of the verification testing. These factors include:

- Ease of operation;
- Degree of operator attention required;
- Response of equipment and treatment process to changes in feedwater quality;
- Electrical requirements;
- System reliability features including redundancy of components;
- Feed flow requirements;
- Discharge requirements;
- Spatial requirements of the equipment (footprint);
- Unit processes included in treatment train;
- Chemicals needed;
- Chemical hazards associated with equipment operation; and
- Response of treatment process to intermittent operation.

Verification testing procedures shall simulate routine conditions as much as possible and in most cases testing may be done in the field. Under such circumstances, simulation of field conditions would not be necessary.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impractical to quantify. These are considered qualitative factors. Important factors that cannot easily be quantified are the safety of the equipment and the logistical requirements necessary for using it.

Typical qualitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment that may include:

- Reliability or susceptibility to environmental conditions;
- Equipment safety;
- Potential for nuisance noise;
- Need for alarms, security and/or lighting; and
- Effect of operator experience on results.

4.2.2 Quantitative Factors

Many factors in this verification testing can be quantified by various means during verification testing. Some can be measured while others cannot be controlled. Typical quantitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment that may include:

- Power and consumable supply (such as chemical) requirements;
- Monitoring requirements;
- Cost factors of operation, expendables, and waste disposal;
- Length of operating cycle; and
- Modular size and weight of the equipment.

These quantitative factors shall be used as an initial benchmark to assess equipment performance.

4.3 Water Quality Considerations

Water treatment equipment is used to treat water and change the quality of feedwater (or raw water) so it does not contain harmful contaminants and is aesthetically pleasing and palatable. The experimental design shall be developed so the relevant questions about water treatment equipment capabilities can be answered.

Equipment manufacturers should recognize that it is highly unlikely that any single item of water treatment process equipment can successfully treat any conceivable feedwater containing all of the regulated contaminants and produce a treated water that meets the quality requirements for every regulated contaminant. Although multiple processes could be placed in a treatment train to accomplish such a goal, for most public water systems such comprehensive treatment capability is not needed and would not be cost effective. Therefore, drinking water treatment has been focused on the water quality aspects of concern for particular locations.

The range of contaminants or water quality problems that can be addressed by water treatment equipment varies, and some treatment equipment can address a broader range of problems than other types. Manufacturers should carefully consider the capabilities and limitations of their equipment and have PSTPs prepared that challenge their product sufficiently to provide data for a broad market. FTOs shall use TSTPs as the basis for preparation of the specific PSTPs.

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4.3.1 Feedwater Quality

One of the key aspects related to water treatment equipment performance verification is the range of feedwater quality that can be treated successfully, resulting in treated water quality that meets water quality goals or regulatory requirements. The manufacturer and FTO should consider the influence of feedwater quality on the quality of treated waters produced by the equipment, such that product waters meet the water quality goals stated in the PSTP. As the range of feedwater quality that can be treated by the equipment becomes broader, the potential applications for treatment equipment with verified performance objectives may also increase.

One of the questions often asked by regulatory officials in approval of water treatment equipment is "Has it been shown to work on the water where you propose to put it?" By covering a large range of water qualities, verification testing is more likely to provide an affirmative answer to that question.

The FTO shall specify in the PSTP the specific water quality parameters to be monitored in the verification testing program. The following feedwater quality characteristics may be important for treatment equipment intended to remove VOCs:

- VOC concentration and
- Temperature.

The following feedwater quality characteristics may be important to potential fouling and/or scaling of treatment equipment over time and should be noted if present in a quantity that could affect longer term operation:

- Total hardness and/or calcium hardness;
- pH and alkalinity;
- Corrosivity (Langelier index);
- Iron and manganese;
- Total dissolved solids (TDS) or conductivity;
- Total sulfide;
- Sulfate;
- Dissolved oxygen;
- Presence of bacteria;
- Presence of algae;
- Dissolved organic carbon (DOC), total organic carbon (TOC), or UV-254 absorbance; and
- Turbidity, particle concentration.

4.3.2 Treated Water Quality

Treated water quality is very important. If an FTO states that water treatment equipment can be used to treat water to obtain certain concentrations, the verification testing must provide data that support such a statement of objectives.

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Furthermore, some water treatment equipment can be used to meet aesthetic goals. Water quality considerations that may be important for some small systems include:

- Color, taste and odor;
- TDS; and
- Iron and manganese.

4.4 Recording Data

For all VOC removal experiments, data should be maintained on the pH, temperature and other water quality parameters listed in Sections 4.3.1 and 4.3.2 above. The following items of information shall also be maintained for each experiment:

- Type of chemical addition, dose and chemical combination, where applicable (e.g., pH adjustment, scale inhibitor, etc.);
- Water type (raw water, pretreated feedwater, product water, waste water); and
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.).

4.5 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95% confidence intervals shall be calculated by the FTO for water quality parameters in which eight or more samples were collected. The PSTP shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. DQOs and the vendor's performance objectives shall be used to assess which water quality parameters are critical and thus require confidence interval statistics. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula shall be employed for confidence interval calculation:

$$\text{confidence interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}}\left(S/\sqrt{n}\right)$$

where: X = sample mean;
S = sample standard deviation;
n = number of independent measurements included in the data set;
t = Student's t distribution value with n-1 degrees of freedom; and
α = significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

According to the 95% confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$\text{95\% confidence interval} = \overline{X} \pm t_{n-1,0.975}\left(S/\sqrt{n}\right)$$

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output will appear as the sample mean value plus or minus the second term. The results of this statistical calculation may also be presented as a range of values

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falling within the 95% confidence interval. For example, the results of the confidence interval calculation may provide the following information: 520 +/- 38.4 µg/L, with a 95% confidence interval range described as (482, 558).

Calculation of confidence intervals shall not be required for equipment performance results (e.g., time between cleanings, cleaning efficiency, etc.) obtained during the equipment verification testing. However, as specified by the FTO, calculation of confidence intervals may be required for such analytical parameters as grab sample alkalinity, iron concentration, and DOC. To provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period. The procedures and sampling requirements shall be provided in detail in the PSTP.

4.6 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations are to be conducted so equipment can be tested to be sure it is functioning as intended. If feedwater quality influences operation and performance of the equipment being tested, the initial operations period serves as the shakedown period for determining appropriate operating parameters. The schedule of testing may also be influenced by coordination requirements with a utility.

One period of verification testing shall be designated, including the coldest temperatures expected because of the impact of cold temperatures on physical properties of the VOCs and an increase in the viscosity of water. Verification testing that is intended to be used to verify the performance of a product would be done after an initial operations phase is completed.

Content of PSTP Regarding Experimental Design:

The PSTP shall include the following elements:

- *Identification of the qualitative and quantitative factors of equipment operation to be addressed in the verification test;*
- *Identification and discussion of the water treatment problem or problems that the equipment is designed to address, how the equipment will solve the problem, and who would be the potential users of the equipment;*
- *Identification of the range of key water quality parameters, given in applicable TSTPs, which the equipment is intended to address and for which the equipment is applicable;*
- *Identification of the key parameters of treated water quality that shall be used for evaluation of equipment performance during the physical removal of microbiological and particulate contaminants. Parameters of significance for treated water quality were listed above in Section 4.3.2 and in applicable TSTPs;*
- *Description of data recording protocol for equipment operation, feedwater quality parameters, and treated water quality parameters;*
- *Description of the confidence interval calculation procedure for selected water quality parameters; and*

- *Detailed outline of the verification testing schedule, with regard to annual testing periods that will cover an appropriate range of annual climatic conditions, (i.e., different temperature conditions, seasonal differences between rainy and dry conditions).*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The TSTP specifies procedures that shall be used to ensure the accurate documentation of both water quality and equipment performance. Careful adherence to these procedures will result in definition of verifiable performance of equipment. (Note that this protocol may be associated with a number of different TSTPs for different types of VOC removal process equipment.)

Design aspects of water treatment process equipment often provide a basis for approval by state regulatory officials and can be used to ascertain if process equipment intended for larger or smaller flows involves the same operating parameters that were relevant to the verification testing. The field operations procedures and testing conditions provided by the FTO shall therefore be specified to demonstrate treatment capabilities over a broad range of operational conditions and feedwater qualities. Specific design aspects to be included in the PSTP are provided in detail, in the Manufacturer Responsibilities section below.

5.2 Communications, Documentation, Logistics, and Equipment

NSF shall communicate regularly with the verification testing participants to coordinate all field activities associated with the verification test and to resolve any logistical, technical, or QA/QC issues that may arise as the verification testing progresses. The successful implementation of the verification testing will require detailed coordination and constant communication between all verification testing participants.

All field activities shall be thoroughly documented. Field documentation shall include field logbooks, photographs, field data sheets, and chain-of-custody forms. The qualified FTO shall be responsible for maintaining all field documentation. Field notes shall be kept in a bound logbook. Each page shall be sequentially numbered and labeled with the project name and number. Field logbooks shall be used to record all water treatment equipment operating data. Completed pages shall be signed and dated by the individual responsible for the entries. Errors shall have one line drawn through them and this line shall be initialed and dated.

All photographs shall be logged in the field logbook. These entries shall include the time, date, direction, subject of the photograph, and the identity of the photographer. Any deviations from the approved final PSTP shall be thoroughly documented in the field logbook at the time of inspection and in the verification report.

Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided at the time of the QA/QC inspection and included in the verification report.

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As available, electronic data storage and retrieval capabilities shall be employed to maximize data collection and minimize labor hours required for monitoring. The guidelines for use of data-loggers, laptop computers, data acquisition systems etc., shall be detailed by the FTO in the PSTP.

5.3 Initial Operations

Initial operations will allow equipment manufacturers to refine their operating procedures and to make operation adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the PSTP, if necessary. A failure at this point in the verification testing could indicate a lack of capability of the process equipment and the verification testing might be canceled.

5.4 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform to requirements provided in the PSTP that was developed and approved for the verification testing being conducted. All sampling and sample analyses conducted during the verification test shall be performed according to the procedures detailed by the FTO in the PSTP. As necessary for verification analyses, state-certified, third-party or EPA-qualified laboratories are selected to perform analytical services using approved Standard or EPA Methods. If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the situation must be discussed with the NSF technical lead. Any deviations from the approved final PSTP shall be thoroughly documented.

During routine operation of water treatment equipment, the total number of hours during which the equipment was operated each day shall be documented. In addition, the number of hours each day during which the operator was working at the treatment plant and performing tasks related to water treatment and the operation of the treatment equipment shall be documented. The tasks performed during equipment operation shall be described by the FTP, the water system or the plant operator.

Content of PSTP Regarding Field Operations Procedures:

The PSTP shall include the following elements:

- *A table summary of the proposed time schedule for operating and testing;*
- *Field operating procedures for the equipment and performance testing, based upon the TSTP, including:*
    - *listing of operating parameters,*
    - *ranges for feedwater quality, and*
    - *sampling and analysis strategy;*
- *Provision of all equipment needed for field work associated with this verification testing;*
- *Provision of a complete list of all equipment to be used in the verification testing. A table format is suggested;*
- *Provision of field operating procedures; and*

- *At a minimum, a table(s) showing all parameters to be analyzed, the analytical methods, the laboratory reporting limits or quantification limits, sample volume, bottle type, preservation method, and holding times.*

Manufacturer Responsibilities:

- *Provision of all equipment needed for field work associated with this verification testing;*
- *Provision of a complete list of all equipment to be used in the verification testing. A table format is suggested; and*
- *Provision of field operating procedures.*

6.0 QUALITY ASSURANCE PROJECT PLAN

Every PSTP for verification testing must include a Quality Assurance Project Plan (QAPP) that specifies procedures that shall be used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the verification testing will provide sound analytical results that can serve as the basis for performance verification.

6.1 Purpose and Scope

The purpose of this section is to outline steps that shall be taken by operators of the equipment and by the analytical laboratory to ensure that data resulting from this verification testing is of known quality and that a sufficient number of critical measurements are taken.

6.2 Quality Assurance Responsibilities

The FTO project manager is responsible for coordinating the preparation of the QAPP for the verification test and for its approval by NSF. The FTO project manager, with oversight from NSF, shall also ensure that the QAPP is implemented during all verification testing activities.

The manufacturer and NSF must approve the entire PSTP including the QAPP before the verification test can proceed. NSF must review and either approve the QAPP or provide reasons for rejection of the QAPP. NSF should also provide suggestions on how to modify the QAPP to make it acceptable, provided that the FTO has made a good faith effort to develop an acceptable QAPP (i.e., the QAPP is 75 to 80% acceptable with only minor changes needed to produce an acceptable PSTP. NSF will not write QAPPs for manufacturers.).

A number of individuals may be responsible for monitoring equipment operating parameters and for sampling and analysis QA/QC throughout the verification testing. Primary responsibility for ensuring that both equipment operation and sampling and analysis activities comply with the QA/QC requirements of the PSTP shall rest with the FTO. QA/QC activities for the equipment shall include those activities recommended by the manufacturer and those required by NSF to assure the verification testing will provide data of the necessary quality.

QA/QC activities for the analytical laboratory that analyzes samples sent off-site shall be the

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responsibility of that analytical laboratory's supervisor. If problems arise or any data appear unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section. The QA/QC measurements made by the off-site analytical laboratory are dependent on the analytical methods being used.

6.3 Data Quality Indicators

The data obtained during the verification testing must be of sound quality for conclusions to be drawn on the equipment. For all measurement and monitoring activities conducted for equipment verification, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include four indicators of data quality: representativeness, completeness, statistical uncertainty, accuracy, and precision.

Treatment results generated by the equipment must be verifiable for the purposes of the verification testing program to be fulfilled. High quality, well-documented analytical laboratory results are essential for meeting the purpose and objectives of this verification testing. Therefore, the following indicators of data quality shall be closely evaluated to determine the performance of the equipment when measured against data generated by the analytical laboratory.

6.3.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this verification testing, representativeness will be ensured by executing consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping. Representativeness also will be ensured by using each method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving.

For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations. For most water treatment processes involving microbiological and particulate contaminant removal, detecting a +/- 10% change in an operating parameter (e.g. headloss) is sufficient. Mixing energies and flows shall be recorded on a daily basis to track changes in operational conditions that exceed this 10% range.

6.3.2 Completeness

Completeness refers to the amount of data collected from a measurement process compared to the amount that was expected to be obtained. Completeness refers to the proportion of valid, acceptable data generated using each method. This portion of the required data for the selected test plan will be reported at the conclusion of each testing period.

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The completeness objective for data generated during verification testing is based on the number of samples collected and analyzed for each parameter and/or method. The test plans will likely require a large number of samples to be collected for key and most important parameters and/or methods. The following chart illustrates the completeness objectives for performance parameter and/or method based on the sample frequency:

Number of Samples Per Parameter and/or Method	**Percent Completeness**
0-10	80%
11-50	90%
>50	95%

Completeness is defined as follows for all measurements:

$$\%C = (V/T) \times 100$$

where: $\%C$ = percent completeness;
V = number of measurements judged valid; and
T = total number of measurements.

Additional testing and collection of additional sample will be required if the percent completeness objectives are not met. If the completeness objectives are still not met through the collection of additional samples, then a retest will be required.

The following are examples of instances that might cause a sample analysis to be incomplete:

- Instrument failure;
- Calibration requirement not being met; and
- Elevated analyte levels in the method blank.

6.3.3 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence interval around the sample mean. Description of the confidence interval calculation is provided in Section 4.5 – Recording Statistical Uncertainty.

6.3.4 Accuracy

For water quality analyses, accuracy refers to the difference between a sample result and the reference or true value for the sample. Loss of accuracy can be caused by such processes as errors in standards preparation, equipment calibrations, loss of target analyte in the extraction process, interferences, and systematic or carryover contamination from one sample to the next.

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In this verification testing, the FTO will be responsible for maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping to maintain a high level of accuracy in system monitoring. The FTO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological samples and analytical techniques in the PSTP.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For water flow, accuracy is the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times (bucket and stopwatch technique) as practiced in hydraulics laboratories or water meter calibration shops. For mixing equipment, accuracy is the difference between an electronic readout for equipment RPMs and the actual measurement based on counted revolutions and measured time. Accuracy of head loss measurement can be determined by using measuring tapes to check the calibration of piezometers for gravity filters or by checking the calibration of pressure gauges for pressure filters. Meters and gauges must be checked periodically for accuracy, and when proven to be dependable over time, the time interval between accuracy checks can be increased. In the PSTP, the FTO shall discuss the applicable ways of determining the accuracy of the operational conditions and procedures.

From an analytical perspective, accuracy represents the deviation of the analytical value from the known value. Since true values are never known in the field, accuracy measurements are made on analysis of QC samples analyzed with field samples. QC samples for analysis shall be prepared with laboratory control samples, matrix spikes and spike duplicates. It is recommended for verification testing that the PSTP include laboratory performance of one matrix spike for determination of sample recoveries. Recoveries for spiked samples are calculated in the following manner:

$$\% \text{ Recovery} = 100 \times (SSR - SR)/SA$$

where: SSR = spiked sample results;
SR = sample result; and
SA = spike amount added.

Recoveries for laboratory control samples are calculated as follows:

$$\% \text{ Recovery} = 100 \times (\text{found concentration})/(\text{true concentration})$$

For acceptable analytical accuracy under the verification testing program, the recoveries reported during analysis of the verification testing samples must be within control limits, where control limits are defined as the mean recovery plus or minus three times the standard deviation.

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6.3.5 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. The percent relative standard deviation may be calculated in the following manner:

$$\%\text{Relative Standard Deviation} = S(100) / X_{\text{average}}$$

where: S = standard deviation and
X_{average} = the arithmetic mean of the recovery values.

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X)^2}{n-1}}$$

where: X_i = the individual recovery values;
X = the arithmetic mean of then recovery values; and
n = the number of determinations.

For acceptable analytical precision under the verification testing program, the percent RSD for drinking water samples must be less than 30%. If the data generated during the ETV test does not meet the DQOs defined in this QA/QC section, additional testing and sampling will be required. If the DQOs are still not met through additional testing and the collection of additional samples, then a retest will be required.

6.4 Quality Control Checks

This section describes the QC requirements that apply to both the treatment equipment and the on-site water quality analyses. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

The QC checks provide a means of measuring the quality of data produced. The FTO may not need to use all the ones identified in this section. The selection of the appropriate quality control checks depends on the equipment, the experimental design and the performance goals. The selection of quality control checks shall be based on discussions among the manufacturer, the FTO, and NSF.

6.4.1 Quality Control for Equipment Operation

This section will explain the methods to be used to check on the accuracy of equipment operating parameters and the frequency with which these QC checks shall be made. A

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key aspect of verification testing is to provide operating results that will be widely accepted by state regulatory officials. If the quality of the equipment operating data cannot be verified, then the water quality analytical results may be of no value. Because water cannot be treated if equipment is not operating, obtaining valid equipment operating data is a prime concern for verification testing.

An example of the need for QC for equipment operations is an incident of state rejection of test data because the treatment equipment had no flow meter to use for determining engineering and operating parameters related to flow.

6.4.2 Water Quality Data

After treatment equipment is being operated and water is being treated, the results of the treatment are interpreted in terms of water quality. The quality of water sample analytical results is just as important as the quality of the equipment operating data. Therefore, the QAPP must emphasize the methods to be employed for sampling and analytical QA. Analytical methods for on-site and off-site monitoring are presented within each TSTP. If new methods are published and approved or current methods updated, the most current methods shall be used. The important aspects of sampling and analytical QA are given below:

6.4.2.1 Duplicate Samples: Duplicate samples must be analyzed to determine the precision of analysis. The procedure for determining samples to be analyzed in duplicate shall be provided in the PSTP with the frequency of analysis and the approximate number. Duplicate samples must include field duplicates and laboratory duplicates. Field duplicates measure the precision of the overall sampling and analysis procedures. Laboratory duplicates measure the precision associated only with the lab procedures.

6.4.2.2 Method Blanks: Method blanks are used to evaluate analytical method-induced contamination, which may cause false positive results.

6.4.2.3 Spiked Samples: The use of spiked samples will depend on the testing program and the contaminants to be removed. If spiked samples are to be used specify the procedure, frequency, acceptance criteria, and actions if criteria are not met.

6.4.2.4 Travel Blanks: Travel blanks shall be provided to the analytical laboratory to evaluate travel-related contamination.

6.4.2.5 Performance Evaluation Samples for On-Site Water Quality Testing: Performance evaluation (PE) samples are samples of unknown concentration prepared by an independent performance evaluation lab and are provided as unknowns to an analyst to evaluate his or her analytical performance. Analysis of PE samples shall be conducted onsite by the FTO and by the offsite laboratory before testing is initiated. If recent PE reports from the laboratory are not available, PE samples shall be submitted by the FTO to the analytical laboratory. The control limits for the PE samples shall be used to evaluate the FTO's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies performed under this protocol would be a VOC PE sample.

A PE sample comes with statistics that have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include a true value of the PE sample, a mean of the laboratory results obtained from the analysis of the PE sample, and an acceptance range for sample values. The analytical laboratory is expected to provide results from the analysis of the PE samples that meet the performance capabilities of the verification testing.

6.5 Data Reduction, Validation, and Reporting

To maintain good data quality, specific procedures shall be followed during data reduction, validation, and reporting. These procedures are detailed below.

6.5.1 Data Reduction

Data reduction refers to the process of converting the raw results from the equipment into concentration or other data in a form to be used in the comparison. The procedures to be used will be equipment dependent. The purpose of this step is to provide data that will be used to verify the statement of performance objectives. These data shall be obtained from logbooks, instrument outputs, and computer outputs as appropriate.

6.5.2 Data Validation

The operator shall confirm the completeness of the appropriate data forms and the completeness and correctness of data acquisition and reduction. The field team supervisor or another technical person shall review calculations and inspect laboratory logbooks and data sheets to confirm precision, accuracy, and completeness. Calibration and QC data shall be examined by the individual operators and the laboratory supervisor. Laboratory and project managers shall confirm that all instrument systems are in control and that QA objectives for precision, accuracy, completeness, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for precision and accuracy for a given analytical method. Should QC data be outside of control limits, the analytical laboratory or field team supervisor shall investigate the cause of the problem. If the problem involves an analytical problem, the sample shall be reanalyzed. If the problem can be attributed to the sample matrix, the result shall be flagged with a data qualifier. This data qualifier shall be included and explained in the final analytical report.

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6.5.3 Data Reporting

The data reported during verification testing shall be explicitly defined by the FTO in the PSTP. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses and equipment operating data. All QC information such as calibrations, blanks and reference samples are to be included in an appendix. All raw analytical data shall also be reported in an appendix. All data shall be reported in hard copy and electronically in a common spreadsheet or database format.

6.6 Calculation of Data Quality Indicators

The equations for any data quality indicator calculations employed shall be provided. These include: precision, relative percent deviation, standard deviation, accuracy, and completeness.

6.7 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories may be conducted as specified by the PSTP. These inspections will be performed by the verification entity to determine if the TSTP and PSTP are being implemented as intended. At a minimum, NSF shall conduct one inspection of the sampling activities, field operations program and laboratories during the verification test. Separate inspection reports will be completed after the inspections and provided to the participating parties.

6.8 Reports

6.8.1 Status Reports

The FTO shall prepare periodic reports for distribution to pertinent parties, e.g., the manufacturer, the EPA, and the community. These reports shall discuss project progress, problems and associated corrective actions, and future scheduled activities associated with the verification testing. When problems occur, the manufacturer and FTO project managers shall discuss them and estimate the type and degree of impact, and describe the corrective actions taken to mitigate the impact and to prevent a recurrence of the problems. The frequency, format, and content of these reports shall be outlined in the PSTP.

6.8.2 Inspection Reports

Any QA inspections that take place in the field or at the analytical laboratory while the verification testing is being conducted shall be formally reported by the FTO to the verification entity and manufacturer.

6.9 Corrective Action

Each PSTP must incorporate a corrective action plan. This plan must include the predetermined acceptance limits, the corrective action to be initiated whenever such acceptance criteria are not met, and the names of the individuals responsible for implementation.

Routine corrective action may result from common monitoring activities, such as:

- Routine site performance evaluation audits and
- Routine technical systems audits.

Content of PSTP Regarding the QAPP:

The PSTP shall include the following elements:

- *Description of methodology for measurement of accuracy;*
- *Description of methodology for measurement of precision;*
- *Description of the methodology for use of blanks, the materials used, the frequency, the criteria for acceptable method blanks and the actions if criteria are not met;*
- *Description of any specific procedures appropriate to the analysis of the samples;*
- *Outline of the procedure for determining samples to be analyzed in duplicate, the frequency and approximate number;*
- *Description of the procedures used to assure that the data are correct;*
- *Listing of equations used for any necessary data quality indicator calculations. These include: precision, relative percent deviation, standard deviation, accuracy, and completeness;*
- *Outline of the frequency, format, and content of reports in the PSTP; and*
- *Development of a corrective action plan in the PSTP.*

The FTO shall be responsible for the following:

- Provision of all QC information such as calibrations, blanks and reference samples in an appendix. All raw analytical data shall also be reported in an appendix; and
- Provision of all data in hard copy and electronic form in a common spreadsheet or database format.

7.0 DATA MANAGEMENT AND ANALYSIS, AND REPORTING

7.1 Data Management and Analysis

The manufacturer, FTO, and NSF each have distinct responsibilities for managing and analyzing verification testing data. The FTO is responsible for managing all the data and information generated during verification testing. The FTO will also be responsible for analyzing and reporting the data in the verification report. The manufacturer is responsible for furnishing those records generated by the equipment FTO. NSF will be responsible for verification of the data.

