April 2002
02/9206/EPADWCTR

Environmental Technology Verification Protocol

Drinking Water Systems Center

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR PHYSICAL CHEMICAL AND BIOLOGICAL REMOVAL OF NITRATE

Prepared by

NSF International

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

EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR PHYSICAL CHEMICAL AND BIOLOGICAL REMOVAL OF NITRATE

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

Recommended by
the Steering Committee for the Verification of
Drinking Water Systems
on October 5, 1999
Modified on July 28, 2000 and in March 2002

With support from
the U.S. Environmental Protection Agency
Environmental Technology Verification Program

NSF INTERNATIONAL

Mission Statement:
NSF International (NSF), an independent, not-for-profit organization, is dedicated to public health safety and protection of the environment by developing standards, by providing education and providing superior third party conformity assessment services while representing the interests of all stakeholders.

NSF Purpose and Organization
NSF International (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.

U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the U.S. 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 substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and U.S. 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's 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 U.S. EPA is authorized through the Safe Drinking Water Act 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, a nonprofit testing and certification organization, 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 their 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 is a model process that 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 verification/Product-Specific Test Plan;
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;
4. Performance and cost (labor, chemicals, energy) verification;
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF International with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development (ORD), National Risk Management Research Laboratory, 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 U.S. EPA and NSF International (NSF) cooperatively organized and developed the ETV Drinking Water Systems Center to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators have an understanding to assist each other in promoting and communicating the benefits and results of the project.

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 nitrate, the public health goal of the Protocol. The remaining chapters describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the Protocol: the removal of nitrate.

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 Field testing Organization must write a "Product-Specific Test Plan" (PSTP). The equipment manufacturer and/or supplier will need this protocol and the test plans herein and other ETV Protocols and Test Plans to develop the Product-Specific Test Plan depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or test plan may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified Field Testing Organization that is selected by the Manufacturer. Water quality analytical work to be completed as a part of an ETV Testing Plan shall be contracted with a state-certified or third party- or EPA-accredited laboratory. For information on a listing of NSF-qualified field testing organizations and state-certified or third party- or EPA-accredited laboratories, contact NSF International.

ACKNOWLEDGMENTS

The U.S. EPA and NSF would like to acknowledge those persons who participated in the preparation, review and approval of this Protocol. Without their hard work and dedication to the project, this document would not have been approved through the process which has been set forth for this ETV project.

Chapter 1: Requirements for All Studies

Writers: Gerald Guter, Guter Consulting and Steven Duranceau, Boyle Engineering
Technical reviewers: Dennis Clifford, University of Houston and Tom Sorg, US EPA

Chapter 2: Test Plan for Reverse Osmosis and Nanofiltration

Writers: Jim Lozier and Paul Mueller, CH2M Hill
Technical reviewer: James Taylor, University of Central Florida

Chapter 3: Test Plan for Ion Exchange

Writers: Gerald Guter, Guter Consulting and Steven Duranceau, Boyle Engineering
Technical reviewers: Dennis Clifford, University of Houston and Tom Sorg, US EPA

Chapter 4: Test Plan for Heterotrophic Biological Denitrification

Writer: Dr. Mohamed F. Dahab, University of Nebraska, Lincoln
Technical reviewer: Dr. Bruce Rittmann, Northwestern University

Steering Committee Members that voted on Chapters 1 through 3:

Mr. Jim Bell
Mr. Jerry Biberstine, Chairperson
Mr. John Dyson
Mr. Allen Hammer
Dr. Joseph G. Jacangelo
Mr. Glen Latimer
Dr. Gary S. Logsdon
Mr. Bob Mann
Mr. David Pearson
Mr. Peter Shanaghan
Mr. John Trax

Steering Committee Members that voted on Chapter 4:

Mr. Jim Bell
Mr. Kevin Brown, Chairperson
Mr. Stephen Clark
Mr. John D. Dyson
Mr. Joe Harrison
Dr. Joseph G. Jacangelo
Mr. Glen Latimer
Dr. Gary S. Logsdon
Mr. Bob Mann
Mr. David Pearson
Mr. Ed Urheim
Mr. Victor Wilford

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CHAPTER 1

EPA/NSF ETV PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR REMOVAL OF NITRATE

REQUIREMENTS FOR ALL STUDIES

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

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1.0 INTRODUCTION

This first chapter is the "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies". Specifically, this protocol discusses the information and procedures requested from equipment manufacturers who wish to have their treatment plants verified and tested under the NSF International/Environmental Protection Agency (NSF/EPA) verification testing program. In order to participate in the equipment verification process a Product-Specific Test Plan (PSTP) using this study protocol and adhering to the requirements herein is necessary.

The contents of the PSTP are described in this protocol document. The manufacturer will include only those items of information that pertain to the specific equipment and testing objectives. The descriptive material in this protocol represents the format and type of information, which would be required for NSF/EPA ETV testing. The PSTP should not be viewed as a promotional document, but as a document which will transfer technical information about the equipment, the site of the testing and information regarding successful operation to those unfamiliar with the equipment and location of the test.

The testing of new technologies and materials that are unfamiliar to the NSF/EPA will not be discouraged. It is recommended that resins or membranes or any other material or chemical in the equipment conform to NSF International/American National Standards Institute (NSF/ANSI) Standard 60 and 61. The disclosure of the existence or use of proprietary or patented material and procedures should be made in the PSTP.

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 ETV Testing Plan or Plans related to the statement or statements of capabilities that are to be verified.

The PSTP may include more than one Testing Plan. For example, testing might be undertaken to verify performance of a system for both nitrate reduction and removal of disinfection by-product precursors.

This protocol document is presented in two fonts. The non-italicized font provides background information that the Field Testing Organization (FTO) may find useful in preparation of the PSTP. *The italicized text indicates specific study protocol deliverables that are required of the Field Testing Organization and 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.
- **EIR** - An Environmental Impact Report that may be required to construct and operate a drinking water treatment plant.
- **Equipment Verification Testing Plan** - specific testing plan for each technology application, such as

nitrate equipment or coagulation and filtration equipment. These plans are being developed by NSF to assist in development of PSTPs.

- **Field Testing Organization (FTO)** - an organization qualified to perform studies and testing of package plants or modular systems. The role of the testing organization is to ensure that there is skilled operation of a system during the intense periods of testing during the study and the tasks required by the Protocol for Equipment Verification Testing are performed. The Testing Organization is responsible for:
    - preparing the application on behalf of the Manufacturer;
    - managing, evaluating, interpreting and reporting on the data produced by the verification testing and study;
    - providing logistical support, scheduling and coordinating the activities, e.g., establishing a communications network, of all participants in the verification testing and study;
    - advising the Manufacturer on feed water quality, waste disposal requirements and test site selection, such that locations selected for the verification testing and study have feed water quality consistent with the objectives of the Protocol for Equipment Verification Testing;
    - collecting and transporting analytical samples of water from water and wastewater streams and maintaining chain of custody documents;
    - collecting all field data on qualitative and quantitative evaluation factors.
- **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 technical support for the verification testing and study. The manufacturer is also responsible for providing assistance to the testing organization during operation and monitoring of the package plant or modular system during the verification testing and study.
- **Modular System** - A functional assembly of components for use in a drinking water treatment system or package plant, each part of which provides a limited form of treatment of the feed water(s). Treated waters may be discharged to another package plant module or to the distribution system if the modular system includes the final step of treatment.
- **Package Plant** - A complete water treatment system including all components from connection to the feed water(s) through discharge to the distribution system. It is the entire system of water treatment plant equipment that is provided by the manufacturer. It shall include all equipment and materials which an owner/operator requires or is required by permits to install the system, operate it and discharge the final product into the distribution system, and to discharge waste into a waste disposal system. Any post treatment or blending facilities are included in the package plant. The package plant does not include any existing source water facilities, but it may or may not include waste discharge or containment facilities.
- **Performance** - Various plant operating factors described either quantitatively or qualitatively which characterize the plant's ability to meet the objectives of the treatment process.
- **Permit** - Any permit that is required to install and operate a drinking water treatment plant such as

conditional use permit, a construction permit, a treatment plant operation permit, a waste discharge permit or other such permit.