A variety of data may be generated during a verification testing. Each piece of data or information identified for collection in the approved PSTP shall be provided in the report. The data management section of the PSTP shall describe what types of data and information needs to be collected and managed, and shall also describe how the data shall be reported to NSF for

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evaluation.

The raw data and the validated data must be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet in the report. In addition to the sample results, all QA/QC summary forms must be provided.

Other items that must be provided include:

- Field notebooks;
- Photographs, slides and videotapes (copies); and
- Results from the use of other field analytical methods.

7.2 Report of Equipment Testing

The FTO shall prepare a draft report describing the verification testing that was carried out and the results of that testing. This report shall include the following topics:

- Introduction;
- Executive Summary;
- Description and Identification of Product Tested;
- Procedures and Methods Used in Testing;
- Results and Discussion (discussion of results should be kept at a minimum to a avoid conclusions and recommendations);
- References;
- Appendices;
- QA/QC Results; and
- Items described in Section 7.1 of this document.

Content of PSTP Regarding Data Management, Analysis, and Reporting:

The PSTP shall include the following:

- *Description of what types of data and information needs to be collected and managed and*
- *Description of how the data will be reported.*

8.0 SAFETY MEASURES

The safety procedures shall address safety considerations and include adherence to all local, state and Federal regulations relative to safety and operational hazards. The safety procedures shall address safety considerations, which relate to the health and safety of personnel required to work on the site of the test equipment and persons visiting the site. Many of these items will be covered by site inspections and construction and operating permits issued by responsible agencies. The safety procedures shall address safety considerations, including the following, as

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applicable:

- Storage, handling, and disposal of hazardous chemicals including VOCs, acids, caustic and oxidizing agents;
- Conformance with National Electric Code;
- Conformance with building permits;
- Presence on site and familiarity with applicable Material Safety Data Sheets;
- Biohazards, if pathogenic microorganisms are used in testing;
- Ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard (one example is ozone); and
- Needs for fire extinguishers, site security, site lighting, and/or air conditioning.

For additional information on pilot plant and laboratory safety, please refer to:

- Palluzi, R. P. Pilot Plant and Laboratory Safety. New York: McGraw-Hill, 1994.
- Fuscaldo, A. A., et al. Laboratory Safety, Theory and Practice. New York: Academic Press. 1980.

Content of PSTP Regarding Safety:

The PSTP shall address safety considerations that are appropriate for the equipment being tested and for the challenge organisms, if any, being used in the verification testing.

The manufacturer shall be responsible for:

- *Provisions of required written material (such as Material Data Safety Sheets);*
- *Compliance with all safety requirements of local, state and Federal laws and regulators; and*
- *Provisions of maintenance information and troubleshooting guidelines and instructions relative to the equipment to be verified.*

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CHAPTER 2

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR REMOVAL OF VOLATILE ORGANIC CHEMICALS BY AIR STRIPPING TECHNOLOGY

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1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for Volatile Organic Compound (VOC) Removal by Air Stripping Technology. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing of air stripping equipment, within the structure provided by the ETV Protocol document for VOC removal. Refer to the “EPA/NSF ETV Protocol For Equipment Verification Testing For Volatile Organic Chemical Removal: Requirements For All Studies” for further information.

In order to participate in the equipment verification process for air stripping, the equipment Manufacturer and their designated Field Testing Organization shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the Product-Specific Test Plan. The Product-Specific Test Plan should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific air stripping equipment. As appropriate, 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 to 6 as identified below, with Task 7 being recommended but optional.

2.0 INTRODUCTION

Air stripping involves the transfer of volatile aqueous contaminants from water to air. Air stripping, sometimes referred to as aeration, involves continuous contact of air with water to allow aqueous contaminants to transfer. The air is swept from the system, treated as necessary, and released to the atmosphere. The driving force for transfer of the contaminants is the difference between the concentration of the contaminant in untreated water and the concentration in water that is at equilibrium with the air.

This plan is applicable to any type of air stripping process as long as it is adequately described by the Manufacturer. Various air stripping processes are currently employed for water treatment applications including:

- packed tower, employing either structured or loose packing;
- shallow tray;
- diffused air;
- spray; and
- gas permeable hollow fiber membrane.

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3.0 GENERAL APPROACH

This ETV Testing Plan is broken down into 7 tasks. As noted above, Tasks 1 to 6 shall be performed by any Manufacturer wanting the performance of their equipment verified under the ETV program. Task 7 is a recommended but optional task. The Manufacturer's designated Field Testing Organization shall provide full detail of the procedures to be followed in each Task in the Product-Specific Test Plan. The Field Testing Organization shall specify the operational conditions to be verified during the Verification Testing Plan.

The verification testing plan shall be performed in a series of short-term testing events for each operating condition to be verified. For surface water applications proper pretreatment must be applied as specified by the manufacturer. Testing shall be performed in the coldest period of the year. In addition, for each feed water tested a 30-day long-term testing period of continuous operation may be performed in the warmest period of the year to determine the effect of scaling and biofouling on the performance of the equipment.

Air stripping results in the transfer of VOCs from the feed water to air. Treatment of the air phase may be necessary. Treatment of the air exiting the air stripping equipment is not considered part of this equipment verification, and thus a verification of equipment performance under this test plan does not constitute verification of any air treatment system.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the required tasks to be included in the air stripping verification testing program.

4.1 Task 1: Characterization of Feed Water

The objective of this task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the origin of the feed water shall be provided to aid in interpretation of these characteristics.

4.2 Task 2: Verification Testing

Water treatment equipment shall be operated under steady state conditions for at least eight hours per operational condition to be verified, during the coldest period of the year, to collect data on equipment performance and water quality for purposes of performance verification.

4.3 Task 3: Operating Conditions and System Performance

During each operational condition of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include water loading rate, air loading rate, and water temperature. Equipment performance involves measurement of the air pressure drop and determination of potential precipitative scaling or biological fouling.

4.4 Task 4: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the air stripping process. Multiple water quality parameters will be monitored during the testing period. The mandatory water quality monitoring parameters shall include: temperature, calcium hardness, alkalinity, pH, dissolved oxygen and the VOCs to be treated. A basic goal of this Task is to confirm percentage removal of a variety of VOCs with a range of Henry's Law coefficients (H). This goal will allow for extrapolation of performance verification under identical operating conditions to other VOCs based on H. Water quality produced will be evaluated in relation to feed water quality and operational conditions.

4.5 Task 5: Data Management

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

4.6 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 air stripping equipment verification testing.

4.7 Task 7: Effect of Scaling or Biofouling (Recommended)

This task is performed in order to determine the reduction in VOC removal efficiency as a result of precipitative scaling or biofouling of the air stripping media. This task should be performed over a 30-day period of continuous operation in the warmest period of the year.

5.0 TESTING PERIOD

The required tasks of the ETV Testing Plan (Tasks 1 through 6) are designed to be completed in one testing period, not including mobilization, shakedown and start-up. VOC removal verification shall be performed in the coldest period of the year. The effect of scaling and biofouling (recommended Task 7) should be performed in a 30-day period during the warmest period of the year.

Cold weather operations will be an important component of water quality testing for surface water sources because of the impact of cold temperatures (1^oC to 5^oC) on water viscosity, diffusional processes and contaminant volatility. In particular, for air stripping equipment, factors that can influence treatment performance include:

- Cold water, encountered in winter or at high altitude locations in mountainous regions of the country.
- Feed waters with high hardness, or iron which may promote precipitation of inorganic materials in the equipment, accelerating the need for chemical cleaning.

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Warm weather long-term operation may also be an important component of performance testing because of the impact of warm temperatures on aqueous solubility and bioactivity. In particular, for air stripping equipment, factors that can influence long-term treatment performance include:

- Warm temperatures, encountered in summer, which increase the rate of bioactivity, resulting in increased biofouling. In general, the rate of bioactivity doubles with a 10^{o}C increase in temperature.
- Warm temperatures also affect on the solubility of scalants. In most cases solubility decreases and scaling increases with an increase in water temperature.
- Feed waters with high total sulfur which may promote biofouling.

Each of the above may accelerate the need for chemical cleaning.

6.0 DEFINITIONS

6.1 **Feed water:** Water introduced to the air stripper.

6.2 **Finished water:** Water exiting the air stripper.

6.3 **Packed Tower Aerator:** A tower containing packing material which provides a large surface area for contact between water and air. Water is passed downflow through the tower and is broken into thin sheets and droplets while air flows up through the packing material. The packing material could be structured media grids, or loose packing which is poured into the column, and can be made of plastic, wood, ceramic, or other materials.

6.4 **Tray Aerator:** Similar to a packed tower, this type of aeration device uses stacked porous shallow trays to distribute the water in thin sheets. Air is generally passed through perpendicularly to the trays.

6.5 **Diffused Aeration:** An aeration process in which compressed air is introduced into the bottom of a water basin through a two-dimensional matrix of microporous air ports.

6.6 **Spray Aerator**: An aeration process in which air is introduced into water by rapidly agitating the water surface with a mechanical mixer, causing a spray of water at the surface.

6.7 **Membrane Air Stripper:** An air stripping process in which the air to water contact is provided in the pores of a microporous hydrophobic gas permeable membrane. Water passes through the lumen of the membrane hollow fibers while air is passed through the membrane air stripper module on the exterior of the membrane fibers.

6.8 **Water Loading Rate or Liquid Loading Rate (L):** Volume of water entering the air stripper per unit time, normalized by the cross-sectional area of the air stripper. The water loading rate has units of volume per area per time: $m^3/(m^2 \times sec)$ or $ft^3/(ft^2 \times sec)$.

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6.9 **Air Loading Rate or Gas Loading Rate (G):** Volume of air entering the air stripper per unit time, normalized by the cross-sectional area of the air stripper. The air loading rate has units of volume per area per time: $m^3/(m^2 \text{ x sec})$ or $ft^3/(ft^2 \text{ x sec})$.

6.10 **Air/Water Ratio (A/W):** The ratio of the air loading rate to the water loading rate. The air to water ratio is dimensionless. (A/W = G/L).

6.11 **Henry's Law Coefficient (H):** Dimensionless ratio of the mass concentration of a given VOC in air to the mass concentration in water present at equilibrium between the two phases.

6.12 **Stripping Factor (S):** Dimensionless expression which is equal to the product of the air to water ratio and the Henry's Law coefficient of the VOC of interest.

6.13 **Removal Efficiency:** Percent removal of a contaminant (VOC) of interest, or:

$$R = [1 - (C_{feed} - C_{fin})/C_{feed}] \text{ x } 100\%$$

6.14 **Channeling:** Flow of water in channels formed along the media surface due to low water flow rate, which causes a reduced area for contact of air and water.

6.15 **Flooding:** Holdup of water in the air stripper due to high air loading rate.

6.16 **Biofouling:** Buildup of biological material on the packing material, resulting in increased air pressure drop.

6.17 **Scaling:** Buildup of precipitated solids on the packing material, resulting in increased air pressure drop.

7.0 BACKGROUND INFORMATION ON AIR STRIPPING

Air stripping for removal of VOCs from water is strictly a mass transfer process. No chemical reaction or transformation of the VOC occurs. Air stripping equipment is designed to provide a large surface area for contact between the water and VOC-free air, allowing VOCs to transfer from the water to the air in response to a concentration gradient between the two phases. Maximum mass transfer will occur in an air stripper that provides the greatest possible interface for contact between the phases, and increases the mass transfer coefficient in the water phase by providing turbulent flow conditions.

Theories of VOC transfer in air stripping are well known (e.g. Dvorak, et al. 1996), especially in packed tower aerators (e.g. Kavanaugh and Trussell, 1980; Ball et al., 1984). Other air stripping equipment, though not as thoroughly studied, can also be well understood using mass transfer theory (e.g. membrane air stripping (Zander et al., 1986); cascade crossflow air stripping (Verma et al., 1994); surface aerators (Parker et al., 1996)).

In all cases two-film theory can be used to describe the resistance to mass transfer encountered by a VOC molecule in transferring from one phase to the other as the sum of the individual resistances to mass transfer in each phase. The overall resistance to mass transfer ($1/K_La$) is given by:

$$1/K_La = 1/k_La + 1/Hk_Ga$$

where K_L is the overall mass transfer rate coefficient based on the water phase driving force, k_L is the water side mass transfer coefficient, and k_G is the gas phase mass transfer coefficient. The term 'a' in each of the above expressions is the interfacial area between water and air per unit volume of the aerator. Each of the mass transfer coefficients, as well as the interfacial area available for mass transfer in a given aerator, are functions of the A/W ratio provided to the aerator.

Design equations are available for the different types of aeration equipment. For the example of packed tower aeration, the depth of tower packing necessary to provide a desired removal efficiency is calculated from a mass balance over a control volume (Hines and Maddox, 1985).

$$\text{Depth} = L/K_La\ [S/(S-1)]\ \ln\{1/S + [(S-1)/S]\ (C_{feed}/C_{fin})\}$$

where, L = water loading rate
S = stripping factor
C_{feed} = mass concentration of the VOC of interest in the feed water
C_{fin} = mass concentration of the VOC of interest in the finished water

Thus in air stripping, removal efficiency is a function of the stripping factor, S, and the overall mass transfer coefficient K_La. More precisely, removal efficiency is a function of the air and water loading rates to the equipment and the Henry's Law coefficient of the VOC of interest.

For a given set of air and water loading rates, verification of a certain removal efficiency for a VOC with a Henry's Law coefficient $H = H_1$, ensures equal or greater removal efficiency for all VOCs with H greater than H_1. Similarly, verification of a certain removal efficiency for a VOC at a given set of air and water loading rates, ensures equal or greater removal efficiency for that VOC at a higher air loading rate and the given water loading rate (assuming flooding does not occur). Finally, verification of a given removal efficiency for a given VOC at a temperature $T = T_1$, ensures equal or greater removal efficiency for that VOC at any T greater than T_1.

For mechanical air stripping equipment such as a spray aerator, verification of removal efficiency for a VOC with a Henry's law coefficient of $H = H_1$, ensures equal or greater removal efficiency for all VOCs with H greater than H_1, and equal or greater removal efficiency of the given VOC at any motor speed greater than that tested.

As each type of air stripping equipment allows calculation of an estimated removal efficiency using design equations, operating conditions and the VOCs to be tested can and should be judiciously chosen to minimize unnecessary testing.

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8.0 TASK 1: CHARACTERIZATION OF FEED WATER

8.1 Introduction

This task is needed to document the chemical and microbiological characteristics of the feed water.

8.2 Experimental Objective

The objective of this task is to document the water quality characteristics of the feed water to the air stripping system, including the initial mass concentration of VOCs of interest in the feed water and potentially including the calculated potential for precipitative scaling, and a measured indication of the potential for microbiological fouling.

8.3 Work Plan

This task can be accomplished by using approved analytical measurements obtained from certified third party sources (i.e. United States Geological Society (USGS), EPA, 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:

- VOCs of interest and their respective mass concentration in the feed water and water temperature.

It is recommended that additional parameters be measured to characterize the water, including:

- Dissolved oxygen, pH and turbidity to establish physical characterization;
- Total Dissolved Solids, Total Alkalinity, Total Hardness, Scaling Potential, Iron, and Manganese to establish inorganic chemical characterization; and
- Heterotrophic Plate Count and Total Sulfur to establish the potential for microbiological fouling.

A brief description of the water source shall be provided to aid in interpretation of feed water characteristics.

Several of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization. Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Tables 1 and 2. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the

State certified, third-party accredited, or EPA accredited laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

8.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a water source for use as feed water in an air stripping Verification Testing Program. In the absence of such data, a set of these measurements performed by an approved lab will suffice for this task. Table 1 outlines the required parameters to be measured and the methods to be used for analysis. Table 2 outlines the recommended parameters to be measured and their respective analytical methods.

Table 1
Required Analytical Parameters and Methods

Parameter	Facility	Standard Method[a]	EPA Method[b]
VOCs (specify)	Lab	6210 C	502.2 / 524.2
Temperature	On-Site	2550 B	

Notes:
[a] APHA, AWWA, WEF, 1999.
[b] EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Samples of feed waters shall be collected for analysis of indigenous bacterial densities by heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the State certified, third-party accredited (e.g. NSF), or EPA accredited analytical laboratory. Samples shall be processed for analysis by the State certified, third-party accredited, or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. HPC densities will be reported as colony forming units per milliliter (cfu/mL).

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Table 2
Recommended Analytical Parameters and Methods

Parameter	Facility	Standard Method[a]	EPA Method[b]
pH	On-Site	4500-H^+	150.1 / 150.2
Turbidity	Lab	2130 B	180.1
Dissolved Oxygen	Lab	4500-O	
Total Dissolved Solids	Lab	2540 C	
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Iron	Lab	3113 B	200.7 / 200.8 / 200.9
Manganese	Lab	3113 B	200.7 / 200.8 / 200.9
Total Sulfide	Lab	4500-S^{2-}	
Heterotrophic Plate Count (HPC)	Lab	9215 B	
Scaling Potential	Calculated	Langlier’s Index	

Notes:
[a] APHA, AWWA, WEF, 1999.
[b] EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

8.5 Evaluation Criteria and Minimum Reporting Requirements

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 using the equipment specified. The Langelier Index or another index which quantifies the scaling potential for the feed water should be calculated and reported along with the raw data collected as part of this task.

9.0 TASK 2: VERIFICATION TESTING

9.1 Introduction

Air stripping equipment shall be operated for Verification Testing purposes. VOC removal efficiency by the air stripping equipment will be tested for the stated VOCs of interest.

9.2 Experimental Objectives

The objective of this task is to operate the 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

This task shall be performed concurrently with Task 3: Operating Conditions and System Performance.

For this task the Manufacturer or Field Testing Organization shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the air stripping system. The Field Testing Organization shall specify the air and water loading rates at which the equipment is to be verified, and the VOCs which should be measured as part of the verification testing.

After set-up and shakedown of the air stripping equipment, operation should be established at the air and water loading rates for the condition to be verified. The air stripping equipment shall be operated under these steady state conditions for a minimum of eight hours per operating condition to be verified.

Additional operational conditions may be verified using the same equipment in successive periods as long as the verification period does not extend beyond the time period of coldest operating temperature for verification purposes. For each testing period the air and water loading rates to be tested shall be explicitly stated prior to testing.

This Verification Testing Plan has been designed with the aim of balancing cost of verification with benefits of testing over a wide range of operating conditions. It shall be understood that beyond the operational characteristics specifically tested, air stripping equipment operation which occurs at an air loading rate higher than specifically tested for a given water loading rate shall also constitute a verifiable condition, as long as the condition does not lead to flooding.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization. Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited, or EPA accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Table 1 with additional recommended parameters in Table 2. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site certified or accredited laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State certified, third-party accredited, or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

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9.4 Analytical Schedule

Samples shall be collected at least three times per operational condition and at least two hours apart from the feed water and the finished water and analyzed to determine the mass concentration of the VOCs of interest. The temperature of the feed water and finished water shall be measured and documented immediately after samples for VOC analysis are collected. The analytical methods are provided in Table 3.

Table 3
Testing Schedule and Methods for Verification Testing

Parameter	Location	Facility	Method
VOCs (specified)	Feed water	Lab	Standard Methods[a] 6210 C or EPA Method[b] 524
VOCs (specified)	Finished water	Lab	Standard Methods[a] 6210 C or EPA Method[b] 524
Temperature	Feed water	On-Site	Standard Method 2550 B
Temperature	Finished water	On-Site	Standard Method 2550 B

Notes:

[a] APHA, AWWA, WEF, 1999.

[b] EPA Methods Source: EPA Office of Ground and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

9.5 Evaluation Criteria and Minimum Reporting Requirements

The goal of this task is to operate the equipment under steady state conditions at each verifiable operating condition. Data shall be provided to substantiate operation at steady state. The concentration of each VOC of interest in the feed water and the finished water shall be reported for each condition, along with the temperature of the feed and finished water. In addition, all operational data collected shall be reported.

10.0 TASK 3: OPERATING CONDITIONS AND SYSTEM PERFORMANCE

10.1 Introduction

During each condition of Verification Testing, and at least twice during each day, operating conditions shall be documented. This shall include a statement of any pretreatment performed on the feed water, documentation of air pressure drop through the equipment, flow measurements, visual inspection of equipment, and any maintenance activities performed.

10.2 Experimental Objectives

The objective of this task is to accurately and fully document the operating conditions that are applied during treatment and the performance of the air stripping equipment. This task is

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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.

10.3 Work Plan

This task shall be performed concurrently with Task 2: Verification Testing.

Measurement of feed water flow rate, air flow rate, and air pressure entering the air stripper shall be performed at a minimum of two times per day. For packed tower and tray aerator systems, air pressure exiting the system shall also be measured two times per day, within 15 minutes of measurement of the influent air pressure.

In an attempt to calculate costs for operation of air stripping equipment, power costs for operation of the equipment shall also be closely monitored and recorded by the Field Testing Organization during the testing period(s). Power usage shall be estimated by the following requirements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor, motor power usage for fans or mixers, etc.

10.4 Evaluation Criteria and Minimum Reporting Requirements

Where applicable, the data developed from this task will be compared to statement 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.

11.0 TASK 4: FINISHED WATER QUALITY

11.1 Introduction

Water quality data shall be collected for the finished water as was performed for the feed water and as shown in Table 1. At a minimum, the required sampling shown in Table 1 shall be observed by the Field Testing Organization on behalf of the Manufacturer. Recommended tests from Table 2 may also be included. Water quality goals and target removal goals for the air stripping equipment shall be recorded in the Product-Specific Test Plan.

11.2 Experimental Objectives

The objective of this task is to assess the ability of the air stripping equipment to meet the water quality goals specified by the Manufacturer and to identify any potential adverse effect on the water quality.

11.3 Work Plan

Several of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization (refer to Table 2). Analysis of the remaining water quality parameters shall be performed by a State certified, third-party accredited, or EPA

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accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in Table 1. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site certified or accredited laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State certified, third-party accredited, or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

11.4 Analytical Schedule

At least once in each verification test the finished water shall be characterized by measurement of the following water quality parameters (as indicated also in Table 2). The specific parameters needed to characterize the water will depend on the equipment being tested, but information on the following characteristics are also recommended for compilation:

- Dissolved oxygen, pH and turbidity to establish any changes in physical characterization relative to the feed water;
- Total Dissolved Solids, Total Alkalinity, Total Hardness, Corrosivity, Iron, and Manganese to establish mass balances on the inorganic parameters; and
- Heterotrophic Plate Count and Total Sulfide to indicate the likelihood of biological fouling.

Additional sampling and data collection may be performed at the discretion of the Field Testing Organization. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Product-Specific Test Plan.

Samples of feed waters shall be collected for analysis of indigenous bacterial densities by heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the State certified, third-party accredited, or EPA accredited analytical laboratory. Samples shall be processed for analysis by the State certified, third-party accredited, or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. HPC densities will be reported as colony forming units per milliliter (cfu/mL).

11.5 Evaluation Criteria and Minimum Reporting Requirements

Where applicable, the data from this task will be utilized to determine if scaling or biofouling has occurred in the air stripping equipment, and as feasible perform a mass balance to determine the extent of that fouling. Any loss of inorganic material shall be interpreted as scaling and increase in biological material shall be interpreted as fouling and must be reported in the Verification Report.

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12.0 TASK 5:DATA MANAGEMENT

12.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheets and manual recording of operational parameters for the air stripping equipment on a daily basis.

12.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for verification purposes.

12.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field 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 spreadsheet software. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a weekly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the Field Testing Organization at least once per week during each testing period. 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 air stripping 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 shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall 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 shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on magnetic storage (e.g. disk), and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment shall 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, third-party accredited, or EPA accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

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13.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

13.1 Introduction

Quality assurance and quality control of the operation of the air stripping equipment and the measured water quality parameters shall be maintained during the verification testing program.

13.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. 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.

13.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily visual check during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Air and water flow rates shall be measured and documented. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm 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.

13.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of feed water and filtrate water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

13.4.1 Temperature

Readings for temperature shall be conducted in accordance with Standard Methods 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°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°C increments would be appropriate for this work.)

13.4.2 pH (Optional)

Analyses for pH shall be performed according to Standard Method 4500-H^+. 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 can confound pH measurements in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended.

13.4.3 Turbidity (Optional)

Turbidity analyses shall be performed in accordance with Standard Method 2130 with a bench-top turbidimeter. (An in-line turbidimeter is acceptable, but unnecessary for this task.) The turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of verification testing and on a weekly basis thereafter using primary turbidity standards of 0.1, 0.5 and 3.0 NTU. The turbidimeter shall be recalibrated after being shut off and re-started.

The method of 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 which cause the vial to fog, allow the vial to warm slightly by submersing partially into a warm water bath for approximately thirty seconds.

13.4.4 Dissolved Oxygen (Optional)

Dissolved oxygen analyses shall be performed in accordance with Standard Method 4500-O with a field dissolved oxygen meter or a field titration. Calibrate either method as described in Standard Methods (APHA, AWWA, WEF, 1999).

Avoid entraining or dissolving atmospheric oxygen during sampling. In sampling from a line under pressure, attach a glass or rubber tube to the tap and extend to the bottom of the sample bottle. Let the bottle overflow two or three times its volume and stopper the bottle.

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13.5 Chemical and Biological Samples Shipped Off-Site for Analysis

13.5.1 VOCs

Samples for measurement of VOC concentrations shall be collected headspace-free in 25- or 40-mL glass bottles equipped with a screw cap with a hole in the center and TFE-lined silicone septa supplied by the State certified, third-party accredited, or EPA accredited laboratory. Samples shall be collected in duplicate, stored at 4°C in an atmosphere free of organic solvent vapors, and shipped at 4°C to the analytical laboratory. Field blanks shall be collected with the samples and subjected to storage and shipping as performed for the analytical samples. Analysis shall occur within 14 days of sampling.

13.5.2 Chemical Analysis: Total Dissolved Solids, Alkalinity, and Hardness (Optional Parameters)

Samples shall be collected headspace-free in polyethylene or borosilicate glass bottles and capped tightly. Store and ship at 4°C. Analyze as soon as possible and in no case store samples more than seven days. Bring samples to room temperature prior to analysis.

13.5.3 Chemical Analysis: Iron and Manganese (Optional Parameters)

Samples shall be collected in acid-rinsed polypropylene or linear polyethylene containers supplied by the State certified, third-party accredited, or EPA accredited analytical laboratory. Preserve samples immediately after sampling with concentrated high-purity nitric acid to a pH less than 2. Usually 1.5 mL concentrated HNO_3 per liter of sample is sufficient. Store and ship at 4°C, and analyze as soon as possible, but within 6 months of sampling.

13.5.4 Chemical Analysis: Total Sulfide (Optional)

Samples shall be collected with minimum aeration in polypropylene or glass bottles containing zinc acetate solution provided by the State certified, third-party accredited, or EPA accredited laboratory. Fill the bottle completely and add NaOH dropwise to a pH greater than 9. Store and ship at 4°C, and analyze as soon as possible, but within 28 days of sampling.

13.5.5 Microbial Analysis: Heterotrophic Plate Count (Optional)

Microbiological samples shall be collected in carefully cleaned and sterilized bottles or bags supplied by the State certified, third-party accredited, or EPA accredited analytical laboratory. Analyze samples as soon as possible, but within 24 hours of sampling. Hold and ship samples at or below 4°C, but do not freeze.

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14.0 TASK 7: EFFECT OF SCALING AND BIOFOULING (RECOMMENDED)

14.1 Introduction

Long-term performance of the air stripping equipment involving the effect of scaling and/or biofouling on the VOC removal efficiency is recommended to be determined in a 30-day continuous operation during the warmest season of the year.

14.2 Experimental Objectives

The objective of this task is to quantify the reduction of VOC removal efficiency over a continuous 30-day operating period for a given feed water.

14.3 Work Plan

This task shall be performed concurrently with Task 3: Operating Conditions and System Performance.

For this task the Manufacturer or Field Testing Organization shall specify the operating condition to be utilized for a 30-day continuous operation during the warmest season of the year. The Field Testing Organization shall specify the air and water loading rates at which the equipment is to be verified, and the VOCs which should be measured as part of the verification testing.

After set-up and shakedown of the air stripping equipment, operation should be established at the air and water loading rates for the condition to be verified. The air stripping equipment shall be operated under these steady state conditions for a minimum of 30 days.

Analysis of the concentration of VOCs in the feed water and the finished water shall be performed by a state certified, third-party accredited, or EPA accredited laboratory. Water samples shall be collected in appropriate containers prepared by the state certified, third-party accredited, or EPA accredited off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

14.4 Analytical Schedule

Samples shall be collected at least every third day from the feed water and the finished water and analyzed to determine the mass concentration of the VOCs of interest.

14.5 Evaluation Criteria and Minimum Reporting Requirements

The goal of this task is to quantify the VOC removal efficiency over a longer operation period. Data should be provided to verify operation for at least 30 days. The concentration of each VOC of interest in the feed water and the finished water shall be reported for at least every third day, along with the temperature of the feed and finished water. Removal efficiency for each VOC shall be calculated for each set of samples. In addition, all operational data collected shall be reported.

15.0 OPERATION AND MAINTENANCE MANUAL CRITERIA - AIR STRIPPING EQUIPMENT

The Field Testing Organization shall obtain the Manufacturer-supplied Operations and Maintenance (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 air stripping for removal of VOCs.

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
- blowers
- valves
- motors
- instruments, such as an in-line turbidimeter
- flow measurement devices

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

- tanks and basins
- tower materials
- tower packing or tray materials
- membrane modules.

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:

- Procedures for setting and measuring air and water flow rates
- Proper cleaning procedures for all equipment provided
- Proper operation of any pretreatment equipment deemed necessary.

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CHAPTER 3

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF VOLATILE ORGANIC CHEMICAL CONTAMINANTS BY ADSORPTIVE MEDIA PROCESSES

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1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the Environmental Technology Verification (ETV) Technology Specific Test Plan (TSTP) for evaluation of drinking water treatment equipment utilizing adsorptive media for volatile organic chemical (VOC) removal. This TSTP is to be used within the structure provided by the *Protocol for Equipment Verification Testing for Volatile Organic Chemical Removal: Chapter 1 General Requirements*. This TSTP is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of adsorptive media and related equipment to achieve removal of VOCs.

This document is applicable only to fixed-bed adsorption processes in which adsorption occurs as water flows through a stationary bed of adsorptive media. It is anticipated that most such systems will use granular activated carbon (GAC) as the adsorptive media, but other media types are also acceptable for verification testing. **This document is NOT applicable to slurry systems, such as those using powdered activated carbon (PAC) or other diffuse adsorption processes in which the adsorptive media are added directly to water.**

To participate in the equipment verification process for adsorption processes, the equipment manufacturer and its designated Field Testing Organization (FTO) shall employ the procedures and methods described in this TSTP and in the referenced ETV protocol document as guidelines for the development of the PSTP. The FTO shall clearly specify in the PSTP, the VOCs targeted for removal and the sampling program that shall be followed during verification testing. The PSTP should generally follow those tasks outlined herein, with changes and modifications made for adaptations to specific equipment. At a minimum, the format of the procedures written in the PSTP for each task should consist of the following sections:

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

The primary goal of equipment employed in this verification testing program is to remove VOCs present in water supplies, treating water to compliance with Phase I, II, and V Rules of the Safe Drinking Water Act (SDWA). The organic contaminants listed in the Phase I (Appendix A, Table A.1) Rule are all classified as VOCs, while the organic contaminants listed in Phase II (Appendix A, Table A.2) and Phase V Rules (Appendix A, Table A.3) include compounds classified as both synthetic organic chemicals (SOCs), including pesticides and herbicides, and VOCs. This document focuses on verification testing of systems for the removal of VOCs as classified in Phase I, II, and V Rules of the SDWA. For verification testing of systems for the removal of SOCs listed in Phase II and V Rules of the SDWA, a companion document should be used: *EPA/NSF ETV Equipment Verification Testing Plan for the Removal of Synthetic Organic Chemical Contaminants by Adsorptive Media* (EPA/NSF 2002). These documents may also be used for verification testing of adsorptive media for the removal of chemicals listed in *Drinking Water Standards and Health Advisories* (USEPA 2000), which are included as Appendix B in this document.

Experimental design of the PSTP shall be developed so that relevant performance specifications for adsorptive media related to VOC removal are addressed. The manufacturer may wish to establish a statement of performance capabilities (see Section 3.0, General Approach) that is based upon removal of target VOCs from influent water sources, or alternatively, one based upon compliance with drinking water standards. For example, the manufacturer could include in the PSTP a statement of performance capabilities that would achieve compliance with maximum contaminant levels (MCLs) stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for a specific water quality parameter. The experimental design of the PSTP shall be developed to address the specific statement of performance capabilities established by the manufacturer. Each PSTP shall include all of the tasks described in this document, Tasks 1 to 8. An overview of the tasks is given in Section 6.0, Overview of Tasks.

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2.0 INTRODUCTION

Fixed-bed adsorptive media processes are currently used for a number of water treatment applications, including removal of color, taste and odor, disinfection by-product precursors (DBPs), SOCs, VOCs, and inorganic compounds (Snoeyink and Summers 1999). Performance of adsorptive media for VOC removal is highly dependent on a number of factors, including influent VOC concentration; influent water quality, including other VOCs or SOCs, background organic matter (BOM), pH, temperature; and system design, including empty-bed contact time (EBCT) and adsorbent type. Adsorption is not a steady-state process; this TSTP is designed based on a statement of performance capabilities that specifies a run time achievable for a given fixed-bed adsorptive media process under specified influent conditions. The run time is the operation time of the system during which time the removal of VOC(s) meets or exceeds that stated in the manufacturer's statement of performance capabilities. Alternatively, the statement of performance capabilities may specify a maximum adsorbent usage rate (AUR) to be verified.

Standard pretreatment, such as cartridge filtration, included as part of the packaged/modular adsorption treatment equipment is considered an integral part of the treatment system. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for evaluation purposes.

Additional pretreatment processes may be required to reduce particle loading to the adsorption process for surface water applications (and ground waters in which iron and manganese precipitation is an issue). These are considered to constitute a separate treatment module whose performance and operation are outside the scope of this document. Where such pretreatment is required to reduce the fouling potential of the adsorption process feed water, consult the ETV document, *EPA/NSF ETV Protocol for Physical Removal of Microbiological and Particulate Contaminants* (EPA/NSF 2002), for evaluation testing procedures.

Two or more parallel contactors, whose effluents are blended prior to further treatment or distribution, are considered one system for the purposes of verification testing.

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3.0 GENERAL APPROACH

Testing of equipment covered by this TSTP shall be conducted by an FTO that is qualified by NSF International (NSF) and selected by the equipment manufacturer. Testing of analytical water quality performed in conjunction with this TSTP shall be contracted with a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA.

For verification testing, the manufacturer shall identify in a statement of performance capabilities, the specific performance criteria to be verified and the specific operational conditions under which the verification testing shall be performed. The statement of performance capabilities must be specific and verifiable. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to under perform or fail. There are different types of statements of performance capabilities that may be verified. Examples are provided in Table 3.1.

Verification testing shall consist of an evaluation of the fixed-bed adsorptive media treatment system using an influent water containing one VOC at target influent concentrations equal to that stated in the statement of performance capabilities, for a minimum period of 13 days and one 8-hour shift. Statistical analyses of the data results shall include averages, minimum, and maximum for each analyte. For sample sets of eight or more, the results shall also include the standard deviation and confidence interval for each analyte. A pilot plant representing the package plant shall not be substituted for the actual package treatment system. The 13.3-day minimum testing period is designed to allow for an evaluation of the system’s mechanical and hydraulic integrity and operability under field conditions, as well as to assess VOC removal performance for 13.3 days of operation. However, breakthrough of the VOC will often not occur within the first 13.3 days of operation. Consequently, verification testing of the system for longer than 13.3 days may be desirable to achieve breakthrough and will be necessary to verify a manufacturer’s statement of performance capabilities of run time greater than 13.3 days. For adsorption systems incorporating in-place media regeneration, the effectiveness of regeneration shall also be assessed.

Table 3.1 Examples of Statements of Performance Capabilities

Testing Mode	Single or Multiple Compounds	Example Statement of Performance Capabilities
Constant influent, low variability	Single	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 60 days (AUR ≤ 0.086 g/L or 0.72 lb/1,000 gal) in GAC influent waters containing mean tetrachloroethylene concentrations at or below 20 µg/L with low variability (RSD ≤ 10%); TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 Nephlometric Turbidity Units (NTU); and temperature between 20 and 25°C, containing no other VOCs or SOCs at levels above 1 µg/L.
	Multiple	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 120 days (AUR ≤ 0.043 g/L or 0.36 lb/1,000 gal) in GAC influent waters containing mean tetrachloroethylene concentrations at or below 20 µg/L with low variability (RSD ≤ 10%); TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 NTU; temperature between 20 and 25°C; containing the following VOCs or SOCs: benzene at 12 µg/L, carbon tetrachloride at 8 µg/L, vinyl chloride at 5 µg/L. *A statement of performance capabilities could also be made for these other compounds.*
Constant influent, high variability	Single	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 60 days (AUR ≤ 0.086 g/L or 0.72 lb/1,000 gal) in GAC influent waters containing mean tetrachloroethylene concentrations at or below 25 µg/L with high variability (ranging from 5 to 40 µg/L, RSD ≥ 30 and ≤ 60%); TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 NTU; and temperature between 20 and 25°C, containing no other VOCs or SOCs at levels above 1 µg/L.
	Multiple	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 90 days (AUR ≤ 0.058 g/L or 0.49 lb/1,000 gal) in GAC influent waters containing tetrachloroethylene concentrations at or below 25 µg/L with high variability (ranging from 5 to 40 µg/L, RSD ≥ 30 and ≤ 60%); TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 NTU; temperature between 20 and 25°C; containing the following VOCs or SOCs: benzene at 12 µg/L, carbon tetrachloride at 8 µg/L, vinyl chloride at 5 µg/L. *A statement of performance capabilities could also be made for these other compounds.*

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Table 3.1 Examples of Statements of Performance Capabilities (cont.)

Attenuation of spiked influent	Single	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 60 days (AUR ≤ 0.086 g/L or 0.72 lb/1,000 gal) after the GAC influent water begins receiving a spike of tetrachloroethylene at a mean concentration of 25 µg/L (with low variability, RSD ≤ 10%) for 48 hours; after treating the following water quality with no SOCs present for 120 days or less; TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 NTU; and temperature between 20 and 25°C, containing no other SOCs at levels above 1 µg/L.
	Multiple	This single-contactor package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining a treated water tetrachloroethylene concentration below 5 µg/L for up to 90 days (AUR ≤ 0.058 g/L or 0.49 lb/1,000 gal) after the GAC influent water begins receiving a spike of tetrachloroethylene at a mean concentration of 25 µg/L (with low variability, RSD ≤ 10%) for 48 hours; after treating the following water quality with no SOCs present for 120 days or less; TOC concentrations at or below 3.0 mg/L; turbidity levels at or below 1.0 NTU; temperature between 20 and 25°C; with the following SOCs also contained in the 48-hour spiked influent: benzene at 12 µg/L, carbon tetrachloride at 8 µg/L, vinyl chloride at 5 µg/L. *A statement of performance capabilities could also be made for these other compounds.*

The design and duration of the equipment verification testing is based on the overall equipment performance demonstration goal of the test. At a minimum, verification testing must accomplish a demonstration of system integrity and initial performance by operating the system for a minimum of 13.3 days [System Integrity Verification Testing (SIVT)]. Equipment verification testing for a time period exceeding 13.3 days may have two objectives. Objective A includes completing the requirements of SIVT, and then evaluating adsorption capacity by testing until breakthrough of the VOC. Objective B also includes completing the requirements of SIVT, and then evaluating adsorption capacity to a run time greater than 13.3 days, but prior to breakthrough of the VOC. Testing under Objective B will result in termination of testing prior to breakthrough, yielding an AUR higher than that potentially achievable by the system. However, due to long run times to breakthrough for highly adsorbable VOCs, it may be preferable to terminate the test prior to breakthrough, still showing that run times substantially greater than 13.3 days are achievable by the system for the VOC tested. For both SIVT and both optional objectives, the AUR shall be determined by the run time of the last effluent sample taken during testing (if testing is terminated prior to breakthrough), or the run time to breakthrough, whichever occurs first.

During verification testing, the target VOC may already be present in the source water used. However, the manufacturer may wish to perform verification testing at an influent concentration higher than that of the VOC normally present in the source water, or the manufacturer may wish to test for a compound not detected in the source water to be tested. In these cases, the adsorption influent water may be spiked to the target concentration with the VOC to be tested.

If a manufacturer's statement of performance capabilities bases performance on simultaneous treatment of multiple VOCs, verification testing shall be performed with an equivalent mixture of multiple VOCs (specific VOCs and influent concentrations targeted based on the statement of performance capabilities). Although testing with multiple influent VOCs is allowable, this TSTP is designed to verify performance of a single VOC influent. However, standard verification testing of a multiple-compound manufacturer's statement of performance capabilities can be conducted using this TSTP. For verification testing of an AUR by testing until breakthrough of the VOC (Objective A), this document provides guidance for estimating the usage rate. This guidance, however, is based on a single compound influent, and is not directly applicable to multiple-compound influents, due to the impact of competitive adsorption. The manufacturer's statement of performance capabilities may be based on a run time for a single compound within the mixture of compounds, or it may be based on multiple run times for each of multiple compounds. For regulated VOCs, the AUR will be based on the first compound to exceed the MCL in the system effluent.

Verification testing of three modes of operation are possible under this TSTP: (1) constant influent with low variability, (2) constant influent with high variability about a target mean concentration, and (3) attenuation of a spiked influent. Most statements of performance capabilities will be based on the presence of a single influent VOC at a constant concentration with low variability, and this TSTP has been designed to verify these types of manufacturer's statements of performance capabilities. However, this TSTP may also be used to perform verification testing under conditions of highly variable influent VOC concentrations about a target mean concentration and attenuation of a spiked influent. For verification testing of attenuation of a spiked influent, the statement of performance capabilities must state the amount of time the system was in operation receiving influent water without the VOC to be spiked before spiking begins, as in the example given in Table 3.1.

Package plants that operate by blending the effluents of more than one contactor in parallel prior to further treatment and distribution shall be evaluated by assessing the water quality of the blended effluent from all contactors. If contactors are operated in staggered operation cycles to improve the overall efficiency of the process, then effluent testing will still be performed on the blended effluent of all contactors. The statement of performance capabilities shall clearly state the number of contactors operated and clearly describe the mode of operation (parallel or parallel-staggered-) so that package plant performance can be evaluated in terms of the mode of operation employed.

For verification testing of Objective A (testing until breakthrough is reached), breakthrough is defined as reaching an effluent concentration of the VOC tested. This concentration can be chosen by the manufacturer, or it can be a level equal to a regulated or proposed MCL, in which case the statement of performance capabilities should designate it as such. Depending on the quality and amount of data gathered to characterize the breakthrough curve, the AUR can be calculated by different methods, as described in Section 11.5.

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4.0 BACKGROUND

This section provides a brief overview of SOC and VOC regulations, health effects, VOC removal by fixed-bed adsorptive systems, and adsorption system design. This information should assist in providing a background on VOC removal by adsorption processes and on the applicability of fixed-bed adsorption processes to treatment of VOCs. Due to the predominance of the use of GAC media for adsorption, the information presented in this section will focus on adsorption using GAC. The term SOC as used in this section includes volatile, semi volatile, nonvolatile compounds, and VOCs as classified in Phase I, II, and V Rule Contaminants of the SDWA.

4.1 VOC and SOC Health Effects and Regulations

Three general types of organic compounds found in water are (1) compounds resulting from the breakdown of naturally-occurring organic material, such as humic materials from plants and algae, microorganisms and their metabolites, and high molecular weight aliphatic and aromatic hydrocarbons; (2) compounds formed due to domestic and commercial activities (SOCs); and (3) compounds formed by chemical reactions during water treatment and transmission (Cohn, Cox, and Berger 1999). SOCs include pesticides, solvents, metal degreasers, and polychlorinated biphenyls.

The 1974 SDWA specified the process by which EPA adopted national drinking water regulations, including the establishment and publication of recommended maximum contaminant levels (RMCLs), set at levels at which no known or anticipated health effects would occur (Pontius and Clark 1999). RMCLs were followed by the establishment of MCLs, set as close to the RMCL as economically and technically feasible. Currently, 56 organic contaminants are regulated under Phase I Volatile Organics, Phase II Rule Organics, and Phase V Rule Contaminants. Appendix A lists currently regulated organic contaminants, including MCL goal (MCLG), MCL, potential health effects and sources of drinking water contamination. Appendix B contains the most recent *Drinking Water Standards and Health Advisories* tables available (USEPA 2000), listing 172 SOCs and VOCs, and describing the status of their legislation, MCLGs, MCLs, health advisory document status, and available health effects data. These tables are revised periodically by EPA and can be accessed on the Internet at www.epa.gov/ost/drinking/standards/summary.html or a copy may be ordered by calling the Safe Drinking Water Hotline (1-800-426-4791).

The SDWA also requires that EPA establish a list of contaminants that serves as the primary source for priority contaminants considered for regulation. The list is divided into contaminants that are priorities for future research, those that need additional occurrence data, and those that are priorities for future rulemaking. The final Drinking Water Contaminant Candidate List (CCL) was published in 1998. The CCL can be accessed on the Internet at www.epa.gov/safewater/ccl/cclfs.html.

4.2 VOC and SOC Removal by Adsorption Processes

Removal of organic compounds by adsorption occurs through several steps: external diffusion, internal diffusion, and adsorption. First, organic compounds are transported from the bulk solution to the boundary layer of water surrounding the adsorbent particle. Second, organic compounds are transported by molecular diffusion through the external boundary layer (film diffusion). Third, organic compounds are transported through the adsorbent's pores to an available internal adsorption site. The transport mechanism for internal diffusion can be pore diffusion, molecular diffusion through the solution within the pores, or surface diffusion (diffusion along the adsorbent surface after adsorption has occurred). The final step is physical adsorption of the organic compound to the adsorbent. The slowest step of these four is the rate-limiting step, and it will control the rate of organic compound removal. In adsorption by GAC, the rate-limiting step is usually film diffusion or pore diffusion (Snoeyink and Summers 1999).

4.3 Application of Adsorptive Media

In a GAC fixed-bed adsorption system, the mass transfer zone (MTZ) is the region in which adsorption is taking place. The activated carbon behind the MTZ is completely saturated with the adsorbate, while that ahead of the MTZ has not been exposed. Within the MTZ, the degree of saturation varies from zero to complete saturation. The length of the MTZ can vary (see Snoeyink and Summers 1999 for more information on factors affecting the MTZ length) and in some cases, the MTZ is very short and an ideal plug-flow behavior can be assumed. This assumption simplifies analysis and prediction of run time to breakthrough for adsorption of a single compound. Breakthrough is defined as the point when the contactor effluent concentration reaches the maximum acceptable effluent concentration, which is also referred to as the treatment objective. The breakthrough curve is a plot of column effluent concentration as a function of operation time or throughput in bed volumes (BV) treated. Throughput is related to operation time by EBCT, as presented in Equation 1:

$$\text{Throughput (BV)} = \frac{\text{Operation time (days)} \cdot 1{,}440 \text{ min/day}}{\text{EBCT (min)}} \qquad (1)$$

EBCT is the hydraulic retention time of an empty contactor. The EBCT parameter normalizes bed depths at different loading rates and it is calculated as the volume of the contactor occupied by the adsorbent divided by the flow rate.

The performance of adsorptive media for removal of VOCs and SOCs varies widely. In large part, performance is dependent on the influent concentration and adsorbability of the compound studied. For a 6-minute EBCT adsorber with bituminous coal-based GAC, breakthrough of trichloroethene to 50% of its influent concentration (310 µg/L) occurred after 25,000 BV (104 days). Breakthrough of cis-1,2 dichloroethene to 50% of its influent concentration (70 µg/L) occurred after 17,000 BV (59 days) in a 5-minute EBCT contactor, also using bituminous coal-based GAC (Sontheimer, Crittenden, and Summers 1988).

The equilibrium relationship between the solid phase concentration (quantity of adsorbate per unit adsorbent), q_E, and the equilibrium solution concentration, C_E, is the adsorption isotherm. This relationship can be described by the Freundlich equation, as presented in Equation 2:

$$q_E = K C_E^{1/n} \qquad (2)$$

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where K and $1/n$ are constants. The constant K is related to the capacity of the adsorbent for the adsorbate, and $1/n$ is a function of the strength of adsorption (Snoeyink and Summers 1999). Values for K and $1/n$ have been tabulated for many SOCs (and VOCs) in the literature (Snoeyink and Summers 1999; Sontheimer, Crittenden, and Summers 1988; Faust and Aly 1998; Speth and Miltner 1990, 1998). The value and units of K are dependent on the units of C_E and q_E.

Many researchers have shown that the presence of BOM can have a negative impact on the adsorption capacity of an adsorbent for VOCs and SOCs. Relative to the SOC targeted for removal by adsorption, BOM will move more rapidly through the contactor and adsorb onto adsorbent sites. As more adsorption sites are taken by preloading with BOM, the capacity of the adsorbent for the SOC is reduced (Crittenden et al. 1985; Sontheimer, Crittenden, and Summers, 1988; Speth and Adams 1993; Snoeyink and Summers 1999). In one study, the capacity of activated carbon for trichloroethene (TCE) was reduced by 50% when the carbon was preloaded with BOM, as compared to adsorption in distilled water (Summers et al. 1989).

Competitive adsorption can also impact performance. In many cases, other VOCs and SOCs will be in solution in the source water to be treated for removal of a specific VOC. The amount of adsorbent required for the same removal of a specific VOC within a mixture of VOCs and SOCs will be greater than that for adsorption of the VOC in a single solute system. VOCs and SOCs will compete for adsorption sites on the adsorbent surface (Snoeyink and Summers 1999). In addition, displacement of adsorbed compounds from the surface of the adsorbent can result in an effluent concentration greater than the influent concentration. More information on competitive effects can be found in the literature (Sontheimer, Crittenden, and Summers 1988; Speth and Adams 1993; Snoeyink and Summers 1999).

Adsorptive media designed for the removal of VOCs can be used to remove a VOC present in the source water at a constant concentration, yielding an effluent concentration below the treatment objective; when the treatment objective is reached, the media is replaced or regenerated in-place. The influent VOC concentration may be fairly constant, or highly variable. In another application, adsorptive media can attenuate a VOC spike event, such as a spill, lowering the effluent concentration of the VOC to a level that is below the treatment objective. This TSTP can be used to evaluate adsorptive media as treatment to constant VOC influent concentration (low or high variability) and to attenuate a short-duration spike of a VOC.