- **Plant Operator** - the person working for a small water system who is certified to operate a water treatment plant and who is responsible for operating drinking 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 Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.
- **Protocol for Equipment Verification Testing** - this document. Protocol shall be used for reference during Manufacturer participation in verification testing program
- **Reclaimed Water** - Water that is a by-product of the treatment process and is discharged as a wastewater and is reused as irrigation water, cooling tower water or to satisfy similar water demands.
- **Recycled Water** - Water that is a byproduct of the treatment process that is reused in the process rather than being discharged as wastewater.
- **Reliability** - The ability of a system to meet the objectives of the treatment process over a long term on a consistent basis without excessive maintenance, operator time and down time.
- **Responsible Water Agency or Owner/Operator** - The person or agency (private or public) that owns the site and facilities where the system will be tested. It is likely that the owner will already be operating some water system facilities, such as a well, pump station, reservoir, treatment plant etc. at this site. This agency also represents a typical end user or purchaser of a system who has public water purveyor responsibilities under numerous local, State and Federal regulations.
- **Verification** - to establish the evidence on the range of performance of equipment and/or device under specific conditions following a predetermined protocol.
- **Waste, Waste Solids, Wastewater** - The solid, liquid, or mixture of solid and liquid material that is produced by the water treatment processing equipment consisting of concentrated nitrate and other salt brines and rinse water and backwash water.
- **Waste System** - The portion of the equipment that contains, stores, transports, or pumps the produced waste.
- **Waste Disposal System** - A facility, such as a sewer system, irrigated area, waste disposal site, ocean outfall, evaporation pond, deep well disposal system or other such system which will accept the waste produced by the equipment. This waste disposal system is not a part of the equipment.

1.1 Background

The U.S. Environmental Protection Agency (EPA) has partnered with NSF, a not-for-profit testing and certification organization, 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. EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, consultants, organizations 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 engineers 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 their 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 is a model process that can help in moving small drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

- Development of a verification/ PSTP;
- Execution of verification testing;
- Data reduction, analysis, and reporting;
- Performance, reliability and cost factor (labor, chemicals, energy) verification;
- Report preparation and information transfer.

1.2 Objectives of Verification Testing

The manufacturer will define the verification testing objective(s). These specific objectives of the equipment verification testing will be different for each Manufacturer, depending upon the statement of objectives of the specific equipment to be tested. The testing 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:

- Generate field data appropriate for verifying the performance of the equipment;
- Evaluate new advances in equipment and equipment design;
- Generate field data appropriate for verifying the performance of the equipment used in a specific environment such as a coastal region where ocean disposal is available;
- Generate field data appropriate for verifying the performance of the equipment operating within a

specific range of untreated water quality;

- Generate field data appropriate for verifying the performance of the equipment used for specific modes of operation such as continuous or interrupted operation.

Multiple testing objectives may be included in the PSTP. The development of specific objectives is discussed in Section 4.1. Water quality treatment objectives must also be defined in the PSTP. The development of these objectives is discussed in Section 3.1.

An important aspect in the development of the verification testing is to describe the procedures that will be used to verify the statement of performance objectives made for water treatment equipment. A verification testing plan document incorporates the quality assurance/quality control (QA/QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Verification testing conducted at a single site may not represent every environmental situation which may be acceptable for the equipment tested, but 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.

1.3 Scope of Verification Process and Testing

This protocol outlines the verification process for equipment designed to achieve the physical chemical or biological removal of nitrate from contaminated water. The scope of this protocol includes Testing Plans for equipment employing ion exchange, reverse osmosis, electrodialysis, or biological processes as the primary process for treatment. The equipment may consist of a single process or a combination of these processes. The equipment may also consist of one or more of these processes combined with a waste treatment process, such as biological denitrification. This protocol is not an NSF or third-party consensus standard and it does not endorse the products or technology described herein. An overview of the equipment verification process and the elements are described in this protocol document.

1.4 Scope of the PSTP

Specifically, the PSTP shall include at least the following items:

- Roles and responsibilities of verification testing participants; (See Section 2.0)
- A brief statement of the objectives of the test plan;
- A brief statement of the water quality treatment objectives;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation; (See Section 3.0)
- Experimental design of the Field Operations Procedures; (See Sections 4.0 and 5.0)

- Quality assurance (QA) and quality control (QC) procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing; (See Sections 6.0 and 7.0) and
- Health and safety measures relating to biohazard (if present), chemical, electrical, mechanical and other safety codes. (See Section 8.0)

1.5 General Content of PSTP:

The remaining sections of this chapter discuss the type of information, which is required in the PSTP. At the end of each section the italicized textual material will give the required outline for treating the subjects discussed in the related section followed by a statement of the responsibilities of the participants. For example, the following is the general outline for the 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.*
- *EXECUTIVE SUMMARY -The Executive Summary describes the contents of the PSTP (not to exceed two pages). A general description of the equipment, the testing objectives, and the statement of water quality treatment objectives and capabilities 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 (See Section 2, below.)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (See Section 3, below.)*
- *EXPERIMENTAL DESIGN (See Section 4, below.)*
- *FIELD OPERATIONS PROCEDURES (See Section 5, below.)*
- *QUALITY ASSURANCE TESTING PLAN (See Section 6, below.)*
- *DATA MANAGEMENT AND ANALYSIS (See Section 7, below.)*
- *SAFETY PLAN (See Section 8, below.)*

2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

This verification testing program is being conducted by NSF International with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division (WSWRD)- Cincinnati, Ohio. The WSWRD and NSF jointly are administering the Equipment Verification Testing Program. NSF's role is to provide technical and administrative leadership and support in conducting the testing.

The specific responsibilities of each participant are discussed in Section 2.6. The required content of the PSTP and the Manufacturer responsibilities are listed at the end of each section. In the development of a PSTP, a table that includes the name, affiliation, and mailing address of each participant, a point of contact, their role, and telephone, fax and E-mail address shall be provided.

The following participants should be listed in the Participants Table:

- NSF;
- Site Owner;
- Site Operator;
- Plant Operator;
- Field Testing Organization;
- Analytical Laboratory; and
- Any other responsible parties.

2.2 Organization

The PSTP shall provide the organizational structure for the verification testing showing lines of communication.

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 feed water, which in most cases will be the source water at the site. The need for treatment should be demonstrated. The name and address of the owner/operator of the proposed site must be submitted along with a letter of agreement from the owner/operator of the site to allow testing of the equipment at the site. The Manufacturer should consider listing a site, which would be typical of the intended market not only in terms of the feed water quality but also in terms of location and environmental conditions. For example, if a manufacturer's market is in mid-western agricultural regions, the water quality, climate, and waste disposal systems would be different than those found in temperate coastal regions. If the manufacturer wishes to demonstrate a membrane system, choice of a site with total dissolved solids (TDS) water quality problems would be desirable. It is likely that the equipment would be tested at a well site owned and operated by a public water agency or private water company. In most cases, the equipment may be demonstrated at more than one site.

2.4 Site Characteristics

The PSTP must include a description of the test site and the immediately surrounding environment. Information about the site should be provided to show that it is feasible to adequately test a system(s). This shall include a description of where the equipment will be located. If available, give the street address, city, state and zip code. An area location map showing access from major streets and highways and a site layout drawing with equipment foot prints and dimensions would be helpful. The drawing should indicate the location of existing facilities, the source of the feed water and where the treated water will go and where the waste will be discharged. It should be specifically mentioned if the treated water will proceed to waste or if it will be introduced into an existing water supply. It is also important to point out if treated water will be blended with untreated water before it is sent to waste or distribution. If so, the blending facility must be a part of the equipment. Indicate if any facilities other than the equipment would be required such as additional buildings or trailers for sample collection and analyses, electrical power, concrete pads, drainage facilities, protective coverings etc. Consider the following questions:

- Will the equipment supply water on a continuous or interrupted basis?
- If the equipment is down, how will the demand be met?
- If the feed water 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 as feed water to the equipment being tested, the pattern of operation of the raw water pumping (is it continuous or intermittent), if source water available from a pressurized line or from a storage reservoir, and facilities for handling treated water and waste (i.e., residuals) from the testing program.
- Do facilities exist on the site for disposal of wastes? If so, is the capacity large enough to handle waste from the equipment? Or, will new waste disposal facilities be required? The equipment will be tested at its maximum sustainable treatment flow rate (gallons per minute).
- What is this value and demonstrate it is compatible with the water supply and demand at the site?
- Will the operation of the test facility be compatible with the existing uses of the site and the surrounding land uses?
- Is it located in a residential area where neighbors may complain? If so, how will this be handled?
- Are any construction or conditional use permits required? Is a permit required to operate the equipment?
- Is a waste discharge permit required?
- What will be the ultimate method of waste disposal?
- Has the manufacturer consulted with the following: The owner/operator, the water agency, the local or State health organization, the waste discharge agency, local emergency officials (regarding safe fire flows), or responsible health agencies who have jurisdiction?