During operation of an adsorbent contactor subjected to a constant influent VOC concentration, the concentration of the VOC in the influent and effluent can be monitored and plotted. A plot of the effluent concentration as a function of operation time or throughput in BV treated is a breakthrough curve. Breakthrough curves are often generated by pilot-scale contactors to develop design criteria for full-scale systems. As defined in this document, breakthrough is reached when the concentration of the target compound in the adsorbent contactor effluent reaches the treatment objective, often the MCL. Immediate breakthrough is the level of adsorbate present in the adsorbent contactor effluent at the start of operation. For many highly-adsorbable VOCs, this level will not be detectable. Initial breakthrough is the point at which effluent concentrations begin to rise above immediate breakthrough levels.

The breakthrough curve is often used to determine the AUR. The AUR is the mass of adsorbent required to treat a specific volume of water to a predetermined quality. High AUR values result

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in increased operation and maintenance (O&M) costs caused by more frequent adsorbent replacement. The AUR can be calculated by the formula presented as Equation 3:

$$\text{AUR} = \frac{r}{\text{BV}_{\text{bt}}} \qquad (3)$$

where r is the apparent density of the adsorbent and BV_{bt} is the BV to breakthrough. The AUR commonly has units of lbs/1,000 gal or g/L. The AUR can be converted from g/L to lbs/1,000 gal by multiplying the value in g/L by 8.35 lb-L/g-1,000 gal.

At an influent concentration, C_0, assuming a symmetrical breakthrough curve, the adsorbent capacity q can be estimated for a specific compound from the breakthrough curve by the formula presented as Equation 4:

$$q = \frac{C_0}{\text{AUR}_{\text{bt}=50\%}} \qquad (4)$$

where $\text{AUR}_{\text{bt}=50\%}$ is the AUR calculated at 50% breakthrough of the compound. This approximation of adsorbent capacity is only valid at the influent concentration (C_0) of the compound. It is not valid at other influent concentrations; capacity is highly dependent on influent concentration.

4.4 Adsorption System Design Considerations

4.4.1 Contactor Configuration and Operation

An important contactor design parameter is the EBCT. The EBCT has a large impact on cost and performance of an adsorbent system. In general, systems with shorter EBCTs have lower capital costs, but higher O&M costs due to more frequent adsorbent replacement. Large EBCTs will result in lower O&M costs, but higher capital costs. Most GAC system EBCTs range from 5 to 20 minutes. The EBCT can be calculated by the following equations, presented as Equation 5:

$$\text{EBCT} = \frac{V}{Q} = \frac{L}{Q/A_c} = \frac{L}{\text{HLR}} \qquad (5)$$

where V is the volume of bed occupied by the adsorbent, Q is the flow rate, L is the adsorbent bed length, A_c is the cross-sectional adsorbent bed area, and HLR is the hydraulic loading rate.

In some cases, it is advantageous to operate two contactors in series, where half of the required adsorbent media (and therefore EBCT) is contained in each. A sampling port between the two contactors allows for monitoring of breakthrough of the compound being treated. The spent adsorbent in the upper half of the system can be replaced or regenerated, and the flow of water rerouted so the contactor containing fresh adsorbent is

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downstream. See Sontheimer, Crittenden, and Summers (1988) and Snoeyink and Summers (1999) for more information on contactor configuration.

Package plants that contain more than one adsorbent contactor in parallel operation can achieve more efficient AURs by staggering the operation of parallel contactors (at the expense of higher capital costs). When multiple contactors are operated in parallel and staggered with respect to their operation cycles (Figure 4.1), the blended effluent of all contactors constitutes the water quality treated by the system. Under this mode of operation, poorer water quality of older contactors is blended with high quality water from contactors containing fresh adsorbent. The water quality of each contactor may exceed the treatment objective, but the blended water quality is maintained below the treatment objective. Thus, each contactor can be operated for a longer period of time as compared to single contactor operation (USEPA 1999).

For small package plants, this mode of operation may not always be feasible since the logistics of staggering the operation of a very small number of contactors (e.g., two), due to the characteristics of the breakthrough curve of the VOC being treated, could lead to an increase in capital costs. A very sharp breakthrough curve could lead to difficulties in scheduling contactors for replacement. However, O&M costs may be lowered substantially when contactors are operated in parallel-staggered mode, especially if the package plant is comprised of several contactors, or if several package plants are operated in parallel. Based on a modeling analysis of multiple contactor operation presented by the USEPA (1999), operation times for two contactors operated in parallel-staggered mode are estimated as 29 to 50% longer than that for a single contactor, assuming a treatment objective of 40 to 60% breakthrough. For the same treatment objective, the gain in individual contactor operation time is estimated as 43 to 67% for three contactors, and 55 to 83% for four contactors. The range in estimates is a function of the shape of the breakthrough curve and the relative treatment objective. These estimates may not be applicable to extremely sharp breakthrough curves.

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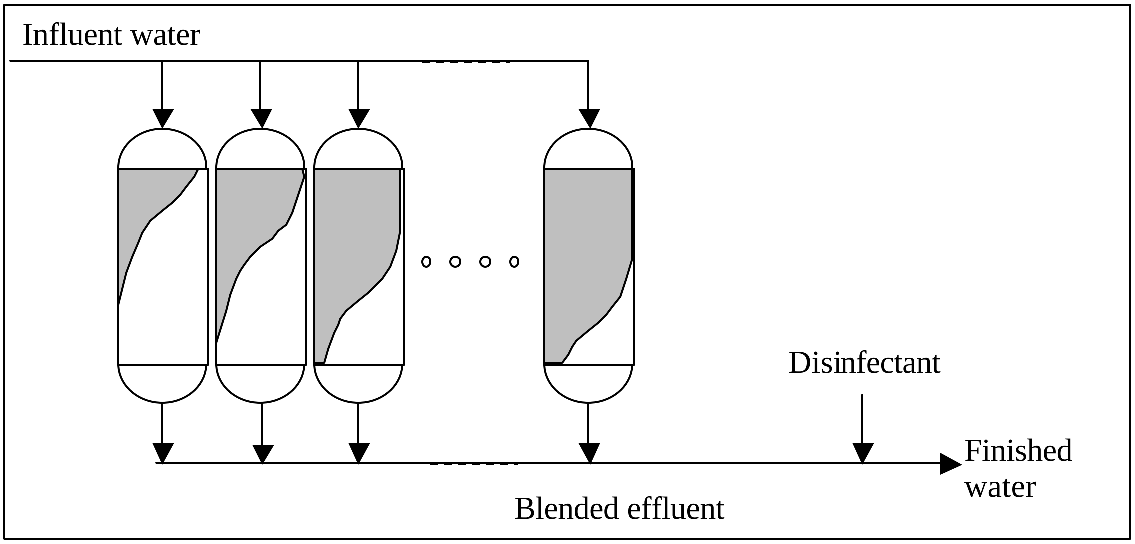

Figure 4.1 Multiple Adsorbent Contactors Operated in Parallel-Staggered Mode (*Adapted from USEPA 1999*)

4.4.2 Types of Adsorbents

The most widely used adsorbent is activated carbon. The most commonly used raw materials for producing activated carbon used in water treatment are bituminous coal, peat, lignite, petrol coke, wood, and coconut shells. The pore structure and adsorbent properties of activated carbon are a function of the raw material used and the activation process—activating agent, length of activation and temperature of activation. The surface area of activated carbon used for water treatment ranges from 600 to 1,500 m^2/g (Sontheimer, Crittenden, and Summers 1988).

Many types of synthetic resins have been used for adsorption of organic compounds from water. Synthetic resins vary in both the functional groups and the matrices that support functional groups (Snoeyink and Summers 1999). More information on types of ion exchange resins can be found in Clifford (1999) and Snoeyink and Summers (1999).

4.5 In-Place Regeneration

Once the effluent concentration of the VOC treated exceeds the treatment objective, the adsorbent is taken off-line and regenerated or replaced with fresh adsorbent. Some adsorption systems, especially resins, are designed for in-place regeneration. Normally, in-place reactivation is produced by addition of a strong base solution or a solvent such as acetone or isopropanol to the adsorbent bed. The ability of the regeneration step to restore the resin's capacity is important and is included as part of the verification testing.

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5.0 DEFINITION OF OPERATIONAL PARAMETERS AND ABBREVIATIONS

Definitions and abbreviations that may apply to adsorptive media processes for VOC include:

$1/n$: Freundlich exponent constant.

Adsorbate: the molecule adsorbed on to the surface of the adsorbent.

Adsorbent: the solid material onto which molecules adsorb, such as GAC or synthetic resins.

Adsorbent capacity: mass of solute adsorbed per unit mass of adsorbent at a given point of operation, commonly equilibrium.

A_c: cross-section area of adsorbent bed.

Adsorption capacity: see adsorbent capacity.

Adsorbent usage rate (AUR): the mass of adsorbent required to treat a specific volume of water to a predetermined quality, in units of g/L or lb/1,000 gal (1 g/L = 8.35 lb/1,000 gal).

$\mathrm{AUR}_{\mathrm{bt=50\%}}$: AUR calculated at 50% breakthrough of the compound.

$\mathrm{AUR}_{\mathrm{DW}}$: AUR for a compound in distilled water.

$\mathrm{AUR}_{\mathrm{NW}}$: AUR for a compound in natural water (in the presence of BOM).

Bed volumes (BV): a normalized unit of throughput, defined as operation time divided by EBCT.

BOM: background organic matter. Measurement of the source water total organic carbon (TOC) concentration will provide an indicator of the level of BOM present.

Breakthrough: the point when the concentration of a target compound in the adsorbent contactor effluent reaches the treatment objective.

Breakthrough curve: a plot of effluent adsorbate concentration as a function of operation time or throughput in BV, usually extending past the breakthrough point to exhaustion. The curve is characteristic of the adsorbent, adsorbate, system parameters, and influent water quality.

$\mathrm{BV}_{\mathrm{bt}}$: BV to breakthrough.

CCL: Drinking Water Contaminant Candidate List.

C_E: equilibrium solution concentration.

C_e: concentration in the adsorbent contactor effluent.

C_0: concentration in the adsorbent contactor influent.

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$\overline{C_e}$: average contactor effluent concentration for a GAC breakthrough curve operated until exhaustion.

d_{10}: effective size, defined as the sieve opening size (mm) at which 10% of the sample passes.

d_{50}: mean particle diameter, defined as the sieve opening size (mm) at which 50% of the sample passes.

Empty-bed contact time (EBCT): the hydraulic retention time of an empty contactor, defined as volume of the contactor occupied by the adsorbent divided by the flow rate, Q.

E_R: the regeneration efficiency (percent).

Exhaustion or saturation: the point in the breakthrough curve when the effluent concentration reaches its influent concentration, indicating that no adsorption is occurring. In practice, effluent concentrations may reach a plateau below the influent concentration because the adsorbate is removed by other mechanisms, such as biodegradation or slow adsorption kinetics.

GAC: granular activated carbon.

gpm: gallons per minute.

HLR: hydraulic loading rate.

Hydraulic loading rate: the velocity or flow rate per area at which water is loaded to the contactor (Q/A_c or L/EBCT), usually in units of gpm/ft^2 or m/hr.

K: Freundlich constant.

L: length of contactor, usually in units of meters.

Loading rate: see hydraulic loading rate.

m: meters.

m_A: mass of adsorbent.

MCL: maximum contaminant level.

MCLG: maximum contaminant level goal.

m_R: mass VOC recovered in the regeneration stream.

MRL: minimum reporting level.

min: minutes.

N_S: minimum number of paired influent and effluent samples required to be taken.

Q: volumetric flow rate.

q: adsorbent capacity, in units of mass of adsorbate/mass of adsorbent (also moles of adsorbate/mass of adsorbent).

q_E: equilibrium adsorbent solid phase concentration of the adsorbate.

$(q)_0$: mass of adsorbate adsorbed (mg/g) when the contactor effluent concentration is equal to the influent concentration.

r: apparent bed density of the adsorbent, in units of g/L, kg/m^3, or lb/ft^3.

r_{GAC}: apparent bed density of the adsorbent, in units of g/L, kg/m^3, or lb/ft^3.

RSD: relative standard deviation, calculated as the standard deviation (s) divided by the mean ($\bar{y}$).

s : standard deviation.

SCADA: Supervisory Control and Data Acquisition System.

SOC: synthetic organic chemical.

t: operation time, usually in units of days or hours.

t_{bt}: operation time to breakthrough, usually in units of days or hours.

Throughput: dimensionless time of operation in BV.

TOC: total organic carbon.

UV-254: ultraviolet absorbance at 254 nm.

V: contactor volume.

VOC: volatile organic chemical.

$\bar{y}$: mean.

Y_{bt}: adsorbent throughput to breakthrough, in units of BV.

6.0 OVERVIEW OF TASKS

6.1 Task 1: Characterization of Source Water Quality

This task includes an analysis of available historic data for the source water to be treated, including the concentrations of SOCs, VOCs, and water quality parameters, as well as seasonal

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variability in concentrations. VOCs and SOCs already present in the source water can impact the performance of the adsorptive media for VOC removal depending on the concentration of the background VOCs and SOCs and their adsorbability relative to the VOC to be tested. Furthermore, BOM can also reduce the capacity of the adsorbent for VOCs, and this "fouling" tends to be greater at higher BOM concentrations. Finally, an assessment of the need for pretreatment or the appropriateness of currently planned pretreatment must be made based on source water quality.

If sufficient historic data is not available to properly evaluate the source water quality, additional monitoring of the source water shall be performed to adequately assess source water quality.

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6.2 Task 2: System Design and Operation

This task involves procedures for determining the design and operating parameters of the adsorptive media treatment system. The following tasks shall be performed or documented: the experimental mode of operation, treatment system design parameters, start-up and O&M procedures, an operations monitoring plan, and an estimate of the run time to VOC breakthrough (for verification testing beyond the minimal 13.3-day period).

6.3 Task 3: System Integrity Verification Testing (SIVT)

The objectives of this task are to demonstrate that the equipment is (1) able to initially produce a finished water as described in the manufacturer's statement of performance capabilities and (2) able to reliably operate under field conditions. The equipment is operated, monitored, and sampled for approximately two weeks. This task evaluates the short-term ability of the equipment to produce water of acceptable quality. SIVT is not designed to evaluate the long-term ability of the equipment to treat water containing VOCs. SIVT must be performed at least once for each system evaluated under this TSTP.

6.4 Task 4: Adsorption Capacity Verification Testing (ACVT)

After Task 3 has been performed, the long-term effectiveness of the treatment system to remove VOCs shall be evaluated by Task 4. The main purpose of Adsorption Capacity Verification Testing (ACVT) is to evaluate the capability of the adsorptive media treatment system for removal of VOCs. Specifically, the AUR will be determined for the VOC tested. The AUR will be assessed under the design and operation conditions of the treatment system, as well as influent water quality conditions of the source water after pretreatment, if any. Influent and effluent sampling guidelines are described based on the experimental design (constant influent with low variability, constant influent with high variability, or attenuation of a spiked influent).

6.5 Task 5: In-Place Regeneration

Some treatment systems may use adsorptive resins that can be regenerated in-place, and may incorporate regeneration capability as an integral part of the equipment. In such cases, the objective of this task is to evaluate regeneration effectiveness and the impact of regeneration of performance.

6.6 Task 6: Operation and Maintenance Manual

The FTO shall obtain the manufacturer-supplied O&M manual(s) to evaluate the instructions and procedures for their applicability during the verification testing period. Recommendations for criteria for the evaluation of O&M manuals for package plants employing adsorptive media for VOC removal are given in this section.

6.7 Task 7: Data Management

The objective of this task is to establish an effective field procedure for data management at the field operations site and for transmission of data obtained during the verification testing from the FTO to NSF.

6.8 Task 8: Quality Assurance/Quality Control

The objective of this task is to develop a Quality Assurance/Quality Control (QA/QC) plan for verification testing. This important item will assist in obtaining an accurate measurement of operational and water quality parameters during adsorptive media system verification testing.

7.0 TESTING PERIOD

Guidelines for adsorptive media equipment verification testing frequency and duration are given in this section. To some extent, the number and length of test runs conducted will depend on how rigorous a demonstration the equipment manufacturer wishes to perform, and how strong a statement of performance capabilities the manufacturer would like to be able to make about equipment performance.

During initial operations, a manufacturer shall evaluate equipment operation and determine the appropriate conditions that result in effective treatment of the feed water. After an initial operations step, a test run shall consist of operating the treatment equipment for 13 days and one 8-hour shift of actual run time, the minimum required testing duration to satisfy the requirements of this TSTP. Although 13.3 days of operation are adequate to verify system integrity (e.g., mechanical and hydraulic functioning, excessive headloss, channeling, etc.), VOCs at levels typically found in natural source waters will not achieve breakthrough within 13.3 days of operation. Equipment manufacturers should recognize that a statement of performance capabilities that their adsorption system could treat a natural source water effectively for 13.3 days without exhibiting VOC breakthrough would not be impressive. For this reason, it is expected that the test will be made more rigorous (strengthening the statement of performance capabilities a manufacturer could make) by operating the test equipment for a longer period or until breakthrough of VOCs is achieved. Task 3 shall consist of 13.3 days of testing for verification of system integrity. Task 4, adsorption capacity verification testing, shall verify the long-term effectiveness of the treatment system to remove VOCs.

For tests not running until breakthrough, the AUR reported can be based on no greater a run time than the total operation time during which the equipment was operated as of the last pair of VOC influent and effluent samples taken. To verify a minimum AUR, or longest possible run time while maintaining the target VOC concentration below the treatment objective as stipulated in

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the manufacturer's statement of performance capabilities, the system must be operated until breakthrough is achieved. Once breakthrough occurs, and the effluent VOC concentration is greater than the treatment objective stated in the manufacturer's statement of performance capabilities, it is no longer necessary to continue operation of the system, unless a complete breakthrough curve is desired. It may be desirable to capture the complete breakthrough curve, however, as the AUR can be calculated based on the last effluent sample with concentration lower than the treatment objective, or by an interpolation of a best-fit curve approach to a complete breakthrough curve data set. These options are described in Section 11.5.

Definition of *target treatment objective exceeded*. Due to analytical and experimental variability, the concentration of the VOC in the contactor may increase above the treatment objective, only to fall below it on a subsequent sampling. Therefore, it is recommended that verification testing be designed to produce the best possible quality data set, one that clearly shows the breakthrough curve trend and minimizes scatter in the data caused by analytical and experimental variability. If the data set clearly shows a breakthrough trend, with some variability, a best-fit curve may be used to fit the data, and the point at which the effluent VOC concentration exceeds the treatment objective can be interpolated. Otherwise, the *last* sample taken (with concentration below the treatment objective) prior to the *first* point at which the effluent equals or exceeds the treatment objective shall designate the run time for purposes of calculation of the AUR. It is worthwhile to develop a very good quality data set that can be fit to a curve. Utilizing the run time of the last data point prior to the first data point with a concentration above the treatment objective will yield a conservative estimate of the run time to breakthrough.

The duration of verification testing to determine the AUR based on operation until the VOC tested reaches breakthrough for many VOCs will be longer than 13.3 days. The length of the testing period will depend on the adsorbability and concentration of the compound tested. Highly adsorbable compounds may yield operation times greater than one year in length prior to breakthrough. The run termination criteria can be based on achieving breakthrough (as defined by an effluent VOC concentration exceeding the MCL or other treatment objective). In this case, the testing period would be the shortest time necessary to verify the AUR. The AUR will be determined for a test regardless of the operation time; when the test is terminated prior to breakthrough, the AUR will be calculated based on the total run time for which the VOC was treated while effluent levels were maintained below treatment objective. For verification testing operating until breakthrough or beyond, a best-fit curve of the data set can be used to interpolate the run time used for the AUR calculation. In addition, a full breakthrough curve is information that may be of benefit to the manufacturer. Determining the AUR is explained in more detail in Task 2, System Design and Operation.

For ACVT of attenuation of a spiked VOC compound, the testing period shall begin when the application of the spike ends (see examples in Table 3.1). The amount of time the system is operated prior to, during, and after the application of the spike shall be specified by the manufacturer. Ideally, the time period during which the system is operated after the application of the spike shall be long enough to demonstrate effective attenuation of the influent pulse.

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8.0 TASK 1: CHARACTERIZATION OF SOURCE WATER QUALITY

8.1 Introduction

A characterization of the source water quality is necessary to identify VOCs and SOCs present in the source water and to evaluate the impact of other water quality parameters or contaminants on adsorption of VOCs. The presence of other VOCs and SOCs at detectable concentrations (e.g., > 1 µg/L) can negatively impact the adsorption of the VOC being tested due to competitive adsorption. The significance of the effect will depend on the concentration of background VOCs and SOCs and their adsorbability relative to the VOC being tested. For studies evaluating AURs at breakthrough, estimates of run times to breakthrough must be examined together with existing water quality to determine the potential reliability of the estimates.

BOM in water can reduce the adsorption capacity of VOCs. Since all source waters contain organic matter, some impact is expected. Higher levels of BOM will typically have an increased impact on adsorption of VOCs, but characteristics of the organic matter are important and the adsorbability of the VOC is also a factor. Measurement of the source water TOC concentration will provide an indicator of the level of BOM present. Pretreatment prior to the adsorption process may reduce TOC levels. Other water quality indicators such as pH, temperature, and conductivity may impact adsorption and should be quantified.

Seasonal variability in water quality may impact the results of equipment verification testing since testing duration often spans several months. Assessment of seasonal variability in water quality prior to equipment verification testing will help in evaluating whether the proposed water source is appropriate, what type of pretreatment might be necessary, or the appropriateness of pretreatment that is already in place. Source water variability should be evaluated in relation to the expected length of the testing period

8.2 Objectives

The objectives of this task are to:

- Identify VOCs and SOCs known to occur in the proposed source water;
- Determine typical values for concentrations of other water quality parameters;
- Identify any characteristic seasonal trends in concentrations of VOCs and SOCs and other water quality parameters;
- Determine the level of BOM present in the source water; and
- Assess the need for pretreatment prior to adsorption, or assess the appropriateness of designed pretreatment.

If historic water quality data is not available for one or more parameters, an analysis of the proposed source water shall be performed for these parameters.

8.3 Work Plan

A combination of laboratory analysis and review of historic data should provide the needed data to evaluate source water quality. Sources for historic data include municipalities, laboratories,

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United States Geographical Survey (USGS), EPA, and local regulatory agencies. Analysis of the proposed source water prior to verification testing shall be performed for those parameters for which no historic data can be located. Ideally, 2 to 5 years of historic water quality data for each parameter will be available for the proposed source water. At a minimum, 1 year of data sampled at no greater than 3-month intervals, may constitute historic data.

The FTO shall prepare a Source Water Quality Evaluation Report containing the historic and monitored data obtained, a statistical evaluation of the data, and graphical summaries for all parameters. This report shall be shared with NSF so that NSF and the FTO can determine the significance of the data for use in developing a PSTP. If the source water quality data is not obtained or analyzed properly, the verification test may fail or the results of the test may not be considered acceptable.

The report shall list all VOCs and SOCs previously identified in the source water, emphasizing those encountered most recently and those that show a seasonal reoccurrence that might impact equipment verification testing.

A description of the source water should also be included in the Source Water Quality Evaluation Report including, but not limited to, the following items:

- Nature of water source (i.e., ground water or surface water);
- Location of water source;
- Size of watershed;
- Brief description of land use; and
- Potential sources of pollution.

If the VOC concentrations in the source water are below that described by the manufacturer's statement of performance capabilities, higher VOC concentrations can be obtained during verification testing by spiking.

8.4 Analytical Schedule

When historic data are not available, it is recommended that at least 12 months of monthly (or more frequent) monitoring be performed prior to verification testing. At a minimum, 2 samples, spaced by a minimum of 4 weeks and a maximum of 12 months, shall be obtained for the parameters listed in Table 8.1.

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Table 8.1 Source Water Sampling Requirements*

Parameter	Notes
Alkalinity	
Ammonia	Optional
Calcium hardness	
Conductivity	Optional
Dissolved oxygen	Required for groundwater sources only.
Hydrogen sulfide	Required for groundwater sources only.
pH	
VOC and SOC scan	*Standard Methods* 6410B, 6420C, 6431C, 6440C, 6630D. EPA Method 525.2 (extended for broad spectrum)
Temperature	
Total chlorine	Total chlorine residual must be < 0.1 mg/L during verification testing.
Total dissolved solids (TDS)	Optional
Total hardness	
TOC	
Total suspended solids (TSS)	
Turbidity	
UV-254	

**See Table 10.1 for analytical methods.*

All data collected, whether from historic records or sampled directly and analyzed, shall be summarized in conjunction with the sampling date. Results shall include the average, minimum, maximum, and number of data points in the data set. For sample sets of eight or more, the results shall also include the standard deviation and confidence interval for each analyte. When summarizing VOC data of sample sets of eight or more, the 10th, 25th, 50th, 75th, and 90th percentiles shall also be reported.

For each water quality parameter, a graph of concentration vs. sampling date shall be constructed. This type of graph aids in the interpretation of seasonal trends that may impact equipment verification testing. Where convenient (e.g., calcium and total hardness) more than one parameter may be combined in one graph. The concentration of each parameter shall be plotted against actual sampling date. A box-and-whisker style plot to demonstrate the distribution of each parameter is also recommended.

8.5 Evaluation Criteria

The source water quality shall be evaluated in the context of the manufacturer's statement of performance capabilities for the removal of VOCs. The source water quality shall also be evaluated with regards to the appropriateness of pretreatment in place prior to adsorption or the need for pretreatment. The source water quality should challenge the capabilities of the equipment, but should not be beyond the range of water quality suitable for treatment by the equipment. Other evaluation criteria are given below:

- Pretreatment for particle removal may be required if the source water turbidity is greater than 5 to 10 NTU or if the source water TSS exceeds 5 mg/L. Manufacturer specifications regarding pretreatment for particle removal should be followed.
- Pretreatment for hardness may be required if the source water hardness is greater than the manufacturer's recommendations or if the pH, alkalinity, and hardness analyses indicate that the water is unstable.
- Adjustment of source water pH may be required if the source water pH is outside the manufacturer's specifications. Water pH can impact adsorption efficiency and, at extremes, may pose a corrosion hazard to the equipment.