- Have alternative sites been considered?
- Why was this site chosen in preference to other sites?
- Environmental documentation such as an EIR or environmental impact assessment relative to the proposed equipment testing should also be submitted or an explanation of why such environmental documentation may or may not be required.

Content of PSTP Regarding Equipment Verification Testing Responsibilities:

The Field Testing Organization 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, telephone, fax and E-mail address.*
- *Organization of operational and analytical support.*
- *List of the site name(s) and location(s). Describe the site and the surroundings. Use location maps and provide other material discussed above.*
- *Description of the test site(s), the site characteristics and identification of where the equipment shall be located (use foot print drawings) and other pertinent material discussed above.*
- *Describe existing facilities on the site, how they will be used. List any permits and environmental documentation required. Provide other material discussed above.*

Manufacturer Responsibilities:

- *Provision of complete, field-ready equipment for verification testing.*
- *Provision of logistical and technical support, as required. Remove equipment and any discarded items from the site after termination of the test program.*
- *Provision of technical assistance to the site owner/operator and the qualified testing organization during operation and monitoring of the equipment undergoing verification testing as discussed above.*

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities, Water Quality Objectives

For this Verification Testing, the Manufacturer and their designated FTO shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The manufacturer's performance objectives are used to establish data quality objectives (DQOs) in order to develop the experimental design of the verification test. The broader the performance objectives, the more comprehensive the PSTP must become to achieve the DQOs. In conjunction with a Statement of Performance Objectives, the FTO shall state the pertinent detection limits for the nitrate analytical method. Statements should be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. The FTO on behalf of the Manufacturer shall also provide information as to what advantages the Verification Testing equipment provides over existing equipment. The PSTP must state the treated water quality objectives.

The Statement of Performance Objectives must be specified and verifiable by a statistical analysis of the data. Below are two different types of Statements of Performance Objectives that may be verified in this testing:

1. This ion exchange system is capable of treating water contaminated with nitrate up to 100 mg NO_3/L by producing water with a nitrate level equal to or less than 35 mg NO_3/L in the treated water samples during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25°C).

2. This system is capable of producing a product water with nitrate concentration less than 10 mg/L during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25°C) in feedwaters having the following composition: TDS = 1200 mg/L (with sulfates = 300 mg/L or greater) and containing nitrate having a level of up to 100 mg NO_3/L and will produce water with a TDS level equal to 150 mg/L and a nitrate level equal to or less than 35 mg NO_3/L in the treated water samples.

Note in the above statement for membrane equipment, the sulfate level must also be stated.

An example of a Statement of Performance Objectives that would not be acceptable is presented below:

> "This system will provide lower nitrate levels than required by the Safe Drinking Water Act (SDWA) on a consistent and dependable basis."

The Manufacturer shall identify the water quality objectives to be achieved in the Statement of Performance Objectives of the equipment to be evaluated in the verification testing. For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided:

- Applications of the equipment;
- Known limitations of the equipment;
- Advantages it provides over existing equipment;
- Percent removal of nitrate;
- Rate of treated water production (i.e., resin loading rate, membrane flux);
- Product water recovery;
- Feed stream water quality regarding pertinent water quality parameters;
- Temperature;

- Concentration of nitrate; and
- Other pertinent water quality and operational conditions.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. The following equation shall be used to determine percent removal of the radionuclides investigated:

$$\%\ \text{Nitrate Removal} = 100 * \left[\frac{C_{feed} - C_{finished}}{C_{feed}} \right]$$

where: C_{feed} = concentration of nitrate in the feedwater; and

$C_{finished}$ = concentration of nitrate in the finished water.

The analysis of nitrates in the feedwater, treated water and wastewater streams shall be performed by a state-certified, third party accredited or EPA-accredited laboratory using an approved Standard Method.

The Statement of Performance Objectives prepared by the FTO (in collaboration with the Manufacturer) shall also indicate the range of water quality under 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. If a manufacturer relies on integrated processes for nitrate removal, the Statement of Performance Objectives must include the overall water treatment system nitrate removal performance. The Statement of Performance Objectives forms the basis of the entire Equipment Verification Testing Program and must be chosen appropriately. Therefore, the design of the PSTP should include a sufficient range of feedwater quality to permit verification of the Statement of Performance Objectives.

It should be noted that many of the drinking water treatment systems participating in the Nitrate Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Protocol and the associated Verification Testing Plans are oriented towards removal of nitrates from feedwaters, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

3.2 Equipment Description

Description of the equipment for the verification testing program shall be provided by the Manufacturer. 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. Open/closed indicators shall be clearly visible on all automatic valves as well as direction of flow arrows on all piping. The following other information is required"

a) Equipment Name

b) Model #

c) Manufacturer's name and address

d) Electrical requirements - volts, amps, and Hertz

e) Serial Number and Year of manufacture

f) Warning and Caution statements in legible and easily discernible print size

g) Capacity or output rate (if applicable)

h) Any proprietary features should be described

Content of PSTP Regarding Equipment Capabilities and Description:

The PSTP shall contain the following:

- *A statement of the water quality objectives to be achieved by the equipment.*
- *Description of the equipment to be demonstrated. This shall include:*
  - *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 system;*
  - *Brief description of the physical construction/components of the equipment. Include 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.*
- *Operation and maintenance manual will be supplied for the equipment. Include a flow diagram, piping and instrumentation diagram, location of sampling points and flow meters, and a description of a typical start up, operation and shut down procedure. Indicate the functioning of alarms and shut down alarms. Indicate plant adjustments required. All valves and controls and similar components are to be clearly marked on the equipment and so identified in the flow diagram.*
- *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. Provide 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.*
- *Discussion of the known limitations of the equipment. Include such items as the range of feed water quality suitable for treatment with the equipment, the upper limits for concentrations of regulated contaminants that can be removed to specified concentrations, 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 NSF should use to evaluate the results of the verification testing.

4.1 Objectives of Experimental Testing

The testing program must have well defined objectives. The PSTP will include a statement of the verification testing objectives to evaluate equipment in one or more of the following areas:

1) performance relative to manufacturer's stated range of equipment objectives;
2) the impacts of variations in feed water quality (specifically variations in TDS, chloride, sulfate, nitrate and alkalinity are important) on its performance;
3) the logistical, human, and economic resources necessary to operate the equipment;
4) the reliability, ruggedness, cost, range of usefulness, safety and ease of operation and maintenance;
5) how much (or how little) waste is produced by the treatment process; and
6) the cost of treatment.

Although the Field Testing Organization is encouraged to include all parameters listed below in the PSTP, the Field Testing Organization shall be responsible for selection of the qualitative and quantitative parameters which must be evaluated to meet the water quality treatment objectives and the verification testing objectives. A list of parameters is listed below and in ETV test plans that are appropriate for most equipment. For example, if equipment is only intended for removal of nitrate, there would be no need to conduct testing to evaluate the removal of TDS. The Field Testing Organization will state the verification testing objective that is appropriate for the equipment. For example, the Field Testing Organization may wish to focus on wastewater production and thus formulate the stated objective to include this factor.

4.2 Equipment Characteristics or Factors to be Tested

This section discusses factors that shall be considered in the design and implementation of the verification testing. These factors will be evaluated either quantitatively or qualitatively during the verification testing. The factors can include such items as: ease of operation; ease of maintenance; degree of operator attention required; operator labor (man-hours) required; response of equipment and treatment process to changes in feed water quality; electrical power requirements; system reliability features including redundancy of components; feed flow requirements; discharge requirements; spatial requirements for the equipment (footprint); unit processes included in treatment train; and chemical inventories needed.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impossible to test or quantify. Important factors that cannot easily be quantified are the modular nature of the equipment, the safety of the equipment toward operators or spectators, the portability of equipment, and the logistical requirements necessary for using it. Aesthetics, security and compatibility with surrounding land use are important qualitative factors. For example, a plant located in a residential area should not appear out of place and it should be protected from and should not attract vandalism.

Maintenance operations such as ease/difficulty of membrane or resin cleaning and replacement should be discussed although these operations may not be carried out during the test procedure. NSF would also require knowing what labor would be required to terminate the tests and remove the equipment from the site.

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 and the test site.