9.0 TASK 2: SYSTEM DESIGN AND OPERATION

9.1 Introduction

This task involves procedures for determining the design and operating parameters of the adsorptive media treatment system.

9.2 Objectives

The objectives of this task are to:

- Establish the experimental design (mode of operation: constant, spike, or variable influent; VOC spiking);
- Document treatment system design parameters;
- Describe system start-up and O&M procedures;
- Develop an operations monitoring plan; and
- Estimate the run time to VOC breakthrough (for verification testing beyond the minimal 13.3-day period).

Documentation of the treatment system design parameters shall be provided to EPA, NSF, and peer reviewers for evaluation.

Each PSTP will include a list of criteria for evaluating O&M information. This shall be compiled and submitted for evaluation by EPA, NSF and technical peer reviewers. An example is provided in Table 9.1. The purpose of this O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and to provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

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Table 9.1 Maintenance and Operability Information for Adsorptive Media Package Plants

Maintenance Information

Equipment	Maintenance frequency	Replacement frequency
Pumps		
Valves		
Motors		
Mixers		
Chemical mixers		
Water meters		
Pressure gauges		
Cartridge filters		
Seals		
Piping		

Operability Information: Rank 1 (easy) to 3 (difficult) or N/A (not applicable)

Operation aspect	Rank
Chemical feed pumps calibration	
Flow meters calibration	
Pressure gauges calibration	
pH meters calibration	
TDS or conductivity meters calibration	

9.3 Work Plan

The PSTP shall specify information on the design and operation of the adsorption system being evaluated. The work activities of this task are described below.

Experimental design. Three types of experimental designs are allowable under this TSTP: (1) constant influent with low variability, (2) constant influent with high variability, and (3) attenuation of a spiked influent. In general, this TSTP is designed for verification testing of a system treating a single VOC at a constant influent concentration with low variability. In some cases, the manufacturer's statement of performance capabilities may be based on a system treating a water with high variability in VOC concentration, or it may be based on attenuation of a spiked influent. In these cases, the experimental design will be based on testing under the influent conditions to be verified.

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If the VOC to be tested for removal by adsorptive media is not present in the influent to the adsorptive media, it shall be spiked into the influent water so that the resulting concentration is equal to the targeted concentration. A sampling point shall be located downstream of the spike location, but prior to the adsorption media, to confirm the influent concentration during testing. All influent samples shall be taken from this sampling point. For testing of highly variable influent conditions or attenuation of a spike influent, spiking shall simulate the conditions of high variability or a spiked influent. For example, a spike concentration of 50 µg/L diquat for a duration of 3 days could simulate a spike influent for an attenuation study. In all cases, spiking of the VOC shall match as closely as possible the influent conditions described in the manufacturer's statement of performance capabilities.

This TSTP is designed to assess the removal of only one VOC in the adsorptive system influent. If a manufacturer's statement of performance capabilities is based on simultaneous treatment of multiple compounds, this should be simulated in the adsorption influent by spiking additional compounds as necessary. Some sections in this document, such as the estimation of run time to breakthrough, are designed based on a single compound influent and are not directly applicable to simultaneous treatment of multiple compounds. In general, run times will be lower (AURs will be higher) for systems subjected to multiple influent compounds as compared to those treating an influent water with a single compound, due to the effects of competitive adsorption.

System design parameters. The FTO shall document the adsorption system design parameters listed in Table 9.2. The PSTP shall contain a simple schematic of the entire treatment system, including any pretreatment processes, showing sampling points, spike location, valves, pumps, etc. An example of this schematic is shown in Figure 9.1.

Start-up and O&M procedures. System start-up and O&M procedures based on manufacturer specifications shall be described by the FTO in the PSTP. Specific procedures for backwashing and regeneration shall be included. Start-up procedures may include bed preparation such as pre-wetting, degassing, and fines removal. Start-up itself will involve setting valves to the correct run status, starting the feed pump to deliver test water to the system, adjusting the flow rate to the target value, and other procedures as required by the manufacturer. Assuming continuous operation, the system shall be operated for 24 hours before sampling commences. For purposes of calculating run times, the start of operation shall constitute the beginning of the run.

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Table 9.2 Adsorption System Design Parameters

Parameter	Units	Notes
General		
Test type		Constant influent with low variability, constant influent with high variability, or attenuation of spiked influent
Test location		
Utility name		
Water source		Surface or ground water
Water source name		
Water source type (surface water only)		Reservoir, lake, river, etc.
Feed mode (semi-batch or continuous)		Describe
Spiked VOC compound(s), if any		
Target spike concentration(s)	µg/L	
Spiking method		Describe
Pretreatment processes		Describe
Adsorptive Media		
Media manufacturer		
Media type		Bituminous, lignite, etc.
Media trade name		
Mesh size	US std mesh sizes	Upper x lower
Effective size, d_{10}	mm	Indicate whether measured in field or as reported by manufacturer
Mean particle diameter, d_{50}	mm	Indicate whether measured in field or as reported by manufacturer
Apparent bed density, r_{GAC}	g/L, kg/m^3, lb/ft^3	Indicate whether measured in field or as reported by manufacturer
Adsorption System		
Contactor configuration		Describe
Number of adsorbers in series		
Adsorber dimensions	m	Diameter, depth and any other appropriate dimensions
BV per adsorber	L	
Bed depth for each adsorber	m	
Volumetric flow rate	mL/min	
EBCT	min	Clearly report total EBCT if more than one contactor in series
Hydraulic loading rate (or superficial velocity)	m/hr	
Mass of dry media per adsorber	kg	
Regeneration system, regenerant fluid, and regeneration procedure		Describe, if system has in-place regeneration capacity

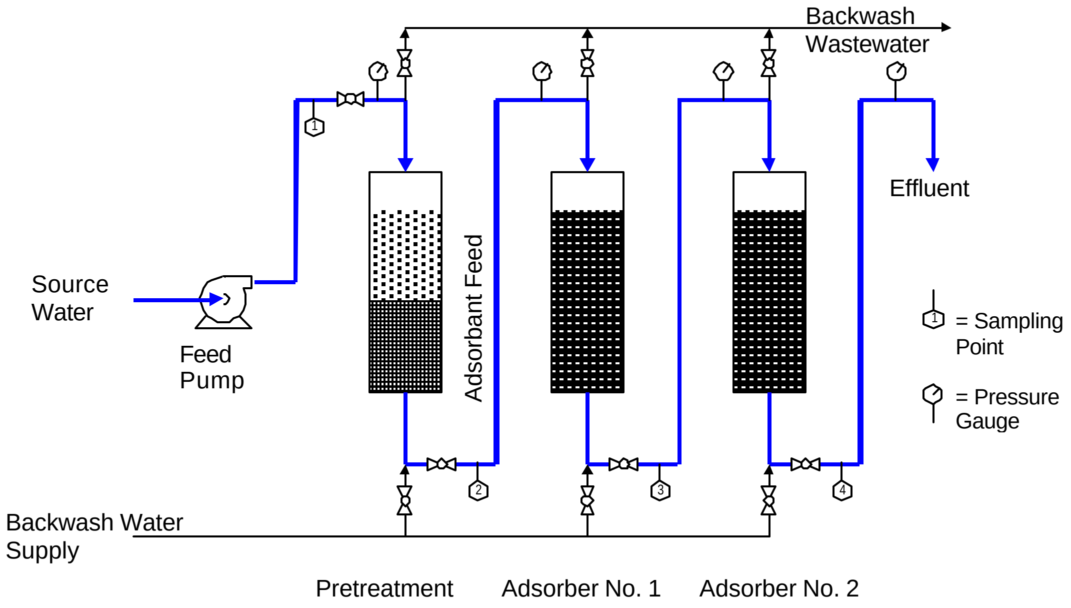

Figure 9.1 Example of an Adsorption Treatment System Schematic

Operation with a continuous flow of test water from the source is preferable, but continuous feeding from a batch-filled feed tank is acceptable. If a batch feed tank is used, the residence time in the feed tank should be minimized to avoid volatilization losses of VOCs. The system flow rate should be adjusted as necessary during operation to maintain the system flow rate within 5% of the target flow. The system should be operated continuously to the extent possible, and only shut down for backwashing, necessary maintenance, or regeneration (for in-place regenerable media). Any down time shall be recorded and not included in the cumulative run time or throughput volume calculations. The reason for each shutdown shall be documented. Adsorbers using non-disposable media should be backwashed at least once during the test period. The manufacturer shall specify backwash parameters including, but not limited to, flow rate, percent bed expansion, and duration of expansion.

If the system is designed for continuous operation, then the system should be evaluated under continuous operation for verification testing. If the system is designed for intermittent or continuous operation, than either mode of operation during verification testing is acceptable. It is preferable that the system be operated continuously. As with down time, total operation time under intermittent operation constitutes the sum of the amount of time the system is in operation providing treated water.

Operations monitoring plan. The FTO shall provide an operations monitoring plan in the PSTP, including operational parameters to be monitored, monitoring points, and monitoring frequencies. At a minimum, flow rate, pressure before and after each adsorption or filtration bed and headloss (differential pressure) across each bed, influent temperature, and influent pH should be monitored routinely. Other parameters recommended by the equipment manufacturer should also be included. Influent and effluent sampling times should also be specified in the monitoring plan.

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Estimation of throughput to breakthrough. For systems evaluating single VOC adsorption under constant influent conditions with low variability, the following section provides a methodology for estimating the run time to breakthrough. This step should still be followed if verification testing is planned for the minimum 13.3-day period, to confirm that breakthrough will most likely not occur within the 13.3-day run time. If the objective of verification testing is to achieve breakthrough of the compound treated, an estimation of throughput to breakthrough is critical for purposes of estimating the duration of the operation cycle, and for purposes of designing a sampling plan to effectively capture the breakthrough curve and/or the breakthrough point (point at which the effluent concentration exceeds the treatment objective).

If the run time estimate to breakthrough is lower than 13.3 days, then effluent sampling during verification testing should be designed assuming that the AUR will be based on operation of the system to breakthrough. This should be done even if verification testing is planned for only 13.3 days: breakthrough may occur earlier than 13.3 days, and sampling guidelines should be followed to best capture the point of breakthrough for use in the AUR calculation. The system must be operated for a minimum 13.3-day period regardless of when the treatment objective is exceeded. If it is very likely that the treatment objective will be exceeded during the 13.3-day minimum verification period, then it is recommended that the manufacturer evaluate modifications to the system design, such as an increase in the adsorber EBCT.

This method of estimating adsorbent bed life to breakthrough is based on a methodology described in Snoeyink and Summers (1999). It is assumed that all the adsorbent in the adsorber will reach equilibrium with the influent concentration, that isotherm data can be successfully extrapolated to the influent concentration to estimate the capacity, and that the length of the mass transfer zone is negligible (a very sharp breakthrough curve is assumed).

This method is based on isotherm data using the Freundlich equation, presented as Equation 6:

$$(q)_0 = KC_0^{1/n} \tag{6}$$

where $(q)_0$ is the mass adsorbed (mg/g) when the effluent concentration, C_e, is equal to the influent concentration, C_0; and K and $1/n$ are constants. Literature sources should be consulted for appropriate values of K and $1/n$ (Snoeyink and Summers 1999; Sontheimer, Crittenden, and Summers 1988; Faust and Aly 1998; Speth and Miltner 1990, 1998).

The AUR (mass of adsorbent in the column divided by the volume treated to breakthrough) is then estimated from isotherm data in the formula presented as Equation 7:

$$\text{AUR(g/L)} = \frac{(C_0 - \overline{C_e})\text{mg/L}}{(q)_0\,\text{(mg/g)}} \tag{7}$$

where $\overline{C_e}$ is the average effluent concentration during the entire run.

Using this estimate of the AUR, the volume of water that can be treated per unit volume of carbon is estimated by Equation 8:

$$Y_{bt} = \frac{r_{\text{GAC}}}{\text{AUR}} \qquad (8)$$

where Y_{bt} is the throughput in BV and r_{GAC} is the apparent density of the adsorbent.

Finally, the operation time to breakthrough, t_{bt}, in days can be calculated from the throughput by Equation 9:

$$t_{bt} = \frac{Y_{bt} \cdot \text{EBCT(min)}}{1{,}440\text{(min/ day)}} \qquad (9)$$

The value of t_{bt} estimated by Equation 9 is a rough estimate of the time to breakthrough, based on several assumptions noted above. It should be used with care, and a generous safety factor should be included, as breakthrough may occur much earlier or later than this run time estimate due to several factors described previously.

Several limitations of this method exist and should be noted. First, it is only valid for a single long contactor, or for columns in series in which all of the adsorbent in the column is in equilibrium with the compound at the influent concentration. Second, this method does not account for the potential impact of biodegradation of the compound during treatment or slow adsorption kinetics. Finally, the impact of competition for adsorption sites on adsorption equilibrium in a batch is not necessarily the same as that on adsorption in a column. Competitive effects may have a larger impact on adsorption in a column than in a batch study (Snoeyink and Summers 1999).

Another limitation of the AUR estimated by this method is that adsorption capacity is based on experiments performed in distilled water, in the absence of BOM that may have a significant impact on adsorption capacity in the field. A natural water correction factor has been proposed, whereby the distilled water AUR (AUR_{DW}) is adjusted, yielding a better estimate of the natural water AUR, AUR_{NW} (Ford et al., 1989; USEPA 1990). For this relationship, the units of AUR are lb/1,000 gal. The correlation described by Equation 10a is valid for values of AUR_{DW} 0.564 lbs/1,000 gal. For values of $\text{AUR}_{\text{DW}} > 0.564$ lbs/1,000 gal, the value for AUR_{NW} used is equal to AUR_{DW}, as described in Equation 10b.

$$\text{AUR}_{\text{NW}} = 0.7443 \cdot (\text{AUR}_{\text{DW}})^{0.4835} \qquad \text{AUR}_{\text{DW}} \quad 0.564 \text{ lbs/1,000 gal} \qquad (10a)$$

$$\text{AUR}_{\text{NW}} = \text{AUR}_{\text{DW}} \qquad \text{AUR}_{\text{DW}} > 0.564 \text{ lbs/1,000 gal} \qquad (10b)$$

Example. To estimate the adsorbent bed life of a 10 minute EBCT GAC (r_{GAC} = 500 g/L) contactor treating chlorobenzene at a constant influent concentration of 300 µg/L, first look up the Freundlich K and $1/n$ values for chlorobenzene, as shown in Equations 11 and 12:

$$K = 91.0 \text{ (mg/g)(L/mg)}^{1/n} \qquad (11)$$

$$1/n = 0.99 \qquad (12)$$

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Use Equation 6 to calculate $(q_e)_0$ = 27.6 mg/g. Assuming $\overline{C_e}$ = 0, use Equation 7 to estimate the AUR_{DW}, 0.0109 g/L (0.0906 lb/1,000 gal). Correcting this value using Equation 10a gives AUR_{NW} = 0.233 lb/1,000 gal or 0.0279 g/L. The throughput, Y_{bt}, is 17,900 BV, calculated by Equation 8. Finally, the estimate of operation time to breakthrough, t_{bt}, is calculated by Equation 9, which is 124 days.

Although Equation 10a includes a correction factor for the impact of BOM on adsorption, it does not account for the impacts of biodegradation or competitive effects due to the possible presence of other VOCs or SOCs. The BOM correction is only an estimate; the actual impact of BOM on performance will vary, depending on the characteristics of BOM, concentration, and the amount of time the adsorbent has been preloaded with BOM prior to verification testing of VOC adsorption.

The above analysis is applicable to single contactor operation. For package plants that operate two or more contactors in parallel, with staggered operation cycles, longer run times are expected for a given treatment objective maintained in the blended effluent of all contactors. Depending on the shape of the breakthrough curve, and the operation time to initial breakthrough for a single contactor, the run time of each of two to four contactors operated in parallel-staggered mode may be increased by 30 to 80%. For extremely sharp breakthrough curves, this mode of operation may not yield any significant benefit, depending on the ratio of the treatment objective to the influent concentration, in relation to the number of parallel contactors. It is recommended that parallel operation of adsorbent contactors be modeled to yield the best estimate of operation times based on maintaining a treatment objective in the blended effluent. See USEPA (1999) for an analysis of multiple contactor effluent blending for GAC. Alternatively, the effluents of each contactor can be monitored, with the experimental results of breakthrough in the first adsorber used to refine the run time estimate based on the blended effluent.

9.4 Analytical Schedule

System flow rate, pressures and headloss across each contactor, and other operational parameters should be measured at the frequencies indicated in Table 9.3. Ideally, flow rate and headloss are measured on a continuous basis. The headloss before and after backwashing should be recorded as a measure of backwash effectiveness. A record of backwashing frequency and backwash water volume produced should also be maintained. See Table 9.3 for further details. Stoppage time should be recorded, including the exact times of stoppage and restart, as well as the reason for the stoppage. This will allow for an accurate assessment and adjustment for the impact of stoppage time on the effective operation time. The cumulative amount of stoppage time that must be taken into account in calculating the total run time of verification testing should be continuously updated.

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Table 9.3 Schedule for Observing and Recording Package Plant Operating and Performance Data

Operational Parameter	Action
Feed water and adsorbent contactor volumetric flow rate	When staffed, check and record every 2 hours; adjust when >5% above or below target. Record before and after adjustment.
GAC contactor headloss	Record initial clean bed total headloss at start of run and record total headloss every 2 hours, when staffed.
Filter backwash	Record time and duration of each filter washing. Record volume used to wash filter. Record headloss before and after backwashing.
Electric power	Record meter daily.
Chemicals used	Record name of chemical, supplier, commercial strength, and dilution used for stock solution to be fed (if diluted) for all chemicals fed during treatment.
Chemical feed volume and dosage	Check and record every 2 hours. Refill as needed and note volumes and times of refill.
RPM of rapid mix and flocculator (if applicable)	Check daily and record.
Hours operated per day	Record in logbook at end of day or at beginning of first shift on the following workday. Any stoppage of flow to the contactors shall be recorded. Flow stoppage that exceeds 2 hours per a 24-hour period or 7 hours per week shall be accounted for by not including it in the cumulative operation time.

9.5 Evaluation Criteria

The contactor flow rate should be maintained within 5% of the target value. The flow rate should be adjusted when it is outside of this range. Criteria for backwashing are usually based on a headloss threshold and should be provided by the equipment manufacturer. The criteria will likely vary depending on EBCT on adsorbent media size.

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10.0 TASK 3: SYSTEM INTEGRITY VERIFICATION TESTING

10.1 Introduction

This task will evaluate the short-term ability of the equipment to produce water of acceptable quality. SIVT is not designed to evaluate the long-term ability of the equipment to treat water containing VOCs. SIVT must be performed at least once for each system evaluated under this TSTP.

10.2 Objectives

The objectives of this task are to demonstrate that the equipment is (1) able to produce a treated water within performance objectives, and (2) able to operate reliably under field conditions.

Specific objectives include:

- Characterization of the influent VOC concentration and variability and
- Evaluation of the concentrations during testing of other water quality parameters that impact VOC adsorption, including TOC, UV-254, pH, temperature, and other background VOCs.

10.3 Work Plan

The manufacturer and its designated FTO shall specify in the PSTP the operating conditions to be evaluated during verification testing and shall supply written procedures on the O&M of the treatment system. For applications where the treatment system is expected to operate continuously, the equipment shall be operated continuously for a minimum of 320 hours (13 full days plus one 8-hour work shift) to complete SIVT. For applications where the treatment system is expected to operate intermittently, such as for very small systems, the equipment shall be operated for a minimum of 2 hours continuously each day for a total minimum operation time of 320 hours. For adsorptive media vessels operated as post-filter adsorbers, the media filters on-line upstream of the adsorptive media vessels shall be operated fom start-up until turbidity breakthrough or terminal headloss is attained, at which time the media filters shall be backwashed and operation shall resume.

For adsorptive media filters that are not operated as post-filter adsorbers, but that specify a backwash cycle as part of normal operation, at least one backwashing event, located between day 3 and 10 of SIVT, shall be included in the test. This backwash shall be performed even if the backwash criteria (e.g., volume treated, headloss, pressure drop) are not experienced or met. Backwashing the adsorber a few days prior to the end of the SIVT allows for an evaluation of system performance after backwashing. For systems that are backwashed more often (e.g., every 3 to 4 days), at least one backwashing event shall occur between days 3 and 10 of SIVT.

Interruptions in the treatment system shall be documented and are allowed only for backwashing events and required equipment maintenance. Since adsorptive media performance is a function of EBCT, which is dependent on the volumetric flow rate, it is critical that verification testing be conducted at a set flow rate that is maintained within 5% of the design value.

Any influent spiking irregularities that occur during the study must be reported by the FTO. This includes, but is not limited to, events such as a period of time when the contaminant feed pump is not pumping at the correct flow rate, a period of time when the contaminant stock solution runs out, or a period of time when volatile losses may have occurred from the stock solution. The FTO must document the occurrence of these events, including a clear description, corrective actions taken, the length of time during which the irregularity occurred (this may have to be estimated), and the approximate dates and times when the event began and ended. The description should include the FTO's opinion as to the severity of the irregularity, in terms of its impact on testing results.

Package plants that contain multiple adsorbent contactors to be operated in parallel should follow manufacturer's guidelines for system start-up. If the contactors are to be operated in a staggered format, then each contactor should be brought on-line sequentially, as designated by the manufacturer's instructions. If the VOC to be treated is already present in the influent water, then the start of verification testing should take place when the first contactor is brought on-line. Alternatively, each contactor can be brought on-line sequentially until all contactors are in operation prior to the start of verification testing if the VOC to be tested is not present in the source water. Spiking of the VOC to be tested would begin when all contactors are operational. The FTO shall provide the details for spiking in the PSTP, such as materials for preparation of the spike solution, details about feed pumps, reservoirs and mixers, and sampling to confirm influent concentrations.

Water Quality Sample Collection. Water quality data shall be collected at regular intervals as described in the analytical schedule (see Table 10.1). Additional or more frequent analyses may be stipulated at the discretion of the FTO. Sample collection frequency and procedure shall be defined by the FTO in the PSTP.

The PSTP shall identify the treated water data quality objectives (DQOs) to be achieved in the statement of performance capabilities of the equipment to be evaluated in the verification test. The PSTP shall also identify in the statement of performance capabilities the specific VOCs that shall be monitored during equipment testing. The statement of performance capabilities prepared by the FTO shall indicate the range of water qualities and operating conditions under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in a VOC removal verification test will be capable of achieving multiple water treatment objectives. Although the VOC TSTP is designed for the removal of VOCs, the manufacturer may want to examine the capabilities of the treatment system for removal of additional water quality parameters. Appropriate EPA/NSF ETV protocol(s) and TSTP(s) should be consulted.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. Representative methods to be used for

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measurement of water quality parameters in the field and lab are identified in Table 10.1. If new methods are published and approved or current methods updated, the most current methods shall be used.

Sample collection procedures for intermittent flow systems must ensure that freshly treated water is collected and not water that was stagnant in the bed. For intermittent flow systems, sample collection should occur during a continuous flow period, after a minimum of 10 BV has passed through the system or after 1 hour of continuous flow.

Table 10.1 Required Water Quality Analyses and Minimum Sampling Frequencies for SIVT

Parameter	Frequency	Sampling Location[1]	Standard Method	EPA Method	Analysis Location[2]
VOCs	Daily	INF, EFF	See Table 10.2	See Table 10.2	2
Alkalinity	Weekly	INF	2320 B		3
Ammonia	Weekly	INF	4500-NH_3 D, G	350.1	3
Calcium hardness	Weekly	INF	3111 D; 3120 B; 3500-Ca D	200.7	3
Chlorine, free	Daily[3]	INF	4500-Cl D, F, G, H		1
Chlorine, total	Daily[3]	INF	4500-Cl D, E, F, G, I		1
Conductivity	Weekly	INF	2510 B	120.1	3
Dissolved oxygen	Weekly	INF	4500-O B, G		1
Hydrogen sulfide	Weekly	INF	4500-S^{2-} D, E, F, G		3
pH	Daily	INF, EFF	4500-H^+ B	150.1; 150.2	1
Temperature	Daily	INF	2550 B		1
TDS	Weekly	INF	2540 C		3
Total hardness	Twice weekly	INF	2340 B, C		3
TOC	Daily	INF, EFF	5310 B, C, D		2
Total suspended solids (TSS)	Weekly	INF	2540 D		3
Turbidity	See note[4]	INF, EFF	2130 B	180.1	1
UV-254	Twice weekly	INF, EFF	5910 B		3

[1] INF: Influent; EFF: Effluent. Where both influent and effluent sampling is required, samples should be paired (taken at approximately the same time).

[2] Analysis location: 1-Must be analyzed on-site; 2-Must be analyzed by a laboratory that is certified, accredited or approved by a state, a third party organization (i.e., NSF), or the EPA; 3-Can be analyzed either on-site or by a laboratory that is certified, accredited or approved by a state, a third party organization (i.e., NSF), or the EPA.

[3] Free and total chlorine should be analyzed daily to ensure the absence of chlorine in the influent water. The FTO may require less frequent monitoring if there is no reason to expect free or total chlorine in the influent water. This will depend on the water source.

[4] For contactors operated in filter-adsorber mode, a continuous turbidimeter should be used. Daily samples should be analyzed using a bench-top turbidimeter to confirm the continuous turbidimeter readings. For contactors operated in post-filter adsorber mode, the minimum sampling frequency for turbidity is weekly.