- Reliability or susceptibility to environmental conditions.
- Equipment safety. Point out any feature or device which could harm the operator if malfunctions or mishandling occurred, such as chemical handling, high pressures discharges, unexpected noises, sudden pressure loss or build up.
- The need for any safety devices (e.g. fire extinguishers, air packs) or clothing which are required such as special shoes or safety glasses.
- Effect of operator experience on results. Discuss the level of experience that an operator should have to successfully achieve reliable and safe operation. Mention if special training would be required such as handling acids, leaks or spills.
- Special equipment required for moving or lifting heavy parts or materials.
- Aesthetics and security.
- Compatibility with surrounding land use.
- Health and safety features.
- Alarms and set points.
- Placement of instrumentation and monitoring devices for convenient operator reading, inspection and replacement.

4.2.2 Quantitative Factors

Many factors in this verification testing can be quantified by various means. Some can be measured and controlled while others such as chemical market prices cannot be controlled but can be measured. Typical quantitative factors to be considered are listed below, and others may be added. The PSTP shall list and give estimates of these factors and describe how they can be measured during the field operation of the test equipment. These factors will be also be field tested, measured and verified by the Testing Organization during the testing and verification procedure.

4.2.3 Quantitative Factors: Definitions

The following definitions apply to the discussion of quantitative factors:

- **Untreated Water** - The raw water which is delivered or available at the site for treatment by the equipment for nitrate removal.
- **Treated Water** - The water stream that has passed through treatment (and post treatment) and is available from the equipment either for direct injection into a distribution system or for blending with untreated water before injection into the water supply system.
- **Blended Water** - A mixture of treated and untreated water that is suitable for injection into the distribution system. This is the same as the distributed water.
- **Percent Blend** - The percent of treated water that is in the blend. Thus a 75 percent blend will refer to water composed of 75 percent treated and 25 percent untreated water. A 100 percent blended water is equal to treated water.
- **Maximum Distribution Flow Rate** - The maximum flow rate (gallons per minute) of blended (distributed) water which the equipment can cause to be discharged into the distribution mains on a continuously operating basis with a nitrate level at or below 80 percent of the MCL.
- **Maximum Treatment Flow Rate** - The maximum flow rate (gallons per minute) of treated water which the equipment can produce on a continuously operating basis while maintaining the Maximum Distribution Flow Rate.
- **Plant Factor** - A factor used in computing water treatment cost. It is the fraction of total time the plant operates or is projected to operate during its period of amortization. To standardize cost computations, a plant factor of 50 percent will be used to determine the annual production of the plant.
- **Percent Waste** - 100 percent times the ratio of the annual wastewater production to the annual amount of treated water production.

4.2.4 Quantitative Cost Factors

All cost data must be quantified for verification testing. Cost will be expressed as cents per 1000 gallons for operating costs and amortized capital costs.

To standardize cost computations, a plant factor of 50 percent will be used to determine the annual production of the plant. The basis of the costs will be production of distributed water at the Maximum Distribution Flow Rate delivered at a pressure of 60 pounds to accommodate distribution system pressure. The total cost of all cost items will be estimated by the Manufacturer for the duration of the testing period.

The following operation and maintenance cost items may be estimated in the PSTP:

- Operating cost of power to operate the plant computed from the cost per kWhr.
- Operating costs of power to boost pressure for distribution.
- Operating cost of chemicals computed from costs as delivered by local suppliers.
- Replacement cost of resin and/or membranes.

- Cost of operator labor computed from direct and indirect labor costs.
- Cost of replacement parts. (List items)
- Cost of maintenance. (List items)
- Cost of service calls by equipment representatives.
- Estimated operating cost of waste disposal. (In cents/1000 gal of blended water).

4.2.5 Quantitative Plant Performance Factors

Significant quantitative factors relating to plant performance (other than the special water quality parameters discussed in the next section) must be included in the PSTP. These parameters relate to the daily and annual quantities of various streams and discharges and their flow rates. These performance factors must be estimated in the PSTP and will be verified during the testing and verification program. Instrumentation such as flow meters, pressure gauges, conductivity meters, sampling taps, etc. must be provided as integral parts of the equipment. A diagram should be provided to illustrate where and how the factor can be measured and verified. If a multi-vessel ion exchange plant is tested, the instrumentation should be located so the parameters can be checked for each vessel.

The following plant performance factors may be measured.

- Flow rate (gpm), electrical conductivity (e.c.), and pressure of treated water during normal treatment.
- Flow rate (gpm), e.c., and pressure of brine stream(s) during production.
- Flow rate (gpm), e.c., and pressure of backwash water during backwash.
- Flow rate (gpm), e.c., and pressure of rinse water during rinse.
- Daily amount of water treated (gallons) and delivered to distribution system.
- Daily amount of backwash water used.
- Daily amount of rinse water used.
- Daily amount of wastewater produced.
- Daily amount of make up water for brine maker.
- Daily amount of saturated brine used for regeneration and amount used per regeneration.
- e.c. and quantity of total wastewater produced.
- Percent of treated water in delivered water.

In nitrate treatment, it is very helpful to evaluate overall plant performance and efficiency factors, which will indicate the amount of chemical, added to the environment or the overall chemical costs associated with the treatment process. For example in ion exchange, sodium chloride must be purchased, transported and disposed of. For a reverse osmosis plant, sulfuric acid must be added for pH adjustment and waste brines are produced. Indices of efficiency can include the following:

- Chemical equivalents of a specific chemical (e.g. salt or sulfuric acid) required by the process to remove one chemical equivalent of nitrate.
- Chemical equivalents of salt materials disposed in wastewater or brine reject by the process for removal of one chemical equivalent of nitrate.
- Operating cost to remove one pound of nitrate.
- Amount of wastewater produced by the process to remove one pound of nitrate.

4.2.6 Quantitative Factors: Plant Health, Safety and Reliability

Health, safety and reliability features are significant in equipment operation and verification testing. The safety features treated here refer to those items which protect the water supply and hence the drinking water public from unintended contamination. (Other types of safety features for on site plant personnel protection are treated in Section 8). The cost effectiveness of treating water diminishes rapidly if waste products and chemicals cause dangerous contamination because of poorly designed and/or operated equipment. In the rush and concern to eliminate the primary contaminant at a low capital cost, the focus on the importance of these safety features is easily lost. Primary dependence must be placed on the reliability and quality of the equipment designer, manufacturer, and operator. It is very likely that these features will be a primary interest of health officials who must review plant designs and issue operating permits. The field testing personnel should be aware of these sources of contamination and may need to devise means to check for acceptable operation.

The PSTP must describe the following:

1) the safety features that have been designed into the equipment;
2) what contamination problem this feature is used to address; and
3) how the features can be field tested.

In nitrate treatment, the problem areas of concern are:

1) Sudden loss of pressure in a distribution system being fed by a package plant can occur either by accident or by intention during distribution maintenance procedures. Pressure loss coupled with other equipment failures could be catastrophic unless reliable safety features are activated. Any mechanical device presents an opportunity for failure such as valve failures due to various mechanical causes including wear. Some valves close at slow rates or are improperly seated upon closure. Failure of a valve to properly close can provide pathways for wastes and brines to unintentionally enter the treated water supply. Treatment equipment pressure vessels, manifolds and piping often serve two purposes at different times: to contain both treated water and wastewater. Such an arrangement constitutes a direct cross connection in the event of isolation valve failure. Connections to distributed water mains for make up water, rinse water etc. present an opportunity for back siphoning of chemicals and waste into the distribution system.
2) An ion exchange bed should not be operated too long or beyond its capacity to adsorb nitrate.

The result is not only lack of nitrate adsorption but also a phenomenon called "dumping" can occur depending on resin types where much of the previously adsorbed nitrate is dumped back into the treated water supply by sulfate.

3) An ion exchange bed, after being regenerated with brine, vessels and piping should be rinsed thoroughly of the waste salt before being put back into service. If not properly rinsed, excessive TDS and salt could be discharged into the treated water.

4) Introduction of waste rinse water or waste backwash water into the process stream or treated stream is also a potential source of contamination.

In proper plant design and operation, the above areas of concern will be carefully considered, although increased cost for safety features and extra use of rinse water and production of more wastewater may result.

As each system will have a different piping design and operating procedure, the location and operation of safety devices can only be generally described in this protocol document.

A simple procedure can be implemented to check for trouble spots in the event of loss of pressure in the distribution system. Use a flow diagram showing sensors and valves as reference and ask questions regarding any one valve, such as:

1) If the valve is normally closed during step 1 (e.g. during treatment) in the treatment process, could contamination result if the valve remained open? (e.g. a valve in a make up supply line and a chemical supply tank.)

2) If the valve is normally closed during step 2 (e.g. cleaning or rinsing), could contamination result if the valve remained open? (e.g. a valve to the treated water line)

Examples of other operation steps can be resin or membrane cleaning, standby, brine making, rinsing, etc. Each valve, whether normally opened or closed, can be so addressed during each different step of the treatment process. The same queries can be made assuming sudden loss of water pressure in the distribution line.