In the case of water quality samples to be shipped to the laboratory that is certified, accredited or approved by a state, a third party organization (i.e., NSF), or the EPA for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Acceptable methods for the required analytical procedures are described in Task 8, Quality Assurance/Quality Control. At a minimum, all PSTPs shall include a table(s) showing all parameters to be analyzed, the analytical methods, the laboratory reporting limits or quantitation limits, sample volume, bottle type, preservation method, and holding time.

If the known or expected concentration of the VOC or VOCs to be tested in the influent water is lower than desired for verification testing, then the influent water should be spiked to achieve the desired concentration. The FTO shall stipulate in the PSTP procedures to be followed for influent spiking. These should be based on information reported in the literature and the experience of the FTO and manufacturer with the compound or compounds to be tested.

In general, three types of experimental designs for ACVT are allowable under this TSTP (as described in Section 9.3). SIVT should be conducted following the procedures applicable to the experimental design to be tested during ACVT. Furthermore, once the SIVT phase is complete, testing may continue under the guidelines and procedures described for ACVT. It is expected that SIVT will be performed with a constant influent concentration of the VOCs to be tested.

10.4 Analytical Schedule

10.4.1 Operational Data Collection

The FTO shall provide written procedures describing the operational parameters that should be monitored, the monitoring points, and the frequency of monitoring. At a minimum, such operational parameters shall include system flow rates and headloss or pressure. The FTO shall include acceptable values and ranges for all operational parameters monitored.

10.4.2 Water Quality Data Collection

During SIVT, the GAC influent and effluent water quality shall be characterized by analysis of the water quality parameters listed in Table 10.1. The first sampling for each required analyte shall be performed 1 day after plant operation start-up and then by the given frequency. Although many parameters may be analyzed off site, free and total chlorine residual, dissolved oxygen, pH, temperature, and turbidity must be analyzed on-site. It is recommended that UV-254 be also analyzed on-site.

The required water quality parameters listed in Table 10.1 are selected to provide state drinking water regulatory agencies with background data on the quality of the GAC influent water being treated and the quality of the treated water. Collection of these data will enhance the acceptability of the SIVT to a wide range of drinking water regulatory agencies.

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Acceptable analytical methods for Phase I, II, and V Rule VOCs are listed in Table 10.2. References to both *Standard Method* and EPA Method procedures for sample analysis are given. If new methods are published and approved or current methods updated, the most current methods shall be used.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain of custody requirements, as specified by the analytical lab.

Table 10.2 Analytical Methods for Phase I, II, and V Rule VOCs

Parameter	Standard Method	EPA Method
Benzene	6200 B, C	502.2; 524.2
Carbon tetrachloride	6200 B, C	502.2; 524.2; 551.1
Chlorobenzene	6040 B; 6200 B, C	502.2; 524.2
o-dichlorobenzene	6040 B; 6200 B, C; 6410 B	502.2; 524.2
p-dichlorobenzene	6040 B; 6200 B, C; 6410 B	502.2; 524.2
1,2-dichloroethane	6200 B, C	502.2; 524.2
1,1-dichloroethylene	6200 B, C	502.2; 524.2
cis-1,2-dichloroethylene	6200 B, C	502.2; 524.2
trans-1,2-dichloroethylene	6200 B, C	502.2; 524.2
Dichloromethane	6200 B, C	502.2; 524.2
1,2-dichloropropane	6200 B, C	502.2; 524.2
Ethylbenzene	6040 B; 6200 B, C	502.2; 524.2
Styrene	6200 B, C	502.2; 524.2
Tetrachloroethylene	6040 B; 6200 B, C	502.2; 524.2; 551.1
Toluene	6200 B, C	502.2; 524.2
1,2,4-trichlorobenzene	6040 B; 6200 B, C; 6410 B	502.2; 524.2
1,1,1-trichloroethane	6040 B; 6200 B, C	502.2; 524.2; 551.1
1,1,2-trichloroethane	6040 B; 6200 B, C	502.2; 524.2; 551.1
Trichloroethylene	6040 B; 6200 B, C	502.2; 524.2; 551.1
Vinyl chloride	6200 B, C	502.2; 524.2
Xylenes (total)	6040 B; 6200 B, C	502.2; 524.2

10.5 Evaluation Criteria

The results of SIVT shall be evaluated based on removal of VOCs. For filter-adsorbers, turbidity removal shall also be evaluated. The *EPA/NSF Equipment Verification Testing Plan for*

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Coagulation and Filtration within the *EPA/NSF ETV Protocol for Physical Removal of Microbiological and Particulate Contaminants* (EPA/NSF 2002) shall be followed if the filter-adsorber is to be verified as a filter of particulate matter. Time series plots shall be generated describing GAC influent and effluent VOC concentration, TOC concentration, UV-254, and turbidity. The other parameters analyzed should be tabulated. Statistical analyses of the data results shall include averages, minimum, and maximum for each analyte. For sample sets of eight or more, the results shall also include the standard deviation and confidence interval for each analyte. When summarizing SOC data of sample sets of eight or more, the 10th, 25th, 50th, 75th, and 90th percentiles shall also be reported. The length of the study, after taking into account all stoppage time, must be clearly reported.

The SIVT should yield high percent removals (low immediate breakthrough) of VOCs, TOC, and UV-254, demonstrating the initial very effective ability of GAC to remove natural and synthetic organic compounds. High levels of immediate breakthrough of VOCs are indicative of failure of the treatment system to initially adsorb VOCs, possibly due to hydraulic channeling, insufficient media, very low GAC adsorption capacity, or inappropriate GAC contactor design for the water quality tested (concentration of VOC combined with concentrations of other water quality parameters). Long-term VOC control will be evaluated during Task 4, Adsorption Capacity Verification Testing.

The mean and variability of the influent VOC concentration during testing shall be reported by the FTO. A target concentration value may be reported as the mean concentration during testing if it is within 5% of the actual measured mean concentration.

11.0 TASK 4: ADSORPTION CAPACITY VERIFICATION TESTING

11.1 Introduction

Removal of VOCs by adsorptive media is an unsteady-state process. The ability of an adsorptive media treatment system to remove VOCs in most cases will initially be excellent, but will diminish over time as breakthrough of the VOC occurs. The breakthrough of a given VOC is characteristic of the VOC and of the treatment system: breakthrough is dependent on design, EBCT, type of adsorptive media used, influent VOC concentration, VOC adsorbability, and influent water quality. Breakthrough behavior is highly dependent on the concentration and adsorbability of VOCs.

The main purpose of ACVT is to evaluate the capability of the adsorptive media treatment system for removal of VOCs. Specifically, the AUR will be determined for the VOC tested. The AUR will be assessed under the design and operation conditions of the treatment system, as well as influent water quality conditions of the source water after pretreatment, if any. Accurate characterization of influent water quality is important because the AUR, as a function of influent water quality, needs to be evaluated in that context. The "influent" is defined as water entering the adsorber after all pretreatment steps. The breakthrough of the VOC must be captured by a sufficient amount of data (number and scheduling of effluent samples) to allow for an accurate determination of the AUR under the conditions of the verification test.

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ACVT shall be performed at least once for a system, but may be performed multiple times on different water qualities to verify the manufacturer's objectives made on the ability of the equipment to remove VOCs under various influent water quality conditions. ACVT may also be performed multiple times to evaluate different levels of influent VOCs (treatment challenge levels) and different modes of testing (constant influent with low or high variability, and attenuation of a spike VOC).

For standard testing (single compound at constant target influent concentration with low variability), it is critical to accurately determine the average influent concentration during testing of a system. Furthermore, variability of the influent concentration above and below the mean must be minimized. Excessive variability may impact the AUR and diminish the validity of the test and, therefore, is not acceptable. The maximum allowable influent concentration variability is defined in this section. The mean and variability of the influent VOC concentration during testing shall be reported by the FTO. A target concentration value may be reported as the mean concentration during testing if it is within 5% of the actual measured mean concentration.

Systems evaluating adsorbent performance under non-standard modes (attenuation of a spiked influent VOC and treatment of a highly variable influent concentration) will not target a constant influent concentration with low variability; restrictions on the variability of the influent concentration do not apply. Separate influent variability guidelines for non-standard modes of operation are described in this section.

Adsorption will also be affected by the concentrations of other water quality parameters, including VOCs and SOCs. Characterization of the influent water quality to the adsorption process is needed so that system performance can be assessed properly and to ensure that influent water quality conditions match those targeted for equipment verification testing. The adsorption process influent water and the source water may or may not be identical, depending on whether the treatment equipment incorporates pretreatment (such as filtration).

Package plants that contain multiple contactors operated in parallel and staggered with respect to operation cycles shall be considered a single adsorptive media system: the influent water as applied in this section relates to the influent to all parallel contactors. The effluent as applied in this section relates to the blended effluent of all contactors in operation. It is assumed that the contactors in a multiple contactor package plant each contain the same EBCT. If the EBCT varies between contactors, then an average EBCT should be reported, as well as the actual EBCTs of each adsorber and an explanation of the system setup and operation.

11.2 Objectives

The objective of this task is to verify the manufacturer's statement of performance capability regarding the operation time and AUR of the adsorptive media treatment system for removal of one or more VOCs to levels below the treatment objective.

Specific objectives include:

- Characterization of the influent VOC concentration and variability;

- Evaluation of the concentrations during testing of other water quality parameters that impact VOC adsorption including TOC, UV-254, pH, temperature, and other background VOCs;
- Evaluation of the breakthrough of VOC to determine the AUR; and
- Evaluation of the breakthrough of other water quality parameters.

11.3 Work Plan

For ACVT, the FTO shall specify a run time criterion. A run time criterion can be set based on treated water quality conditions (such as exceeding the MCL for the VOC tested), or set to a specific maximum run time. A combination of treated water quality and maximum run time criteria may also be utilized. Since the duration of SIVT is 13 days plus one 8-hour shift, the minimum duration of ACVT shall also be 13 days plus one 8-hour shift. However, it is expected that all ACVT runs will be longer than 2 weeks in duration.

The PSTP shall identify the treated water DQOs to be achieved in the statement of performance capabilities of the equipment to be evaluated in the verification test. The PSTP shall also identify in the statement of performance capabilities the specific VOCs that shall be monitored during equipment testing. The statement of performance capabilities prepared by the FTO shall indicate the range of water qualities and operating conditions under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in a VOC removal verification test will be capable of achieving multiple water treatment objectives. Although the VOC TSTP is designed for the removal of VOCs, the manufacturer may want to examine the capabilities of the treatment system for removal of additional water quality parameters. Appropriate EPA/NSF ETV protocol(s) and TSTP(s) should be consulted.

Some of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. For the water quality parameters requiring analysis off site, water samples shall be analyzed by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 10.2. The analytical methods utilized for on-site monitoring of raw and finished water qualities are described in Task 8, Quality Assurance/Quality Control.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain of custody requirements, as specified by the analytical lab.

Package plants that contain multiple adsorbent contactors to be operated in parallel should follow manufacturer's guidelines for system start-up. If the contactors are to be operated in a staggered format, then each contactor should be brought on-line sequentially, as designated by the

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manufacturer's instructions. If the VOC to be treated is already present in the influent water, then the start of verification testing should take place when the first contactor is brought on-line. Alternatively, each contactor can be brought on-line sequentially until all contactors are in operation prior to the start of verification testing if the VOC to be tested is not present in the source water. Spiking of the VOC to be tested would begin when all contactors are operational.

For multiple contactor verification testing of attenuation of a spiked compound, all contactors should be brought on-line sequentially as designated by the manufacturer prior to spiking the compound.

Any influent spiking irregularities that occur during the study must be reported by the FTO. This includes, but is not limited to, events such as a period of time when the contaminant feed pump is not pumping at the correct flow rate, a period of time when the contaminant stock solution runs out, or a period of time when volatile losses may have occurred from the stock solution. The FTO must document the occurrence of these events including a clear description, corrective actions taken, the length of time during which the irregularity occurred (this may have to be estimated), and the known or estimated dates and times when the event began and ended. The description should include the FTO's opinion as to the severity of the irregularity in terms of its impact on testing results.

11.4 Analytical Schedule

11.4.1 Influent Sampling Requirements

Standard testing. All VOCs named in the manufacturer's statement of performance capabilities or analyzed in the adsorptive system effluent shall be sampled in the influent water. Influent VOC samples shall be taken at a sampling port located prior to the adsorptive media, after all pretreatment steps. During the first 2 weeks of testing, systems being tested for the first time should follow the influent sampling guidelines specified under Task 3, System Integrity Verification Testing. These systems should then follow the requirements specified in this section for influent sampling after the first 2 weeks. Systems that have already completed SIVT requirements can follow the influent sampling guidelines specified in this section for the entire study.

"Standard testing" applies to systems expected to be tested with a constant VOC influent concentration study with a low amount of influent variability. Standard testing also applies to studies in which the influent VOC is spiked to a constant level into a source water in which the influent VOC is either not present or is present at a lower, constant concentration. For standard testing, influent VOC concentration variability should not exceed the guidelines summarized in Table 10.2.

Since variability of source water VOC concentration may be higher than expected during any study, about twice as many influent samples are required to be taken as are analyzed. Equation 13 defines the total number of influent samples that must be taken (this number will be greater than the number analyzed, as long as variability is shown to be within the guidelines summarized in Table 11.1).

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$$N_S = \frac{63.7 + t_{bt}}{8.24} \tag{13}$$

where N_S is the required minimum number of samples taken (but not necessarily analyzed) for low-variable influent studies and t_{bt} is the operation time to breakthrough in days.

The result of this formula should be rounded to the nearest whole integer. Of the total number of samples taken (as given by Equation 13), every second sample must be analyzed, beginning with the first sample taken. By using this formula, the minimum frequency of influent sampling is gradually reduced: for a 1-year study, a minimum of 26 samples must be analyzed, or 1 sample every 2 weeks. This compares to 8 analyzed samples required for a 60-day study, or approximately 1 every week. The intent of this minimum influent sampling schedule is to reduce the sampling burden on more lengthy studies. The equation is not valid for run times shorter than 60 days. Assuming SIVT is not applicable to the study, the frequency of sampling between day 1 and 60 should be 3 samples per week. As before, every second sample should be analyzed. When SIVT is performed for the first 2 weeks of operation, then the sampling guidelines given in Task 3, System Integrity Verification Testing, must be followed for the first 2 weeks. Between 14 and 60 days, 3 samples per week are required, with every second sample analyzed.

If the data resulting from the analysis of every second influent sample confirms that the variability of the influent VOC concentration is low, then the samples taken but not analyzed can be discarded. However, if the data shows that the influent variability is unexpectedly high, then the “skipped” samples must be analyzed for a more accurate assessment of influent VOC concentration variability. The breakpoint between low and high variability is defined in Table 11.1.

For purposes of determining the minimum influent sampling rate, the testing period is defined as the operation time between start-up and breakthrough. If the VOC being tested reaches breakthrough (as defined in this document) on day 100, but the system is operated for an additional 150 days (for a total of 150 days since start-up), the minimum number of influent samples taken between day 1 and day 100 should be 10, as defined by Equation 13. Influent samples taken after breakthrough occurs should not be used to determine the mean influent concentration and influent concentration variability statistics. As stated earlier, breakthrough is defined in this document as the point during the run when the VOC concentration in the adsorber effluent exceeds the treatment objective.

In addition to the minimum frequency of influent sampling requirement, studies performed on a source water with low VOC variability (or studies in which the VOC is spiked to a constant concentration) must maintain an influent VOC concentration variability below the maximum allowable, as defined by the relative standard deviation (RSD), Equation 14:

$$\text{RSD} = s / \overline{y} \tag{14}$$

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where σ is the standard deviation and $\bar{y}$ is the mean. Since low-level VOC concentrations [in relation to the method minimum reporting level (MRL)] will likely result in higher analytical variability as compared to measured VOC concentration at higher levels, the maximum RSD is set based on the average concentration expressed as a multiple of the MRL, as shown in Table 11.1.

Table 11.1 Influent Concentration Variability Requirements for Standard Testing During ACVT

Average concentration (expressed as a multiple of the method MRL)	Maximum RSD of all influent samples (between t=0 and t=t_{bt})
1.0 - 1.5	50.0
>1.5 – 3.0	40.0
>3.0 – 10.0	30.0
>10.0	20.0

For example, if the method MRL for trichloroethylene is 1.0 µg/L, and the average measured influent trichloroethylene concentration of all samples analyzed between day 1 and t_{bt} is 5.0 µg/L, then the maximum RSD allowable is 30.0%. If the MRL was 2.0 µg/L for the same average influent VOC concentration, then the maximum RSD allowable would be 40.0%. Studies that exceed this maximum RSD must be classified as adsorptive systems treating an influent water with a highly variable VOC concentration: the "skipped" samples taken, but not analyzed, must now be analyzed. Additional sampling requirements are stipulated for highly variable influent VOC concentration studies as detailed below. Since the sampling rate required for studies conducted with highly variable influent VOC concentration is more stringent than that for studies conducted on influent VOCs with low variability, steps should be taken to minimize variability of the influent VOC during low-variability studies. If variability is higher than anticipated, the number of influent and effluent samples analyzed will be greater.

Highly variable influent concentration. For studies designed to test adsorptive media performance at a constant target influent concentration for a water source where a high amount of variability is expected, a higher number of samples is necessary to capture the variability of the influent VOC concentration. This higher sampling frequency is also required for studies in which the influent VOC concentration varies over time, resulting in an increasing or decreasing concentration over the course of the study, or other long-term trends that will impact the calculated RSD. The influent VOC concentration in such a study may not be extremely variable on a day-to-day basis, but the long-term trend must be characterized with the increased sampling frequency. Such a study is not ideal as the long-term change in influent concentration hampers data interpretation. This higher influent sampling frequency is also recommended when the expected VOC influent concentration variability is unknown.

The minimum number of influent samples for high-variability studies is also determined by Equation 13. Every sample taken must be analyzed. By using this formula, the minimum frequency of influent sampling is gradually reduced: for a 1-year study, a minimum of 52 samples must be taken and analyzed, or 1 sample every week. This compares to 15 samples required for a 60-day study, or approximately 2 every week. The intent of this minimum influent sampling schedule is to reduce the sampling burden on more lengthy studies. The equation is not valid for run times lower than 60 days. Assuming SIVT is not applicable to the study, the frequency of sampling between day 1 and 60 should be 3 samples per week. Again, every sample should be analyzed. When SIVT is performed for the first 2 weeks of operation, then the sampling guidelines given in Task 3, System Integrity Verification Testing, must be followed for the first 2 weeks. Between 14 and 60 days, 3 samples per week are required, with every second sample analyzed.

For purposes of determining the minimum influent sampling rate, the testing period is defined as the operation time between start-up and breakthrough. Therefore, if the VOC being tested reaches breakthrough (as defined in this document) on day 100, but the system is operated for an additional 50 days (for a total of 150 days since start-up), the minimum number of influent samples taken between day 1 and day 100 should be 20, as defined by Equation 13. Influent samples taken after breakthrough occurs should not be used to determine the mean influent concentration and influent concentration variability statistics. As stated earlier, breakthrough is defined in this document as the point during the run when the adsorber effluent reaches or exceeds the treatment objective.

No maximum measure of variability shall be set for these highly variable influent studies, but the variability in VOC influent concentration shall be summarized statistically by calculating the mean, standard deviation, 10th, 25th, 50th, 75th, and 90th percentiles, minimum, and maximum. In addition, a statement shall be included describing the variability observed in the influent VOC concentration over the course of the study.

VOC spike attenuation. For spike attenuation studies, the sampling frequency required for low-variability studies (standard testing) shall be followed. The purpose of sampling will be mainly to demonstrate the absence of significant levels of the VOC before and after the spike. During the spike, the influent shall be sampled more often, at a rate sufficient to capture the spike and confirm the accuracy of the spike concentration for purposes of data interpretation. During the spike, at least 2 samples per day are required, and a minimum total of 6 samples is required. Samples should be taken daily for at least 2 days before the spike and for at least 3 days after the spike.

Multiple VOC testing. Sampling requirements for verification testing of multiple VOCs should follow the guidelines set forth above. Each VOC tested shall be sampled at the minimum specified frequency.

Influent sampling requirements for other water quality parameters. Regardless of the type of study performed (low VOC variability, high VOC variability, or VOC spike attenuation), the sampling frequency for water quality parameters summarized in Table 11.2 shall be followed.

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Table 11.2 Minimum Influent Sampling Frequency Requirements for Water Quality Parameters

Parameter	Frequency
Alkalinity	Monthly
Ammonia (optional)	Monthly
Calcium hardness	Monthly
pH	Weekly
TDS or conductivity	Monthly
Temperature	Weekly
TOC	Monthly
Total hardness	Monthly
TSS	Monthly
Turbidity	See note[1]
UV-254	Monthly

[1] For contactors operated in filter-adsorber mode, a continuous turbidimeter should be used. Daily samples should be analyzed using a bench-top turbidimeter to confirm the continuous turbidimeter readings. For contactors operated in post-filter adsorber mode, the minimum sampling frequency for turbidity is weekly.

Multiple contactor operation influent sampling requirements. Ideally, water quality parameter samples should be taken from an influent line that is then split to each contactor. If this is not possible, then the influent to each contactor should be sampled at the required sampling frequency. For studies in which the VOC is spiked into the influent water, the spike should be located at an influent line or batch container that is then split to each contactor in service.

11.4.2 Effluent Sampling Requirements

To verify the manufacturer's run time or AUR statement of performance capability, an accurate determination of the run time to breakthrough of the VOC must be obtained during ACVT. Due to the unsteady-state nature of breakthrough, the uncertain impact of BOM and other VOCs on adsorption capacity, and the potential for lengthy analysis turnaround time, it is difficult to design a sampling plan that will always capture the complete breakthrough curve, especially when it is very sharp. A few strategies for sampling designed to improve the chances of collecting samples at critical points (during breakthrough) while minimizing the analytical cost are presented in this section.

The minimum effluent sampling requirements (N_S) are identical to those defined for the influent, described in Section 11.4.1, Influent Sampling Requirements. Samples should be paired: influent and effluent samples should always be taken at the same time, regardless of study design. If the influent VOC concentration variability is higher than expected, requiring the "skipped" samples to be run, then the paired effluent for each additional influent sample analyzed must also be analyzed.

For purposes of determining the minimum effluent sampling rate, the testing period is defined as the operation time between start-up and breakthrough. Thus, if the VOC being tested reaches breakthrough (as defined in this document) on day 100, but the system is operated for an additional 150 days (for a total of 150 days since start-up), the minimum number of effluent samples taken between day 1 and day 100 should be 20, as defined by Equation 13. As stated earlier, breakthrough is defined in this document as the point during the run when the adsorber effluent concentration exceeds the treatment objective.

A conservative sampling schedule approach is recommended, since breakthrough could occur earlier than expected. Care exercised in establishing the sampling plan will improve the potential of the data generated to verify the AUR for the VOC tested. This includes, but is not limited to, an increase in the sampling rate when breakthrough is expected. Guidance follows on developing a conservative sampling plan.

If prior experience with breakthrough of the target VOC under similar BOM conditions is identified, the results of previous experiments can be used to improve the run time estimate obtained during Task 2 using Equations 6 through 9. For example, if prior experience with adsorption of the same compound on the same water source indicates a run time to breakthrough 50% shorter than that predicted assuming the absence of BOM, then the run time estimated in Task 2 should be adjusted accordingly. Prior experience with other VOCs on the same water source can be used in the same manner, assuming similar adsorption characteristics to the present compound of interest. Differences in adsorbent type, temperature, EBCT, pH, etc. should be taken into account when applying the results of previous studies to the current verification testing.

If no prior experience with VOC adsorption on the water source to be used for verification testing is available, then two approaches can be followed: a) isotherm tests with the VOC and adsorbent preloaded with the BOM and b) literature isotherm values for the VOC and adsorbent can be used with, and adjusted for, non-distilled water conditions. Isotherm testing can be used to determine the Freundlich adsorption constant values under preloaded conditions. To do so, adsorbent that has been preloaded with BOM should be used for isotherm testing. Details on performing isotherm tests can be found in the literature (Randtke and Snoeyink 1983; Sontheimer, Crittenden, and Summers 1988; Snoeyink and Summers 1999). Literature Freundlich isotherm constant values from the literature can be modified by using Equations 6 and 10a to yield an estimate of the breakthrough time (see example in Section 9.3).

Once the best possible estimate of run time to breakthrough is determined, a sampling plan that adequately captures the breakthrough curve must be used. It is recommended that the rate of effluent sampling for the VOC be increased before, during and after the expected breakthrough point. It is extremely difficult to estimate run time to breakthrough accurately. Therefore, a safety factor should be placed around the estimate of run time in case the compound breaks through earlier than expected. This safety factor should be as large as feasible. This scenario assumes that all samples taken are subsequently analyzed.

Another method is to collect many more samples than will be analyzed, such as 5 times as many samples. Only every 10th sample is analyzed, while the rest are stored appropriately. When the zone in which breakthrough occurs is known, selected reserve

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samples that will fill in the breakthrough curve are analyzed. Only samples that capture the breakthrough curve are analyzed, thus minimizing the number of samples analyzed. This method requires that results for the initial samples analyzed are received before the holding times for the stored samples are exceeded. Overall, the sampling frequency should be equal to or greater than the minimum described in this section.

Special care should be exercised when evaluating the breakthrough of a VOC in the presence of other VOCs or SOCs at significant concentrations. Due to competitive adsorption effects, breakthrough of the VOC tested may occur earlier than expected.