The following devices, piping and valve arrangements have been used to reduce unintentional contamination in specific cases.

1) Simple air gaps. The gaps should be frequently inspected for obstructions.

2) Sensors for shut down or warning alarms. High nitrate and TDS alarms are effective to detect contamination after it has occurred.

3) Back flow preventors, check valves and double check valves allow flow in only one direction. Addition of manually operated valves allows periodic testing by the operator.

4) Block and bleed valve arrangements. This arrangement consists of two automatically operated isolation valves in series with a third automatic valve between the two to act as a bleed valve. Flow from the bleed valve is a visual indication of failure of the blocking valves.

4.2.7 Cross Connection Control References and Guidelines

It is likely that each state will have adopted regulations covering the requirements for using cross connection prevention devices. Although the manufacturer's equipment will be tested in a given state (or states) it would be to the advantage to adopt measures which would apply to all states to give the broadest market for the equipment. Useful publications are available from individual state and local health agencies such as "Guidance Manual For Cross Connection Control Programs" published by the State of California, Department of Health Services, Sept 1988, Public Water Supply Branch. Other sources of information on this subject can be obtained from literature and certification training courses given by local plumbing unions. For example, "A Course Of Instruction For Certification In Cross-Connection Prevention" Fresno Area Plumbers, Pipe and Refrigeration Fitters JATC. The Foundation for Cross Connection Control and Hydraulic Research at the University of Southern California, Los Angeles, is another resource of information (213/749 2032).

The PSTP must describe the following:

1) the safety features that have been designed into the equipment;
2) what contamination problem this feature will address; and
3) the recommended field testing procedure and frequency.

4.3 Water Quality Considerations

Water treatment equipment is used to treat water and change the quality of feed water (or raw water) to reduce contaminants to a safe level. In addition, the treated water should be 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 process employed within a system can successfully treat any conceivable feed water 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 generally not needed and would not be cost effective.

The equipment is typically designed to treat only specific contaminants within a defined range of untreated water quality. It is, however, possible to broaden the applicability of treatment in the case of nitrate removal processes. In certain cases, water quality improvements regarding other constituents such as hardness, sodium, TDS, chloride, sulfate, etc. may also be desirable. The manufacturer can use auxiliary ion exchange treatment or membrane processes to reduce these constituents as well as the nitrate, which is the constituent of primary concern. The Field Testing Organization should state the range of water qualities and contamination that the equipment can successfully treat and the range of contaminants or water quality problems that can be addressed. Manufacturers should carefully consider the capabilities and limitations of their equipment and have the PSTP prepared to challenge their equipment sufficiently. The verification testing should enable broad marketing for their products, while recognizing the limitations of the equipment and not subjecting it to testing for contaminant removal when the outcome is known in advance to be failure and the testing would be fruitless. The ETV Testing Plans shall be used as the basis for the specific PSTPs.

4.3.1 Feed Water Quality

One of the key aspects related to water treatment equipment performance verification is the range of feed water quality that can be treated successfully, resulting in treated water quality that meets water quality goals. The PSTP preparer should consider the influence of feed water quality on the quality of treated waters produced by the equipment, such that product waters meet the water quality goals. They should also consider the impact of various water quality parameters on the cost of the treatment process and the quality and quantity of the waste produced. As the range of feed water quality that can be treated by the equipment becomes broader, the potential market for treatment equipment with verified performance capabilities will also increase. The Field Testing Organization shall specify in the PSTP the specific water quality parameters to be monitored in the Verification Testing Program. Also, the recommended operating range of these parameters should be stated. The following feed water quality characteristics are important in nitrate treatment using ion exchange and membrane processes.

- A general mineral analysis including nitrate, nitrite, chloride, sulfate, bicarbonate, carbonate, pH, TDS, hardness, barium, silica, and all other major cations and anions.
- Turbidity, particle concentration.
- Temperature, with temperatures near freezing having potential for the most difficult treatment conditions.
- Dissolved organic carbon (DOC), total organic carbon (TOC), or UV-254 absorbance.
- Color.
- Density (concentration) of microorganisms (bacteria).
- Iron and manganese.
- Presence of algae, particularly filter clogging algae.

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

4.3.2 Treated Water Quality

Treated water quality is the most significant measurement to be made in the testing program. For nitrate treatment processes, the Manufacturer must provide a statement of objectives to provide certain nitrate levels. In addition, the Manufacturer may wish to make a statement about performance objectives of the equipment for removal of other contaminants.

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
- total dissolved solids
- iron and manganese

Finally, other water quality parameters are useful for assessing equipment performance. These may include:

- particle count or concentration
- heterotrophic plate count bacteria (HPC)
- biological dissolved organic carbon (BDOC) or assimilable organic carbon (AOC)

Other water quality considerations must also be made. Any treatment process, which removes a contaminant also, changes the composition of other constituents. For example in ion exchange, nitrate is removed, sulfate and alkalinity are also removed and chloride is added; in a membrane process, nitrate is removed as well as other substances. The removal of these materials may produce a water quality incompatible with an existing distribution system. These items must be addressed in the test plan.

4.3.3 Wastewater Characteristics, Quality and Quantity

The quality and quantity of wastewater produced by the treatment plant is a very important consideration in testing the performance and acceptability of the plant. In many cases these factors can be the major determining considerations in the choice of treatment. In the case of an ion exchange plant treating for nitrate, the waste brine, although small in quantity, will be high in dissolved salts such as sodium chloride, bicarbonate, sulfate and nitrate. The waste discharge regulator or agency, which accepts the waste, will need to know the exact composition and quantity of waste before accepting it for discharge. Many wastes are discharged into a local sewer line, which, in turn transfers waste to a wastewater treatment facility. Often, the high TDS may impact the process of waste treatment or disposal. The Manufacturer and their designated FTO should do some assessment of this impact. Often the wastewater treatment agency will charge a fee for accepting the waste into their system. If the nitrate treatment process is reverse osmosis, the wastewater will also contain high TDS as well as be high in volume. The agency accepting the waste must be assured that the facilities are adequate for accepting the waste.

In either case, the PSTP should contain the chemical composition and quantities of the various types of waste produced by the test plant. The methods of waste discharge and disposal should be listed and discussions and requirements of local wastewater disposal agencies should be documented in the PSTP.

4.4 Recording Water Quality Data

For all nitrate removal tests, data should be maintained on the quality parameters listed in Sections 4.3.1 and 4.3.2 above and any other data required by the plant operating and waste discharge permitting agencies as described in Section 4.3.3. The frequency for each parameter will vary with nitrate measurements being the most frequent. The procedures and sampling requirements shall be provided in detail in the Verification

Testing Plan. The following items of information shall also be maintained for each experiment:

- Type of chemical addition, dose and chemical combination, where applicable (e.g., salt, acid, chlorine, scale inhibitor, etc.);
- Water type (raw water, pretreated feed water, product water, wastewater);
- Experimental run number (e.g. 1^{st} run, 2^{nd} run, 3^{rd} run, etc.).

The manufacturer must provide labeled sampling taps and locations on the equipment to allow either manual or automatic sampling. The manufacturer must also provide a diagram showing where each labeled sample tap is located and the parameter, which can be sampled at that location.

4.5 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95% confidence intervals shall be calculated by the Field Testing Organization for water quality parameters in which eight or more samples were collected. The product-specific test plan shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. Data quality objectives 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:

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

where: X is the sample mean;
S is the sample standard deviation;
n is the number of independent measurements included in the data set; and
t is the Student's t distribution value with n-1 degrees of freedom;
α is the 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 falling within the 95% confidence interval. For example, the results of the confidence interval calculation may provide the following information: 520

+/- 38.4 mg/L, with a 95% confidence interval range described as (481.6, 558.4).

Calculation of confidence intervals shall not be required for equipment performance results (e.g., filter run length, cleaning efficiency, in-line turbidity or in-line particle counts, etc.) obtained during the equipment testing verification program. However, as specified by the Field Testing Organization, calculation of confidence intervals may be required for such analytical parameters as TOC, DOC, grab samples of turbidity, nitrate, etc. In order to provide sufficient analytical data for statistical analysis, the Field Testing Organization 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 Verification Testing Plan.

4.6 Instrumentation for Plant Control and Monitoring

The membrane and ion exchange equipment used for nitrate treatment are mechanical in nature and allow the use of probes and instrumentation to monitor or control the plant operation. The PSTP should contain a description of these controls, their function and accuracy. The following are examples.