Effluent sample requirements for the water quality parameters summarized in Table 11.3 should be evenly spaced over the course of the run. These requirements should be followed for all types of studies, including low and high variability, spike attenuation, and multiple parallel contactors.

Table 11.3 Minimum Effluent Sampling Frequency Requirements for Other Water Quality Parameters

Parameter	Frequency
TOC	Monthly
UV-254	Monthly
Turbidity	See note[1]

[1] For contactors operated in filter-adsorber mode, a continuous turbidimeter should be used. Daily samples should be analyzed using a bench-top turbidimeter to confirm the continuous turbidimeter readings. For contactors operated in post-filter adsorber mode, the minimum sampling frequency for turbidity is weekly.

The effluent sampling requirements outlined in this section apply also to package plants that blend the effluents of multiple parallel adsorbers prior to further treatment and distribution. For purposes of sampling, the set of multiple parallel contactors constitutes the adsorption treatment system evaluated.

11.5 Evaluation Criteria

Data analysis and interpretation for this task includes:

- Effluent VOC data collected and analyzed as described in Section 11.4.2, Effluent Sampling Requirements, shall be evaluated on a continuous basis to determine whether breakthrough is occurring or has occurred. A fast turnaround time for sample analysis is preferable.

- The effluent VOC data shall be used in conjunction with the run time estimate described in Section 9.3 to determine when to terminate test runs. Due to the turnaround time required for VOC analysis, it may take time to establish when breakthrough has occurred and that the test can be terminated. It is not recommended that the test be terminated on the basis of the run time estimate alone. The length of the study, after taking into account all stoppage time, must be clearly reported.

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- Plots of effluent concentration against operation time or throughput shall be prepared for all VOCs evaluated. Breakthrough curves should be prepared on a continuous basis, as data is available, to aid in evaluating the status of VOC breakthrough. Similar plots should be prepared for all other water quality analyses conducted.

- The AUR shall be determined based on data obtained during verification testing that shows effluent concentrations lower than the effluent criteria specified in the manufacturer's statement of performance capabilities. The run time will be shorter than the maximum testing run time if breakthrough of the VOC evaluated occurs prior to the end of the run.

- The mean and variability of the influent VOC concentration during testing shall be reported by the FTO. Results shall include the average, minimum, maximum, and number of data points in the data set. For sample sets of eight or more, the results shall also include the standard deviation and confidence interval for each analyte. When summarizing VOC data of sample sets of eight or more, the 10th, 25th, 50th, 75th, and 90th percentiles shall also be reported. A target concentration value may be reported as the mean concentration during testing if it is within 5% of the actual measured mean concentration.

- Based on t_{bt}, the AUR is calculated using the following equation, Equation 15:

$$\text{AUR(g/L)} = \frac{\boldsymbol{r}\text{(g/L)}}{Y_{bt}} \tag{15}$$

where $\boldsymbol{r}$ is the apparent media density and Y_{bt} is the number of BV to breakthrough. The value for Y_{bt} is calculated from t_{bt} by Equation 16:

$$Y_{bt} = \frac{t_{bt}\,\text{(days)} \cdot 1{,}440\,\text{min/day}}{\text{EBCT(min)}} \tag{16}$$

- For spike attenuation studies, the influent data should be evaluated to determine if influent VOC concentration matches that described by the manufacturer's statement of performance capabilities. Effluent data should be evaluated to determine if effluent VOC levels exceed the MCL as stated in the manufacturer's statement of performance capabilities. If effluent data exceed the MCL, the operation time at which it exceeded the MCL should be determined (relative to when the spike occurred) the same way that the operation time is determined for constant influent studies. Thus the effective AUR may also be determined for spike attenuation studies.

Constant influent studies: determination of run time to breakthrough. For manufacturers wishing to make a stronger performance capabilities statement and operate their adsorptive media system for run times long enough to observe breakthrough of the VOC(s) tested, an evaluation of the influent and effluent data on which the AUR is based must be performed. This section provides some guidance on performing this evaluation, which will help with experimental design and data analysis.

As stated previously, it is difficult to predict when breakthrough will occur for a given VOC during removal by adsorptive media. After appropriate influent and effluent sampling that provides the best possible evaluation of the manufacturer's statement of performance capabilities (described previously in this section), the data analyzed should be evaluated to determine the run time to breakthrough. Run time to breakthrough can be determined from the data in two ways, depending on the quality of the data.

Basic quality data is best described as effluent data that is not evenly spaced, that fails to capture the shape of the breakthrough curve (i.e., an effluent data point below detection limits is followed by one that approximates influent concentrations), or that is so variable that a best-fit breakthrough curve would contain excessive uncertainty. Examples of these are shown in Figure 11.1. One or more of these conditions may result in a data set that is difficult to interpret in determining when breakthrough occurred. Therefore, a conservative approach to determining the operation time to breakthrough for basic quality data must be utilized: the operation time of the last sample taken prior to a sample that exceeds the treatment objective is the run time used for the AUR calculation. Sub-optimal quality data is a result of a variety of factors, including insufficient or poorly-spaced sampling, variability in system flow rate, analytical variability, excessive influent VOC concentration variability, or variability of other water quality parameters, such as pH, TOC, turbidity, or other VOCs. A poor quality data set may result in an effective AUR much higher than that actually achievable by the treatment system evaluated. Therefore, it is in the manufacturer's best interest that the data generated during verification testing be of the highest quality possible.

The operation time to breakthrough and AUR can be calculated from good quality data using the same method described for basic quality data. Alternatively, a curve fit of a good quality data set can be performed to determine the operation time to breakthrough by interpolation. In many cases, good quality data will allow for a straightforward evaluation of the breakthrough curve, from the point of initial breakthrough to column exhaustion. Evenly spaced data points will be located throughout the breakthrough curve. Data will often be collected at operation times well beyond the point of breakthrough (the point at which the effluent concentration reaches the treatment objective). Examples of good quality data are also given in Figure 11.1.

The FTO shall assess the quality of the data generated by the study. Based on this analysis, the FTO shall determine which method of calculating the run time to breakthrough should be employed. In either case, a graph of the data must be included in the report. If a curve fit is performed to determine the operation time to breakthrough, a graph of the data and the curve fit should be included, along with the curve fit type or method, and relevant statistical information on the goodness of fit (e.g., r^2), and confidence intervals. A confidence interval on the calculated AUR should be reported.

Again, since basic quality data will yield a conservative estimate of the run time to breakthrough, it is advantageous for the study to be designed and performed so that the best possible quality data is obtained.

The methods for estimating the operation time to breakthrough described in this section apply to both low variability and high variability constant influent studies.

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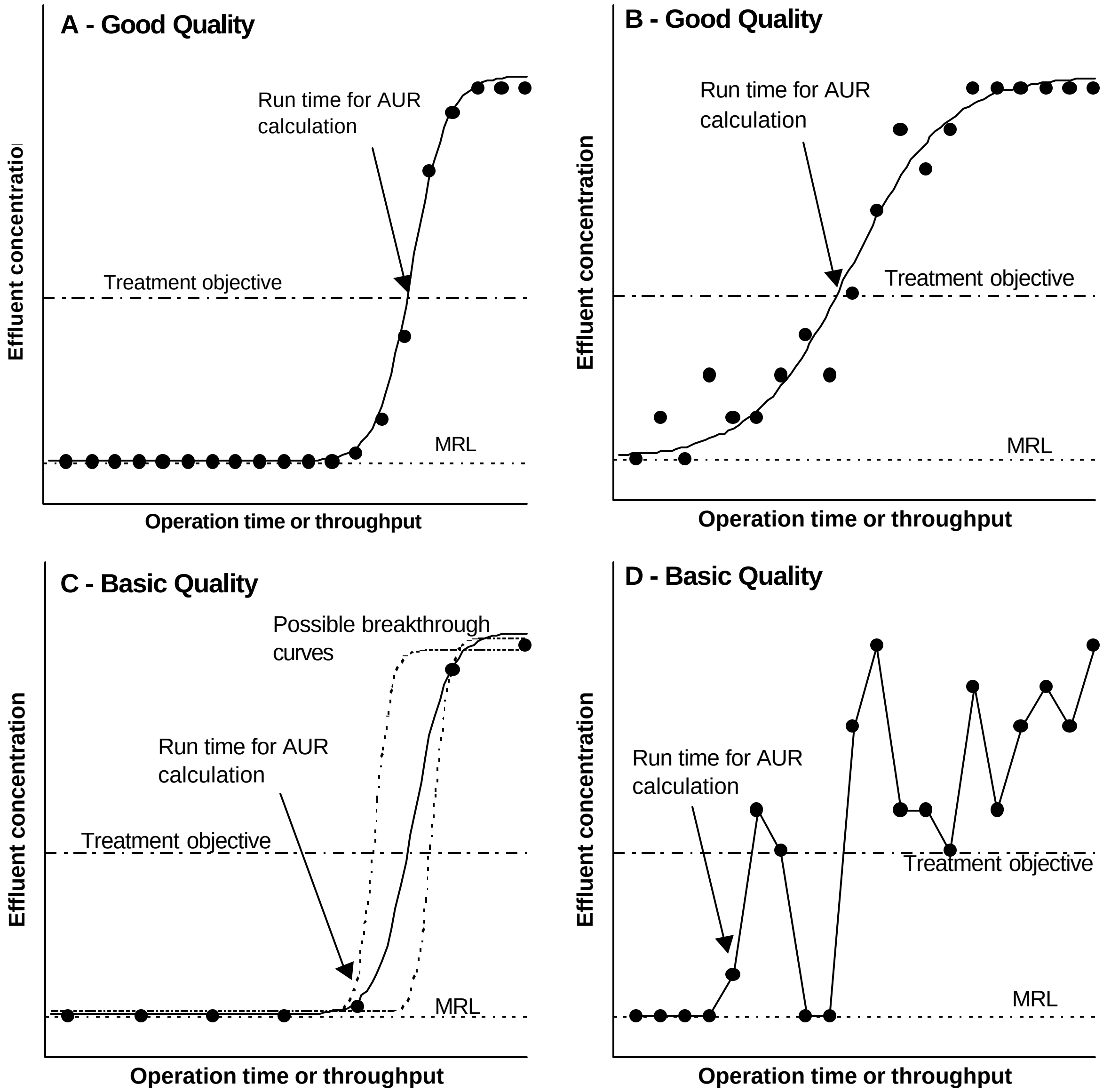

Figure 11.1 Examples of Good and Basic Quality Breakthrough Curves

Attenuation of spiked influent. For studies designed to assess the ability of the adsorptive media to attenuate a spiked influent, the FTO shall analyze the data obtained to assess that effluent concentrations were reduced and did not exceed the treatment objective. If effluent concentrations exceeded the treatment objective, then the AUR should be calculated based on the point of breakthrough. Based on the data quality, the methods described above for constant influent studies should be applied.

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12.0 TASK 5: IN-PLACE REGENERATION

12.1 Introduction

This task is applicable only to adsorption treatment systems that use adsorptive media that can be regenerated in-place and that incorporate regeneration capability as an integral part of the equipment being tested. If the manufacturer wishes to make a statement of performance capabilities about the in-place regeneration capability of the equipment, verification testing must include, as a minimum, two complete cycles: an initial loading cycle, followed by a regeneration cycle, and then a second loading cycle, followed by a second regeneration cycle. This additional requirement allows for a comparison of adsorptive media performance before and after regeneration. Furthermore, the regeneration efficiency shall be determined based on the second regeneration cycle.

Verification of in-place regeneration based on two complete loading/regeneration cycles is limited, and additional cycles are recommended if possible. However, the guidelines for modified testing to verify an in-place regeneration statement of performance capabilities are described under this task. The regeneration system, regenerant fluids used, and regeneration procedure shall be documented as part of Task 2, System Design and Operation.

12.2 Objectives

The objectives of this task are to:

- Describe operation and sampling requirements for systems in which in-place regeneration will be verified;
- Evaluate adsorptive media performance before and after in-place regeneration;
- Characterize any residuals produced during regeneration; and
- Evaluate regeneration efficiency.

12.3 Work Plan

To verify a manufacturer’s statement of performance capabilities regarding the in-place regeneration capability of adsorption equipment, verification testing shall be conducted as described in Section 10.0 (Task 3, System Integrity Verification Testing) and Section 11.0 (Task 4, Adsorption Capacity Verification Testing), combined with the additional requirements or modifications as described in this task.

The testing period shall include, as a minimum, two complete cycles: an initial loading cycle, followed by a regeneration cycle, and then a second loading cycle, followed by a second regeneration cycle. During each loading period, the adsorptive media system must be operated at least until breakthrough of the VOC occurs, based on the treatment objective defined in the manufacturer’s statement of performance capabilities.

The VOC influent target concentration shall be the same during both loading cycles. The mode of testing (low-variability constant influent, high-variability constant influent, or attenuation of a spiked influent VOC) shall also be identical during both loading cycles. All other experimental parameters, such as water source, pretreatment, and presence of background VOCs, shall be as similar as possible during the two (or more, if necessary) loading cycles. If the four-step cycle is completed in less than 60 days, additional loading/regeneration cycles shall be performed until the total run time is at least 60 days.

If possible, incorporation of additional cycles into the verification test would increase the amount of data on regeneration effectiveness and retention of adsorption capacity over time. Whether or not additional cycles are completed, the FTO must make a statement about the long-term efficiency of regeneration for the adsorptive media tested. If the long-term efficiency of regeneration is not studied as part of this verification test, or available from other studies, a statement by the FTO is required indicating that the long-term regeneration efficiency is unknown. For adsorptive media that has been well studied, a statement on the long-term regeneration efficiency can be based on the results of previous peer-reviewed published studies.

Any residuals produced during in-place regeneration of the adsorptive media shall be fully characterized and documented with respect to quantity and VOC composition. For example, if an off-gas stream is produced by a high temperature gas purge of the media, the off-gas flow rate, duration, and total off-gas volume emitted should be measured, and sampling and analysis should be conducted to determine VOC concentrations and total VOC mass emissions. Likewise, if a solvent solution is used for regeneration, the quantity and characteristics of the regenerant before and after use (including VOC concentrations) should be measured and reported. The information from this residuals characterization task shall be used to determine the efficiency of regeneration. A mass balance approach shall be used to determine whether all the VOCs were removed during the regeneration process. The regeneration efficiency and the AUR for each cycle shall be reported.

12.4 Analytical Schedule

Influent and effluent sampling requirements described in Section 10.0 and Section 11.4, shall be applied to *each* loading cycle to assess VOC breakthrough and other water quality parameters. For characterization of regeneration residuals, a sampling and analytical plan shall be developed by the FTO in the PSTP to thoroughly characterize the VOC content of the residual stream.

12.5 Evaluation Criteria

Verification testing of adsorption treatment systems with in-place regeneration includes the same types of data analysis and interpretation as described previously for standard adsorption systems in Section 11.5. In addition, a comparative analysis of adsorption characteristics before and after media regeneration shall be performed. The purpose of the comparative analysis is to assess and quantify whether any reduction in adsorptive media service life or adsorption capacity occurs as a result of in-place regeneration. This shall be evaluated by determining the media service life (operation time, throughput in BV of water treated, and AUR until breakthrough) for the initial and subsequent loading periods, and by quantitatively comparing the results. Similarly, the adsorption capacity before and after regeneration can be determined and compared. In addition, a mass balance should be developed for the VOC tested to evaluate the regeneration efficiency using Equation 17:

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$$E_R = \frac{q \cdot m_A}{m_R} \tag{17}$$

where E_R is the regeneration efficiency, q is the adsorption capacity estimated using Equation 4 (and subject to the limitations noted earlier), m_A is the mass of adsorbent, and m_R is the mass VOC recovered in the regeneration stream. The regeneration efficiency shall be calculated after both regeneration cycles.

13.0 TASK 6: OPERATION AND MAINTENANCE MANUAL

13.1 Objectives

The FTO shall obtain the manufacturer-supplied O&M manual(s) to evaluate the instructions and procedures for their applicability during the verification testing period. Below are recommendations for criteria to evaluate O&M manuals for package plants employing adsorptive media for VOC removal.

13.2 Operation

The manufacturer shall provide readily understood information on the required or recommended procedures related to the proper operation of the package plant equipment including, but not limited to, the following.

Monitoring of Preconditioning of Adsorptive Media:

- Utilize manufacturer's procedure, which may vary depending upon adsorptive media selected;
- Backwash parameters (flow rate, time, backwash water turbidity, etc.);
- Pretreatment chemical application (chemical concentration, time, and flow rate);
- Volume of wastewater; and
- Wastewater disposal requirements (see Regeneration Wastewater Disposal below).

Monitoring Operation:

The feed water is the untreated or pretreated water that serves as influent to the package plant, prior to any treatment processes preceding adsorption in the package plant. Treated water is the adsorptive media effluent water, and is blended if multiple contactors are operated in parallel.

- Feed water VOC concentration;
- Feed water pH;
- Feed water adjusted pH (if applicable);
- Feed water flow rate;
- Feed water pressure;
- Treated water VOC concentration;
- Treated water pH;

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- Treated water adjusted pH;
- Treated water pressure;
- Chemical feed rates;
- Chemical consumption;
- Maintenance and operator labor requirements; and
- Spare parts requirements.

Monitoring Regeneration of Adsorptive Media:

- Utilize manufacturer's procedure for regeneration which shall vary depending upon selected adsorptive media, equipment, and process variables;
- Backwash parameters (flow rate, time, backwash water turbidity, etc.);
- Regeneration parameters (flow rate, time, regeneration chemical concentration and flow rate, effluent concentration, effluent pH, etc.);
- Neutralization parameters (flow rate, time, neutralization chemical concentration); and
- Adsorptive media makeup requirement.

Monitoring Regeneration Wastewater Disposal:

- Utilize manufacturer's procedure for processing, reclaiming, and/or disposing of regeneration wastewater, adsorptive media preconditioning wastewater, and waste solids, which shall vary depending upon selected adsorptive media, equipment, treatment chemicals and process variables;
- pH adjustment parameters (flow rate, pH, time, pH adjustment chemical consumption, etc.);
- Flocculation/coagulation parameters (flow rate, time, flocculation/coagulation chemical consumption, etc.);
- Liquid/solid separation parameters (flow rate, time, etc.);
- Solids dewatering parameters (flow rate, time, sludge conditioning chemical consumption, dewatered sludge solids, content, toxicity of dewatered solids, etc.);
- Solids disposal parameters (volume, toxicity, permits, transportation of solids to disposal site, cost factors of transportation and disposal, etc.); and
- Liquid disposal parameters (volume, toxicity, pH, permits, adjustment requirements, cost factors of disposal, etc.).

13.3 Maintenance

The manufacturer shall provide readily understood information on the required or recommended maintenance schedule for each piece of operating equipment including, but not limited to:

- Pumps;
- Valves;
- All chemical feed and storage equipment; and
- All instruments.

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The manufacturer shall provide readily understood information on the required or recommended maintenance schedule for non-mechanical or non-electrical equipment including, but not limited to:

- Adsorptive media vessels;
- Feed lines; and
- Manual valves.

14.0 TASK 7: DATA MANAGEMENT

14.1 Introduction

The data management system used in the verification test shall involve the use of computer spreadsheets, manual recording methods, or both, for recording operational parameters for the adsorptive media treatment equipment on a daily basis.

14.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data to ensure that the FTO provides sufficient and reliable operational data to NSF for verification purposes.

14.3 Work Plan

The following procedure has been developed for data handling and data verification to be used by the FTO. 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 Microsoft Excel or similar spreadsheet software. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a weekly basis at a minimum.

In the case that a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks (daily measurements shall be recorded on specially-prepared data log sheets as appropriate). The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week. This procedure shall not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the adsorptive media 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 shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall 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 shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each sample shall be assigned a unique identification (ID) number that shall then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to NSF-qualified analytical laboratories, the data shall be tracked by use of the same system ID numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and checked in the same manner as the field data.

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15.0 TASK 8: QUALITY ASSURANCE/QUALITY CONTROL

15.1 Introduction

QA/QC for the operation of the adsorptive media treatment equipment and the measured water quality parameters shall be maintained during the verification test.

15.2 Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the equipment verification test. 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 determine the exact conditions at the time of testing.

15.3 Work Plan

When developing the Quality Assurance Project Plan (QAPP) within the PSTP, the FTO should refer to Chapter 1, Section 6.0 Quality Assurance Project Plan, in addition to the information provided herein. All of the requirements and guidelines described in Chapter 1 shall be included in the development of the PSTP. In addition to the general ETV Program QA/QC described in Chapter 1, the PSTP shall incorporate the specific adsorptive media QA items detailed in this section.

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

It is extremely important that system flow rates be maintained at set values and monitored frequently. Doing so allows a constant and known EBCT to be maintained in the adsorbent contactor. Adsorbent performance is directly affected by the EBCT, which in turn is proportional to the volumetric flow rate through the contactor. Therefore, an important QA/QC objective shall be the maintenance of a constant volumetric flow rate through the adsorbent contactor by means of frequent monitoring and documentation. Documentation shall include an average and standard deviation of recorded flow rates through the adsorbent contactor.

15.3.1 Daily QA/QC Checks

- Chemical feed pump flow rates (checked volumetrically; more frequent monitoring, such as every 8 hours, is recommended);
- In-line turbidimeter flow rates (checked volumetrically, if employed);
- Adsorbent contactor(s) flow rate(s) (checked volumetrically every 2 hours when staffed; at least twice daily. The flow rate should be adjusted to maintain its value within 5% of the design flow rate); and
- Recalibration of in-line pH meters (if used).

15.3.2 Weekly QA/QC Checks

- Recalibration of conductivity meters, and/or turbidimeters (if used). If less frequent recalibration of conductivity meters and turbidimeters is recommended by manufacturer, then follow manufacturer’s recommendation;
- In-line flow meters/rotameters (confirm flow rate volumetrically over a specific period of time to confirm instrument reading and, if necessary, clean equipment to remove any foulant buildup); and
- Tubing (check condition of all tubing and connections and replace if necessary).

15.3.3 Monthly QA/QC Checks

- In-line turbidimeters (clean out reservoirs and recalibrate, if employed) and
- Differential pressure transmitters (confirm gauge readings and electrical signal using a pressure meter).

15.4 Analytical Methods

On-Site Analyses. The analytical methods utilized in this study for on-site monitoring of feed and effluent water quality are described below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

pH. Analyses for pH shall be performed according to *Standard Method* 4500-H^+ (APHA, AWWA, and WEF 1998). A 3-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

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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.

Temperature. Temperature measurements shall be made in accordance with *Standard Method* 2550. The thermometer used should be a high quality, mercury-filled, Celsius thermometer with a scale marked for every 0.1°C that covers the range of expected temperatures with markings etched in the glass. The thermometer should be checked periodically against a precision thermometer certified by the National Institute of Standards and Technology (NIST). An in-line thermometer is acceptable for this work.

Turbidity. Turbidity analyses shall be performed according to *Standard Method* 2130 with either an in-line or bench-top turbidimeter. During verification testing, the in-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The FTO shall document any problems experienced with the monitoring turbidity instruments during testing, and shall also document any subsequent modifications or enhancements made to monitoring instruments.

Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument shall 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 verification testing 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 check the calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples shall 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. In the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

In-line Turbidimeters. In-line turbidimeters shall be used for measurement of turbidity in the filtrate water during verification testing and must be calibrated and maintained as specified in the manufacturer's O&M manual. It will be necessary to check 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.

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If the comparison suggests 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 checks of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. The LED readout should also be checked to ensure that it matches the data recorded on the data acquisition system, if the latter is employed.