4.6.1 Nitrate Measurements

At no time should the nitrate in the water leaving the plant (or water entering the distribution system) exceed the MCL value. Frequent manual analysis of grab samples or automatic nitrate monitoring is required to assess the performance of nitrate removal plants. Feed water nitrate water quality can change suddenly; however, ion exchange processes have the capacity to handle influent nitrate fluctuations. Monitoring this parameter in both the feed, treated and blended water is very informative of plant performance. Measurement of nitrate on a once or twice per day basis is not sufficient to detect rapidly changing values, which can occur. It is well known that nitrate levels can change from minute to minute in water supplied by an intermittently operated pump. Likewise, whenever an ion exchange vessel undergoes a regeneration cycle, potential for high nitrates exists. Some vessels are regenerated five or more times per day. These potential fluctuations demand frequent manual or automatic monitoring. (Note: If an automatic nitrate monitor is supplied as part of the equipment control system, its operation should be evaluated as any other part of the plant. Such a monitor, however, should not be used for the nitrate measurements discussed in this paragraph. If the test plan requires an automatic monitor, one should be supplied by the Field Testing Organization).

Similarly, if membrane processes are used, nitrate variations can also occur as driving pressure changes.

4.6.2 Electrical Conductivity Measurements

Electrical conductivity measurements (e.c.) can be an indicator of plant performance and can be measured and recorded on a continuous basis. If ion exchange is the process, this parameter will indicate if excessive salts from improperly operating equipment has contaminated the water supply. The excessive salts in the water supply should not exceed the secondary standards for chloride, sulfate and TDS and should be as close to the feed water electrical conductivity as possible. If a membrane process is used, the electrical conductivity of the product water will be less than that of the feed water and will be an indication of properly functioning equipment. The PSTP should indicate the range of conductivities to be expected in the various streams.

4.7 Verification Testing Schedule

Verification testing activities include equipment set-up, start up and initial operation, verification operation, sampling and analysis, maintenance procedures and plant shut down. Initial operations are intended to be conducted so Manufacturers and their designated FTOs can test their equipment and be sure it is functioning as intended. If feed water (or source water) quality influences operation and performance of equipment being tested, the initial operations period serves as the shake-down period for determining appropriate operating parameters.

For nitrate treatment equipment, specific care must be taken during the start up procedure to disinfect equipment and media. Both ion exchange resins and membrane materials are sensitive to oxidants and disinfectants. The manufacturer should provide a procedure to ensure proper disinfection of the equipment for the start up procedure and for subsequent occasions if required.

It is recommended under this protocol that a minimum of one test period of Verification Testing of a length specified in the appropriate test plan be conducted in order to allow testing over a period of time to collect representative data. The specific operating and water quality parameters shall be stipulated by the selected Test Plan under this protocol and shall be used in development of the experimental plan and the preparation of the PSTP. Climatic changes between rainy and dry seasons or local agricultural practices may produce substantial variability in feed water nitrate and other water quality parameters. The timing for verification testing should consider cold weather operations because of seasonal water quality variations and because of the impact of cold temperatures on mechanical devices, filtration and membrane devices. For instance:

- cold temperatures (1^o to 5^oC) can have an adverse effect on some water treatment processes due to the increase in water viscosity at cold temperatures. Cold temperature considerations are particularly important for membrane filtration applications;
- water flows treated by many types of water treatment equipment are so great (80 to 100 liters/minute, or greater) that use of mechanical refrigeration to attain temperatures of 1^o to 5^oC would be prohibitively expensive;
- cold temperatures have an adverse effect on mechanical pumps, chemical feed pumps, compressors and automatically operated valves.

Verification testing with operations for which data are collected and used to verify performance are done after initial operations are completed. The verification entity, NSF, is to be notified of the date when verification testing is scheduled to begin.

Content of PSTP Regarding Experimental Design:

The PSTP shall contain the following:

- *Statement of the verification testing objectives.*

- *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 ETV Testing Plans, 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. Parameters of significance for treated water quality were listed above in Section 4, and in applicable ETV Testing Plans.*
- *Identification of the key qualitative parameters that shall be used for evaluation of equipment performance. Parameters of significance for treated water quality were listed above in Section 4, and in applicable ETV Testing Plans.*
- *Identification of the key quantitative parameters that shall be used for evaluation of equipment performance. Parameters of significance for treated water quality were listed above in Section 4, and in applicable ETV Testing Plans.*
- *Identification, description and testing procedures for safety components designed to prevent back flow, cross connections, or any unintended contamination of treated water.*
- *Detailed outline of the verification testing schedule.*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The ETV Testing Plan 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 ETV Testing Plans for different types of physical removal process equipment.)

Operation and design aspects of water treatment process equipment often provide a basis for approval or permitting by State regulatory engineers and can be used to pinpoint specific areas of concern related to operation of the equipment. Specific operation and 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 this verification testing and to resolve any logistical, technical, or QA 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 Manufacturer, FTO and NSF field activities shall be thoroughly documented. Field documentation shall include field logbooks, photographs, field data sheets, and chain-of-custody forms. The qualified testing organization 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 and provided to NSF.

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 to NSF.

5.3 Initial Operations

Initial operations will allow equipment Manufacturers and their designated FTOs to refine their operating procedures and to make operation adjustments as needed to successfully treat the feed water. 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

The qualified testing organization shall supervise equipment operation and water quality sampling and analysis during the verification phase of testing, using the procedures described below. NSF should oversee or inspect these activities. All field activities shall conform to requirements provided in the PSTP that was developed and approved for the verification testing being conducted.

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 as well as the time required by the operator to perform various tasks. The qualified Testing Organization will record and verify the number of hours each day spent by the operator of the treatment plant and provide a description of the daily tasks performed by the operator of the treatment equipment.

Content of PSTP Regarding Field Operations Procedures:

The Field Testing Organization shall be responsible for including the following elements in the PSTP:

- *A table summary of the proposed time schedule for operating and testing,*

- *Field operating procedures for the equipment and performance testing, based upon the ETV Testing Plan with listing of operating parameters, ranges for feed water quality, and the sampling and analysis strategy.*

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;*
- *Provision of field operating procedures.*

6.0 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The QAPP for this verification testing 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 primary 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 Field Testing Organization project manager is responsible for coordinating the preparation of the QAPP for this verification testing and for its approval by NSF. The Field Testing Organization project manager, with oversight from NSF, should 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 testing can proceed. NSF must review and either approve the QAPP or provide reasons for rejection of the QAPP along with 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 plan). NSF will not write QAPPs for Manufacturers or FTOs.

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 (Section 6) shall rest with the qualified testing organization, with oversight by NSF. QA/QC activities for the equipment shall include those activities recommended by 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 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, NSF and the 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:

- Accuracy;
- Precision;
- Representativeness; and
- Statistical Uncertainty.

Treatment results generated by the equipment must be verifiable for the purposes of this 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 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;
- interference; and
- systematic or carryover contamination from one sample to the next.

In this Verification Testing, accuracy will be ensured by

- maintaining consistent sample collection procedures, including sample locations;
- timing of sample collection;

- sampling procedures;
- sample preservation;
- sample packaging;
- sample shipping; and
- by random spiking procedures for the specific inorganic constituents chosen for testing.

The FTO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological sampling and analytical techniques in the PSTP.

For water quality analysis, accuracy is usually expressed as the percent recovery. Percent recovery is the amount recovered during analysis. In general percent recovery can be calculated by dividing the measured amount added to the amount actually added.

$$\%\ \text{Recovery} = \frac{\text{Measured}_{\text{Sample+Spike}} - \text{Measured}_{\text{Sample}}}{\text{Actual}_{\text{Spike}}} * 100\% = \frac{\text{Measured}_{\text{Spike}}}{\text{Actual}_{\text{Spike}}} * 100\%$$

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For equipment operating data, accuracy entails collecting a sufficient quantity of data during operation to be able to detect a change in operations. For water flow, accuracy may be 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 rotations per minute (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.

6.3.2 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. The standard deviation and the relative percent deviation recorded from sample analyses may be reported as a means to quantify sample precision. Precision measures the repeatability of measurement. It is usually expressed as the percent relative standard deviation (% RSD). In general % RSD can be calculated by dividing the standard deviation by the average. The methods to be employed for use of deviation shall be described by the FTO in the PSTP.

$$\% \text{ RSD} = \frac{\text{Standard Deviation}}{\text{Average}} * 100\% = \frac{\sqrt{\sum_{i=1}^{n} \frac{\left(y_i - \bar{y}\right)^2}{n-1}}}{\sum_{i=1}^{n} \frac{y_i}{n}} * 100\%$$

y_i = sample measurement

n = number of samples

6.3.3 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 maintaining consistent sample collection procedures, including:

- sample locations;
- timing of sample collection;
- sampling procedures;
- sample preservation;
- sample packaging;
- sample shipping;
- sample equipment decontamination; and
- blind spikes.