Off-Site Analyses. All off-site analytical work associated with equipment verification testing shall be performed by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. Sampling for off-site analyses shall be conducted using proper sampling techniques and samples shall be collected in appropriate volumes and containers provided by the laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

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APPENDIX A: REGULATED VOCS

Table A.1 Phase I Rule VOCs

Contaminant	MCLG (mg/L)	MCL (mg/L)	Status	Potential health effects	Sources of contaminant in drinking water	BAT
Benzene	Zero	0.005	Final	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	GAC, PTA
Carbon tetrachloride	Zero	0.005	Final	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	GAC, PTA
p-dichlorobenzene	0.075	0.075	Final	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	GAC, PTA
1,2-dichloroethane	Zero	0.005	Final	Increased risk of cancer	Discharge from industrial chemical factories	GAC, PTA
1,1-dichloroethylene	0.007	0.007	Final	Liver problems	Discharge from industrial chemical factories	GAC, PTA
1,1,1-trichloroethane	0.2	0.2	Final	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	GAC, PTA
Trichloroethylene	Zero	0.005	Final	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	GAC, PTA
Vinyl chloride	Zero	0.002	Final	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	PTA

Abbreviations:

MCL: maximum contaminant level
MCLG: maximum contaminant level goal
BAT: best available technology
GAC: granular activated carbon
PTA: packed tower aeration

Sources: USEPA, 2002; adapted from Pontius and Clark (1999) and Faust and Aly (1998)

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Table A.2 Phase II Rule VOCs

Contaminant	MCLG (mg/L)	MCL (mg/L)	Status	Potential health effects	Sources of contaminant in drinking water	BAT
Chlorobenzene	0.1	0.1	Final	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	GAC, PTA
o-dichlorobenzene	0.6	0.6	Final	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	GAC, PTA
cis-1,2-dichloroethylene	0.07	0.07	Final	Liver problems	Discharge from industrial chemical factories	GAC, PTA
trans-1,2-dichloroethylene	0.1	0.1	Final	Liver problems	Discharge from industrial chemical factories	GAC, PTA
1,2-dichloropropane	Zero	0.005	Final	Increased risk of cancer	Discharge from industrial chemical factories	GAC, PTA
Ethylbenzene	0.7	0.7	Final	Liver or kidneys problems	Discharge from petroleum refineries	GAC, PTA
Styrene	0.1	0.1	Final	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	GAC, PTA
Tetrachloroethylene	Zero	0.005	Final	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	GAC, PTA
Toluene	1	1	Final	Nervous system, kidney, or liver problems	Discharge from petroleum factories	GAC, PTA
Xylenes (total)	10	10	Final	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	GAC, PTA

Abbreviations:

MCL: maximum contaminant level
MCLG: maximum contaminant level goal
BAT: best available technology
GAC: granular activated carbon
PTA: packed tower aeration

Sources: USEPA, 2002; adapted from Pontius and Clark (1999) and Faust and Aly (1998)

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Table A.3 Phase V Rule VOCs

Contaminant	MCLG (mg/L)	MCL (mg/L)	Status	Potential health effects	Sources of contaminant in drinking water	BAT
Dichloromethane (methylene chloride)	Zero	0.005	Final	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	PTA
1,2,4-trichlorobenzene	0.07	0.07	Final	Changes in adrenal glands	Discharge from textile finishing factories	GAC, PTA
1,1,2-trichloroethane	0.003	0.005	Final	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	GAC, PTA

Abbreviations:

MCL: maximum contaminant level
MCLG: maximum contaminant level goal
BAT: best available technology
GAC: granular activated carbon
PTA: packed tower aeration

Sources: USEPA, 2002; adapted from Pontius and Clark (1999) and Faust and Aly (1998)

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APPENDIX B: DRINKING WATER STANDARDS AND HEALTH ADVISORIES

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Table B.1 Drinking Water Standards and Health Advisories

	Standards				Health Advisories						
					10-kg child						
Chemicals	Status Reg.	MCLG (mg/L)	MCL (mg/L)	Status HA Document	One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	Cancer Group
Acenaphthene	-	-	-	-	-	-	0.06	2	-	-	-
Acifluorfen (sodium)		-	-	F '88	2	2	0.01	0.4	-	0.1	B2
Acrylamide	F	zero	TT[1]	F '87	1.5	0.3	0.0002	0.007	-	0.001	B2
Acrylonitrile		-	-	-	-	-	-	-	-	0.006	B1
Alachlor	F	zero	0.002	F '88	0.1	0.1	0.01	0.4	-	0.04[2]	B2
Aldicarb[3]	F[4]	0.007	0.007	F '95	0.01	0.01	0.001	0.04	0.007	-	D
Aldicarb sulfone[3]	F[4]	0.007	0.007	F '95	0.01	0.01	0.001	0.04	0.007	-	D
Aldicarb sulfoxide[3]	F[4]	0.007	0.007	F '95	0.01	0.01	0.001	0.04	0.007	-	D
Aldrin	-	-	-	F '92	0.0003	0.0003	0.00003	0.001	-	0.0002	B2
Ametryn	-	-	-	F '88	9	9	0.009	0.3	0.06	-	D
Ammonium sulfamate	-	-	-	F '88	20	20	0.2	8	2	-	D
Anthracene (PAH)[5]	-	-	-	-	-	-	0.3	10	-	-	D
Atrazine[6]	F	0.003	0.003	F '88	-	-	0.035	1	0.2	-	C
Baygon	-	-	-	F '88	0.04	0.04	0.004	0.1	0.003	-	C
Bentazon	-	-	-	F '99	0.3	0.3	0.03	1	0.2	-	E
Benz[a]anthracene (PAH)	-	-	-	-	-	-	-	-	-	-	B2
Benzene	F	zero	0.005	F '87	0.2	0.2	-	-	-	0.1	A
Benzo[a]pyrene (PAH)	F	zero	0.0002	-	-	-	-	-	-	0.002	B2
Benzo[b]fluoranthene (PAH)	-	-	-	-	-	-	-	-	-	-	B2
Benzo[g,h,i]perylene (PAH)	-	-	-	-	-	-	-	-	-	-	D
Benzo[k]fluoranthene (PAH)	-	-	-	-	-	-	-	-	-	-	B2
bis-2-Chloroisopropyl ether	-	-	-	F '89	4	4	0.04	1	0.3	-	D
Bromacil	-	-	-	F '88	5	5	0.1	5	0.09	-	C
Bromobenzene	-	-	-	D '86	4	4	-	-	-	-	D

[1] When acrylamide is used in drinking water systems, the combination (or product) of dose and monomer level shall not exceed that equivalent to a polyacrylamide polymer containing 0.05% monomer dosed at 1 mg/L.

[2] Determined not to be carcinogenic at low doses by OPP.

[3] The lifetime HA value or the MCLG/MCL value for any combination of two or more of these three chemicals should remain at 0.007 mg/L because of similar mode of action.

[4] Administrative stay of the effective date.

[5] PAH = Polycyclic aromatic hydrocarbon

[6] Under review

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

Chemicals	Standards			Status HA Document	Health Advisories						Cancer Group
					10-kg child		RfD (mg/kg/day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	
	Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)					
Bromochloromethane	-	-	-	F '89	50	1	0.01	0.5	0.09	-	D
Bromodichloromethane (THM)	F	zero	0.08[1]	D '93	6	6	0.02	0.7	-	0.06	B2
Bromoform (THM)	F	zero	0.08[1]	D '93	5	2	0.02	0.7	-	0.4	B2
Bromomethane	-	-	-	D '89	0.1	0.1	0.001	0.05	0.01	-	D
Butyl benzyl phthalate (PAE)[2]	-	-	-	-	-	-	0.2	7	-	-	C
Butylate	-	-	-	F '89	2	2	0.05	2	0.4	-	D
Carbaryl	-	-	-	F '88	1	1	0.1	4	0.7	-	D
Carbofuran[3]	F	0.04	0.04	F '87	0.05	0.05	0.005	0.2	0.04	-	E
Carbon tetrachloride	F	zero	0.005	F '87	4	0.2	0.0007	0.03	-	0.03	B2
Carboxin	-	-	-	F '88	1	1	0.1	4	0.7	-	D
Chloramben	-	-	-	F '88	3	3	0.015	0.5	0.1	-	D
Chlordane	F	zero	0.002	F '87	0.06	0.06	0.0005	0.02	-	0.001	B2
Chloroform (THM)	F	zero	0.08[1]	D '93	4	4	0.01	0.4	-	0.6	B2
Chloromethane	-	-	-	F '89	9	0.4	0.004	0.1	0.003	-	C
Chlorophenol (2-)	-	-	-	D '94	0.5	0.5	0.005	0.2	0.04	-	D
p-Chlorophenyl methyl sulfide/sulfone/sulfoxide	-	-	-	-	-	-	-	-	-	-	D
Chlorothalonil	-	-	-	F '88	0.2	0.2	0.015	0.5	-	0.15	B2
Chlorotoluene o-	-	-	-	F '89	2	2	0.02	0.7	0.1	-	D
Chlorotoluene p-	-	-	-	F '89	2	2	0.02	0.7	0.1	-	D
Chlorpyrifos	-	-	-	F '92	0.03	0.03	0.003	0.1	0.02	-	D
Chrysene (PAH)	-	-	-	-	-	-	-	-	-	-	B2
Cyanazine	-	-	-	D '96	0.1	0.1	0.002	0.07	0.001	-	-

[1] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for trihalomethanes is 0.08 mg/L.

[2] PAE = phthalate acid ester

[3] Under review

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

	Standards				Health Advisories						
					10-kg child						
Chemicals	Status Reg.	MCLG (mg/L)	MCL (mg/L)	Status HA Document	One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	Cancer Group
Cyanogen chloride[1]	-	-	-	-	0.05	0.05	0.05	2	-	-	D
2,4-D (2,4-dichlorophenoxyacetic acid)	F	0.07	0.07	F '87	1	0.3	0.01	0.4	0.07	-	D
DCPA (Dacthal)	-	-	-	F '88	80	80	0.01	0.4	0.07	-	D
Dalapon (sodium salt)	F	0.2	0.2	F '89	3	3	0.03	0.9	0.2	-	D
Di(2-ethylhexyl)adipate	F	0.4	0.4	-	20	20	0.6	20	0.4	3	C
Di(2-ethylhexyl)phthalate (PAE)	F	zero	0.006	-	-	-	0.02	0.7	-	0.3	B2
Diazinon	-	-	-	F '88	0.02	0.02	0.00009	0.003	0.0006	-	E
Dibromochloromomethane (THM)	F	0.06	0.08[2]	D '93	6	6	0.02	0.7	0.06	0.04	C
Dibromochloropropane (DBCP)	F	zero	0.0002	F '87	0.2	0.05	-	-	-	0.003	B2
Dibutyl phthalate (PAE)	-	-	-	-	-	-	0.1	4	-	-	D
Dicamba	-	-	-	F '88	0.3	0.3	0.03	1	0.2	-	D
Dichloroacetic acid	F	zero	0.06[3]	D '93	5	5	0.004	0.1	-	-[4]	B2
Dichlorobenzene o-	F	0.6	0.6	F '87	9	9	0.09	3	0.6	-	D
Dichlorobenzene m-[5]	-	-	-	F '87	9	9	0.09	3	0.6	-	D
Dichlorobenzene p-	F	0.075	0.075	F '87	11	11	0.1	4	0.075	-	C
Dichlorodifluoromethane	-	-	-	F '89	40	40	0.2	5	1	-	D
Dichloroethylene (1,1-)	F	0.007	0.007	F '87	2	1	0.01	0.4	0.007	-	C
Dichloroethane (1,2-)	F	zero	0.005	F '87	0.7	0.7	-	-	-	0.04	B2
Dichloroethylene (cis-1,2-)	F	0.07	0.07	F '90	4	1	0.01	0.4	0.07	-	D
Dichloroethylene (trans-1,2-)	F	0.1	0.1	F '87	20	1	0.02	0.7	0.1	-	D
Dichloromethane	F	zero	0.005	D '93	10	2	0.06	2	-	0.5	B2
Dichlorophenol (2,4-)	-	-	-	D '94	0.03	0.03	0.003	0.1	0.02	-	E
Dichloropropane (1,2-)	F	zero	0.005	F '87	-	0.09	-	-	-	0.06	B2
Dichloropropene (1,3-)	-	-	-	F '88	0.03	0.03	0.03	1	-	0.04	B2
Dieldrin	-	-	-	F '88	0.0005	0.0005	0.00005	0.002	-	0.0002	B2
Diethyl phthalate (PAE)	-	-	-	-	-	-	0.8	30	-	-	D

[1] Under review

[2] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for trihalomethanes is 0.08 mg/L.

[3] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for five haloacetic acids is 0.06 mg/L.

[4] A quantitative risk estimate has not been determined.

[5] The values for m-dichlorobenzene are based on data for o-dichlorobenzene.

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

	Standards				Health Advisories						
					10-kg child						
Chemicals	Status Reg.	MCLG (mg/L)	MCL (mg/L)	Status HA Document	One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	Cancer Group
Diisopropyl methylphosphonate	-	-	-	F '89	8	8	0.08	3	0.6	-	D
Dimethrin	-	-	-	F '88	10	10	0.3	10	2	-	D
Dimethyl methylphosphonate	-	-	-	F '92	2	2	0.2	7	0.1	0.7	C
Dimethyl phthalate (PAE)	-	-	-	-	-	-	-	-	-	-	D
Dinitrobenzene (1,3-)	-	-	-	F '91	0.04	0.04	0.0001	0.005	0.001	-	D
Dinitrotoluene (2,4-)	-	-	-	F '92	0.5	0.5	0.002	0.1	-	0.005	B2
Dinitrotoluene (2,6-)	-	-	-	F '92	0.4	0.4	0.001	0.04	-	0.005	B2
Dinitrotoluene (2,6 & 2,4)[1]	-	-	-	F '92	-	-	-	-	-	0.005	B2
Dinoseb	F	0.007	0.007	F '88	0.3	0.3	0.001	0.04	0.007	-	D
Dioxane p-	-	-	-	F '87	4	0.4	-	-	-	0.3	B2
Diphenamid	-	-	-	F '88	0.3	0.3	0.03	1	0.2	-	D
Diquat	F	0.02	0.02	-	-	-	0.002	0.07	-	-	D
Disulfoton	-	-	-	F '88	0.01	0.01	0.00004	0.001	0.0003	-	E
Dithiane (1,4-)	-	-	-	F '92	0.4	0.4	0.01	0.4	0.08	-	D
Diuron	-	-	-	F '88	1	1	0.002[2]	0.07	0.01	-	D
Endothall	F	0.1	0.1	F '88	0.8	0.8	0.02	0.7	0.1	-	D
Endrin	F	0.002	0.002	F '87	0.02	0.005	0.0003	0.01	0.002	-	D
Epichlorohydrin	F	zero	TT[3]	F '87	0.1	0.1	0.002	0.07	-	0.4	B2
Ethylbenzene	F	0.7	0.7	F '87	30	3	0.1	3	0.7	-	D
Ethylene dibromide (EDB)[4]	F	zero	0.00005	F '87	0.008	0.008	-	-	-	0.00005	B2
Ethylene glycol	-	-	-	F '87	20	6	2	70	14	-	D
Ethylene Thiourea (ETU)	-	-	-	F '88	0.3	0.3	0.00008	0.003	-	0.02	B2
Fenamiphos	-	-	-	F '88	0.009	0.009	0.00025	0.009	0.002	-	D

[1] technical grade.

[2] New OPP RfD = 0.003 mg/kg/day.

[3] When epichlorohydrin is used in drinking water systems, the combination (or product) of dose and monomer level shall not exceed that equivalent to an epichlorohydrin- based polymer containing 0.01% monomer dosed at 20 mg/L.

[4] 1,2-dibromomethane

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

Chemicals	Standards			Status HA Document	Health Advisories						Cancer Group
	Status Reg.	MCLG (mg/L)	MCL (mg/L)		10-kg child One-day (mg/L)	10-kg child Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	
Fluometuron	-	-	-	F '88	2	2	0.01	0.5	0.09		D
Fluorene (PAH)	-	-	-	-	-	-	0.04	1	-	-	D
Fonofos	-	-	-	F '88	0.02	0.02	0.002	0.07	0.01	-	D
Formaldehyde	-	-	-	D '93	10	5	0.15	5	1	-	B11
Glyphosate	F	0.7	0.7	F '88	20	20	0.12	4	0.7	-	D
Heptachlor	F	zero	0.0004	F '87	0.01	0.01	0.0005	0.02	-	0.0008	B2
Heptachlor epoxide	F	zero	0.0002	F '87	0.01	-	0.00001	0.0004	-	0.0004	B2
Hexachlorobenzene	F	zero	0.001	F '87	0.05	0.05	0.0008	0.03	-	0.002	B2
Hexachlorobutadiene	-	-	-	F '89	0.3	0.3	0.002	0.07	0.001	0.05	C
Hexachlorocyclopentadiene	F	0.05	0.05	-	-	-	0.007	0.2	-	-	D
Hexachloroethane	-	-	-	F '91	5	5	0.001	0.04	0.001	-	C
Hexane (n-)	-	-	-	F '87	10	4	-	-	-	-	D
Hexazinone	-	-	-	F '96	3	2	0.05[3]	2	0.4	-	D
HMX[4]	-	-	-	F '88	5	5	0.05	2	0.4	-	D
Indeno[1,2,3,-c,d]pyrene (PAH)	-	-	-	-	-	-	-	-	-	-	B2
Isophorone	-	-	-	F '92	15	15	0.2	7	0.1	4	C
Isopropyl methylphosphonate	-	-	-	F '92	30	30	0.1	4	0.7	-	D
Isopropylbenzene (cumene)	-	-	-	D '87	11	11	0.1	4	-	-	D
Lindane[5]	F	0.0002	0.0002	F '87	1	1	0.0003	0.01	0.0002	-	C
Malathion	-	-	-	F '92	0.2	0.2	0.02	0.8	0.1	-	D
Maleic hydrazide	-	-	-	F '88	10	10	0.5	20	4	-	D
MCPA[6]	-	-	-	F '88	0.1	0.1	0.00057	0.02	0.004	-	D
Methomyl	-	-	-	F '88	0.3	0.3	0.025	0.9	0.2	-	E
Methoxychlor	F	0.04	0.04	F '87	0.05	0.05	0.005	0.2	0.04	-	D
Methyl ethyl ketone	-	-	-	F '87	75	7.5	0.6	20	-	-	D
Methyl parathion	-	-	-	F '88	0.3	0.3	0.00025	0.009	0.002	-	D

[1] Carcinogenicity based on inhalation exposure.

[2] New OPP RfD = 2 mg/kg/day.

[3] The Health Advisory is based on a new OPP RfD rather than the IRIS RfD.

[4] HMX = octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine

[5] Lindane = γ-hexachlorocyclohexane

[6] MCPA = 4(chloro-2-methoxyphenoxy)acetic acid

[7] New OPP RfD = 0.0015 mg/kg/day

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

Chemicals	Standards			Status HA Document	Health Advisories						Cancer Group
	Status Reg.	MCLG (mg/L)	MCL (mg/L)		10-kg child One-day (mg/L)	10-kg child Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	
Metolachlor	-	-	-	F '88	2	2	0.15[1]	0.5	0.1	-	C
Metribuzin	-	-	-	F '88	5	5	0.025[2]	0.9	0.2	-	D
Monochloroacetic acid	F	-	0.06[3]	-	-	-	-	-	-	-	-
Monochlorobenzene	F	0.1	0.1	F '87	4	4	0.02	0.7	0.1	-	D
Naphthalene	-	-	-	F '90	0.5	0.5	0.02	0.7	0.1	-	C
Nitrocellulose (non-toxic)	-	-	-	F '88	-	-	-	-	-	-	-
Nitroguanidine	-	-	-	F '90	10	10	0.1	4	0.7	-	D
Nitrophenol p-	-	-	-	F '92	0.8	0.8	0.008	0.3	0.06	-	D
Oxamyl (Vydate)	F	0.2	0.2	F '87	0.2	0.2	0.025	0.9	0.2	-	E
Paraquat	-	-	-	F '88	0.1	0.1	0.0045	0.2	0.03	-	C
Pentachlorophenol	F	zero	0.001	F '87	1	0.3	0.03	1	-	0.03	B2
Phenanthrene (PAH)	-	-	-	-	-	-	-	-	-	-	D
Phenol	-	-	-	D '92	6	6	0.6	20	4	-	D
Picloram	F	0.5	0.5	F '88	20	20	0.07[4]	2	0.5	-	D
Polychlorinated biphenyls (PCBs)	F	zero	0.0005	D '93	-	-	-	-	-	0.01	B2
Prometon[5]	-	-	-	F '88	0.2	0.2	0.015	0.5	0.1	-	D
Pronamide	-	-	-	F '88	0.8	0.8	0.075	3	0.05	-	C
Propachlor	-	-	-	F '88	0.5	0.5	0.01	0.5	0.09	-	D
Propazine	-	-	-	F '88	1	1	0.02	0.7	0.01	-	C
Propham	-	-	-	F '88	5	5	0.02	0.6	0.1	-	D
Pyrene (PAH)	-	-	-	-	-	-	0.03	-	-	-	D
RDX 6	-	-	-	F '88	0.1	0.1	0.003	0.1	0.002	0.03	C
Simazine	F	0.004	0.004	F '88	0.5	0.5	0.005	0.2	0.004	-	C
Styrene	F	0.1	0.1	F '87	20	2	0.2	7	0.1	-	C
2,4,5-T (Trichlorophenoxyacetic acid)	-	-	-	F'88	0.8	0.8	0.01	0.4	0.07	-	D

[1] New OPP RfD = 0.1 mg/kg/day

[2] New OPP RfD = 0.013 mg/kg/day

[3] 1998 Final Rule for Disinfectants and Disinfection By-products: the total for five haloacetic acids is 0.06 mg/L.

[4] New OPP RfD = 0.2 mg/kg/day

[5] Under review.

[6] RDX = hexahydro-1,3,5- trinitro-1, 3,5- triazine

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

	Standards				Health Advisories						
					10-kg child						
Chemicals	Status Reg.	MCLG (mg/L)	MCL (mg/L)	Status HA Document	One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/ day)	DWEL (mg/L)	Lifetime (mg/L)	mg/L at 10^{-4} Cancer Risk	Cancer Group
2,3,7,8-TCDD (Dioxin)	F	zero	3E-08	F '87	0.000001	1E-07	1E-09	4E-08	-	2E-08	B2
Tebuthiuron	-	-	-	F '88	3	3	0.07	2	0.5	-	D
Terbacil	-	-	-	F '88	0.3	0.3	0.01	0.4	0.09	-	E
Terbufos	-	-	-	F '88	0.005	0.005	0.0001	0.005	0.0009	-	D
Tetrachloroethane (1,1,1,2-)	-	-	-	F '89	2	2	0.03	1	0.07	0.1	C
Tetrachloroethane (1,1,2,2-)	-	-	-	F '89	0.04	0.04	0.00005	0.002	0.0003	0.02	C
Tetrachloroethylene	F	zero	0.005	F '87	2	2	0.01	0.5	0.01	-	-
Trichlorofluoromethane	-	-	-	F '89	7	7	0.3	10	2	-	D
Toluene	F	1	1	D '93	20	2	0.2	7	1	-	D
Toxaphene	F	zero	0.003	F '96	0.004	0.004	0.0004	0.01	-	0.003	B2
2,4,5-TP (Silvex)	F	0.05	0.05	F '88	0.2	0.2	0.008	0.3	0.05	-	D
Trichloroacetic acid	F	0.3	0.06[1]	D '96	4	4	0.1	4	0.3	-	C
Trichlorobenzene (1,2,4-)	F	0.07	0.07	F '89	0.1	0.1	0.001	0.05	0.01	-	D
Trichlorobenzene (1,3,5-)	-	-	-	F '89	0.6	0.6	0.006	0.2	0.04	-	D
Trichloroethane (1,1,1-)	F	0.2	0.2	F '87	100	40	0.035	1	0.2	-	D
Trichloroethane (1,1,2-)	F	0.003	0.005	F '89	0.6	0.4	0.004	0.1	0.003	0.06	C
Trichloroethylene 2	F	zero	0.005	F '87	-	-	0.007	0.2	-	0.2	B2
Trichlorophenol (2,4,6-)	-	-	-	D '94	0.03	0.03	0.0003	0.01	-	0.3	B2
Trichloropropane (1,2,3-)	-	-	-	F '89	0.6	0.6	0.006	0.2	0.04	-	-
Trifluralin	-	-	-	F '90	0.08	0.08	0.0075	0.3	0.005	0.5	C
Trimethylbenzene (1,2,4-)	-	-	-	D '87	-	-	-	-	-	-	D
Trimethylbenzene (1,3,5-)	-	-	-	D '87	10	-	-	-	-	-	D
Trinitroglycerol	-	-	-	F '87	0.005	0.005	-	-	0.005	0.2	-
Trinitrotoluene (2,4,6-)	-	-	-	F '89	0.02	0.02	0.0005	0.02	0.002	0.1	C
Vinyl chloride[2]	F	zero	0.002	F '87	3	3	-	-	-	0.002	A
Xylenes	F	10	10	D '93	40	40	2	70	10	-	D

[1] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for five haloacetic acids is 0.06 mg/L.

[2] Under review

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

DEFINITIONS

The following definitions for terms used in the Tables are not all-encompassing, and should not be construed to be "official" definitions. They are intended to assist the user in understanding terms found on the following pages.

Action Level: The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow. For lead or copper it is the level which, if exceeded in over 10% of the homes tested, triggers treatment.

Cancer Group: A qualitative weight-of-evidence judgement as to the likelihood that a chemical may be a carcinogen for humans. Each chemical is placed into one of the following five categories:

Group Category
A: Human carcinogen
B: Probable human carcinogen:
B1: indicates limited human evidence;
B2: indicates sufficient evidence in animals and inadequate or no evidence in humans
C: Possible human carcinogen
D: Not classifiable as to human carcinogenicity
E: Evidence of noncarcinogenicity for humans

This categorization is based on EPA's 1986 Guidelines for Carcinogen Risk Assessment. The Proposed Guidelines for Carcinogen Risk Assessment which were published in 1996, when final, will replace the 1986 cancer guidelines.

10^{-4} Cancer Risk: The concentration of a chemical in drinking water corresponding to an estimated lifetime cancer risk of 1 in 10,000.

DWEL: Drinking Water Equivalent Level. A lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from drinking water.

HA: Health Advisory. An estimate of acceptable drinking water levels for a chemical substance based on health effects information; a Health Advisory is not a legally enforceable Federal standard, but serves as technical guidance to assist Federal, state, and local officials.

> **One-day HA:** The concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for up to one day of exposure.
>
> **Ten-day HA:** The concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for up to ten days of exposure.
>
> **Lifetime HA:** The concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure.

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Table B.1 Drinking Water Standards and Health Advisories (Cont.)

LED_{10}: Lower Limit on Effective $Dose_{10}$. The 95% lower confidence limit of the dose of a chemical needed to produce an adverse effect in 10% of those exposed to the chemical, relative to the control.

MCLG: Maximum Contaminant Level Goal. A non-enforceable health goal which is set at a level at which no known or anticipated adverse effect on the health of persons occur and which allows an adequate margin of safety.

MCL: Maximum Contaminant Level. The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLG as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

RfD: Reference Dose. An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

SDWR: Secondary Drinking Water Regulations. Non-enforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water.

TT: Treatment Technique. A required process intended to reduce the level of a contaminant in drinking water.

ABBREVIATIONS
D: Draft
F: Final
NA: Not Applicable
NOAEL: No-Observed-Adverse-Effect-Level
OPP: Office of Pesticide Programs
P: Proposed
Reg: Regulation
TT: Treatment Technique

Source: U.S. EPA 2000.

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