Using each method at its optimum capability to provide results that represent the most accurate and precise measurement that it is capable of achieving also will ensure representativeness. For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations.

6.3.4 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence level around the sample mean.

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 quality control checks provide a means of measuring the quality of data produced. The Manufacturer 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 FTO and NSF. Some types of quality control checks applicable to operating water treatment equipment were described in Section 6.3.4.

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 quality control checks shall be made. A key aspect of the Equipment Verification Testing Program is to provide operating results that will be widely accepted by state regulatory engineers. 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. Therefore the quality of water sample analytical results is just as important as the quality of the equipment operating data. Most QA plans emphasize analytical QA. 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 with the frequency of analysis and the approximate number.

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 whose composition is unknown to the analysts that are used to evaluate analytical performance. Analysis of PE samples shall be conducted before testing is initiated. PE samples shall be submitted by the field testing organization to the analytical laboratory and also to the equipment testing organizations if appropriate. The control limits for the PE samples shall be used to evaluate the equipment testing organization's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies done under this protocol would be a turbidity PE sample.

PE samples come with statistics about each sample, which 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 objectives 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, which shall 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 verify 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 verify accuracy, completeness. The individual operators and the laboratory supervisor shall examine calibration and QC data. Laboratory and project managers shall verify that all instrument systems are in control and that QA objectives for 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.

6.5.3 Data Reporting

This section contains a list of the water quality and equipment operation data to be reported. At a minimum, the data tabulation shall list the results for feed water 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 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories shall be conducted as specified by the ETV Testing Plan. These inspections will be performed by NSF to determine if the ETV Testing Plan is being implemented as intended. Separate inspection reports will be completed after the inspections and provided to the participating parties through NSF.

6.7 Reports

6.7.1 Status Reports

The equipment testing organization shall prepare periodic reports for the NSF project managers. 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 equipment testing organization project managers shall discuss them with the NSF technical lead, 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.

6.7.2 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 equipment testing organizations to the NSF project manager who will forward them to the Manufacturer and NSF QC Manager for appropriate actions.

6.8 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:

- Performance evaluation audits
- Technical systems audits

Content of PSTP Regarding Quality Assurance Project Plan:

The Field Testing Organization shall be responsible for including the following elements in the PSTP:

- *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 PE samples. It has to be clear how these samples are going to be used in the verification testing. One use of PE samples is in the conduct of a performance audit (see Section 6.7.1).*
- *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.*
- *Development of a corrective action plan in the PSTP.*
- *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.*
- *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 qualified testing organization and NSF each have distinct responsibilities for managing and analyzing verification testing data. The field testing organization is responsible for managing all the data and information generated during the verification testing and furnishing those records generated. The FTO will also be responsible for analyzing the data in the verification report. 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 ETV Testing Plan shall be provided to NSF. The data management section of the PSTP shall describe what types of data and information needs to be collected and managed. It shall also describe how the data shall be reported to NSF for evaluation.

Laboratory Analyses: The raw data and the validated data must be provided to NSF. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet, and a data dictionary shall be provided. 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);
- results from the use of other field analytical methods;

7.2 Report of Equipment Testing

The qualified testing organization 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
- Conclusions and Recommendations
- References
- Appendices
- PSTP
- QA/AC Results

NSF will review the draft report, the results of testing, the QA/QC results, and will prepare a final report.

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

The Field Testing Organization shall be responsible for including the following elements in the PSTP:

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

8.0 SAFETY MEASURES

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. They will include:

- Regulations covering the storage and transport of chemicals.
- Conformance with the National Electric Code.

- Provision of parking facilities, sanitary facilities.
- Provision of and access to fire extinguishers.
- Regulations covering site security.
- Conformance to any building permits requirement such as provision of handicap access or other health and safety requirements.
- Ventilation and air conditioning of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard.

Content of PSTP Regarding Safety:

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

CHAPTER 2

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN REMOVAL OF NITRATE BY REVERSE OSMOSIS AND NANOFILTRATION

Prepared By:
NSF International
789 Dixboro Road
Ann Arbor, MI

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1.0 INTRODUCTION

1.1 Background

This document is the ETV Testing Plan for Reverse Osmosis and Nanofiltration Processes for the Removal of Nitrates from Contaminated Water. This Testing Plan is to be used as a guide in the development of Product-Specific Test Plan (PSTP) procedures for testing reverse osmosis and nanofiltration (RO/NF) treatment equipment, within the structure provided by the ETV Protocol Document for nitrate removal. Refer to the Test Plans for Equipment Verification Testing for Physical-Chemical Removal of Nitrate by Ion Exchange and Membrane Processes for further information.

This document is applicable only to pressure-driven membrane processes such as RO/NF. This document is NOT applicable to electrically-driven, thermally-driven, or concentration-driven membrane processes.

Standard pretreatment such as cartridge filtration and acid and/or antiscalant addition included in a RO/NF treatment system that is to be evaluated for removal of nitrates 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 optional evaluation purposes.

Additional pretreatment processes which may be required to reduce particle loading to the RO/NF system for surface water applications are considered to be a separate treatment module whose performance and operation are outside the scope of this document. Where such pretreatment is required to meet reduce the fouling potential of the RO/NF feedwater as measured by silt density index and turbidity values.

In order to participate in the equipment verification process for RO/NF processes, the Equipment Manufacturer shall retain an NSF-qualified Field Testing Organization (FTO) to employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the PSTP. The procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

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

2.0 GENERAL APPROACH

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

The FTO shall provide full detail of the procedures to be followed for each task in the PSTP. The FTO shall specify the operational conditions to be evaluated during the Verification Testing.

3.0 OVERVIEW OF TASKS

This ETV Testing Plan is divided into 6 tasks. A brief overview of the tasks to be included in the verification testing program is presented below.

3.1 Task 1: Characterization of Feed Water

A full characterization of the source water must be made prior to initiating operation so that the potential for fouling and mineral precipitation (scaling) can be defined. Results of this analysis will be used to define feedwater pretreatment requirements and system operating conditions, and to identify potential foulants in the source water for monitoring during operation.

3.2 Task 2: RO/NF Performance

The objective of this task is to evaluate RO/NF operation. RO/NF productivity and the rate of fouling will be evaluated in relation to feed water quality. The relative fouling rates will be used, in part, to evaluate operation of the RO/NF equipment under the flux and recovery conditions to be verified.

3.3 Task 3: Product and Waste Water Quality

The objective of this task is to evaluate the quality of water produced by the RO/NF system, referred to as product water or permeate. Multiple water quality parameters will be monitored during each operational period. A basic goal of this Task is to confirm that RO/NF-treated waters meet the manufacturer's statement of performance objectives for nitrate. Permeate quality will be evaluated in relation to feed water quality and operational conditions. The waste water (concentrate) stream will also be characterized.

3.4 Task 4: RO/NF Cleaning

An important aspect of RO/NF operation is the restoration of membrane productivity after fouling has occurred. The objective of this task is to evaluate the efficiency of membrane cleaning. Normalized product flow, normalized salt passage, and differential pressure before and after cleaning will be used as the primary criteria for evaluation of cleaning effectiveness.

3.5 Task 5: Data Reduction and Presentation

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

Verification Testing.

3.6 Task 6: Quality Assurance/Quality Control

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 Verification Testing.

4.0 TESTING PERIODS

If the source water is a groundwater which exhibits little or no significant changes in seasonal water quality, the required operational tasks in the Verification Testing Plan (Tasks 1-4) shall be performed once (minimum) or twice (preferred) over a one-year period. Each test run, excluding equipment mobilization, startup/troubleshooting, and demobilization is to be based on a minimum of 1,000 hours of membrane system operation.

A schedule describing the sequence and duration of each of the required tasks is provided in Figure 1. In the rare event that the source water is a surface water, the operational tasks shall be performed for four weeks each quarter over a calendar year.

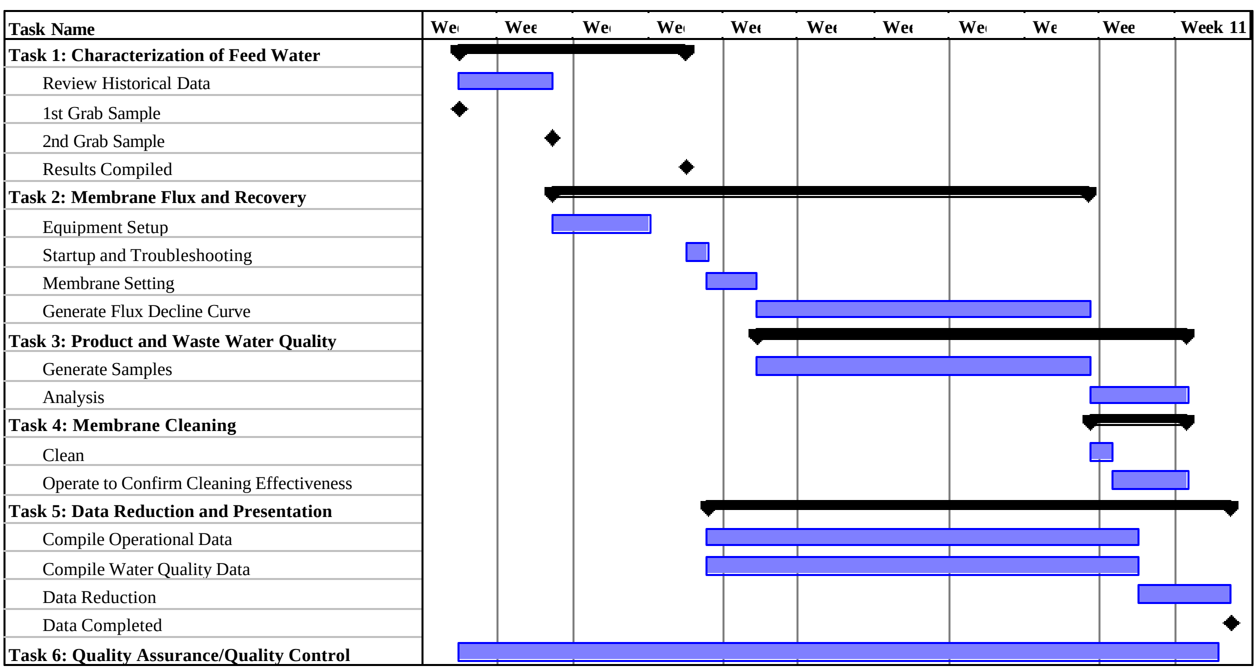

Figure 1 - Membrane Treatment System Verification Testing Schedule
(Single Test Period)

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following definitions are used to characterize performance of the RO/NF system.

5.1 Permeate: Product water produced by the RO/NF treatment system.

5.2 System Feedwater: Source water introduced into the RO/NF treatment system for treatment.

5.3 Element Feedwater: Water introduced into the RO/NF element, consisting of system feedwater for single-pass systems, or a combination of system feedwater and recycled concentrate for systems with concentrate recycle.

5.4 Membrane Fouling: A reduction in permeate flux caused by the accumulation of feedwater contaminants within or on the surface of the membrane or within or on the feedwater spacer. Fouling that can be restored by hydraulic or chemical means is termed "reversible" fouling. In contrast, "irreversible" fouling is defined as a permanent loss in permeate flux that cannot be restored by hydraulic or chemical means.

5.5 Stage: An assemblage of one or more pressure vessels, each containing between three and seven membrane elements, plumbed to receive a common feedwater. Each vessel receives approximately equal feed flow, produces approximately equal permeate and concentrate flow and operates at equal recovery.

5.6 Feedwater System Recovery: The ratio of permeate flow to system feedwater flow, expressed as a percentage:

$$\%\ System\ Recovery = 100\ x \left[\frac{Q_p}{Q_f} \right]$$

Where: Q_p = Permeate flow rate
Q_f = Feed flow rate to the membrane system

5.7 Membrane Element Recovery: The ratio of permeate flow to element feedwater flow, expressed as a percentage:

$$\%\ Element\ Recovery = 100\ x \left[\frac{Q_p}{Q_f + Q_r} \right]$$

Where: Q_p = Permeate flow rate
Q_f = System feed flow rate to the element
Q_r = Concentrate recycle flow rate to the element (if present)

5.8 Permeate Flux: The flow of permeate produced by the RO/NF system divided by the total membrane surface area of all elements in the system. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

Where:	J_t	=	Permeate flux at time t (gallons per square foot per day)
	Q_p	=	System permeate flow at time t (gpd)
	S	=	Membrane surface area (ft^2)

5.9 Salt Passage: The ratio of the concentration of any salt present in the permeate to its concentration in the feed stream, expressed as a percentage:

$$SP = \frac{C_p}{C_f} \; x\; 100$$

Where:	SP	=	Salt passage
	C_p	=	Permeate concentration for a given salt (mg/L)
	C_f	=	Feed concentration for a given salt (mg/L)

5.10 Temperature Adjustment for Permeate Flow and Salt Passage Calculations: Flow of water and salt through a RO/NF membrane is proportional to feedwater temperature based primarily on the viscosity of water. Permeate flow and salt passage must be corrected to a reference temperature of 25°C to enable an accurate determination of how changes in these parameters are affected by feedwater constituents according to the following equation:

$$J_{25} = \frac{J_T}{1.03^{(T-25)}}$$

Where:	J_{25}	=	Instantaneous flux at reference temperature of 25°C (gfd)
	J_T	=	Instantaneous flux at operating temperature T (gfd)
	T	=	Operating temperature (°C)

In many cases, membrane manufacturers have developed temperature correction factor (TCF) values specific to their membrane products that are more accurate than the equation shown above. Where available, the manufacturer-provided TCF should be used.

5.11 Feed-Concentrate Differential Pressure: The difference in measured pressure between the feed stream and the concentrate stream of a stage of the membrane array or of the entire membrane system. Expressed as an equation:

$$\Delta P = P_f - P_c$$

Where:	ΔP	=	Feed-concentrate differential pressure (psi)
	P_f	=	Feed stream pressure for a stage or the system (psig)
	P_c	=	Concentrate stream pressure for a stage or the system (psig)

5.12 Differential Osmotic Pressure: The difference in osmotic pressure between the feed and permeate streams. Osmotic pressure of the feed is defined as average osmotic pressure of the feedwater into and the concentrate out of the membrane system. Osmotic pressure is a measure of the force exerted by the natural tendency of water to flow across a semi-permeable membrane from a solution of lower salt concentration to a solution of higher salt concentration. Expressed as a formula:

$$\Delta\pi = \left[\left(\frac{TDS_f + TDS_c}{2}\right) - TDS_p\right] x\ 0.01$$

Where:	$\Delta\pi$	=	Differential osmotic pressure (psi)
	TDS_f	=	Feedwater total dissolved solids (mg/L)
	TDS_c	=	Concentrate total dissolved solids (mg/L)
	TDS_p	=	Permeate total dissolved solids (mg/L)

5.13 Net Driving Pressure: The pressure available to drive water through the membrane, equal to the average feed pressure (average of feed pressure and concentrate pressure) minus the differential osmotic pressure, minus the permeate pressure. Expressed as a formula:

$$NDP = \left(\frac{P_f + P_c}{2}\right) - \Delta\pi - P_p$$

Where:	NDP	=	Net Driving Pressure (psi)
	P_f	=	Feed pressure (psi)
	P_c	=	Concentrate pressure (psi)
	$\Delta\pi$	=	Differential osmotic pressure (psi)
	P_p	=	Permeate pressure (psi)

5.14 Normalized Product Flow: To clearly observe changes in permeate flux caused by membrane fouling or scaling, measured permeate flow must be corrected or "normalized" for variations in Net Driving Pressure and Temperature, using the following formula:

$$NPF = \frac{NDP_i}{NDP_t} x \frac{TCF_i}{TCF_t} x Q_p$$

Where:	NPF	=	Normalized product flow (gpm)
	NDP_i	=	Net Driving Pressure at initial conditions of operation (psi)
	NDP_t	=	Net Driving Pressure calculated at time t (psi)
	TCF_i	=	Temperature Correction Factor based on temperature at initial conditions of operation
	TCF_t	=	Temperature Correction Factor based on temperature at time t
	Q_p	=	permeate flow (gpm)

5.15 Normalized Salt Passage: To more clearly observe changes in the flow of any salt through the membrane caused by membrane fouling and scaling or changes in the permeability of the membrane itself from exposure to feedwater constituents, salt passage is normalized using the following equation:

$$NSP = \frac{NDP_t}{NDP_i} \ x \ \frac{C_{fb\,i}}{C_{fb\,t}} \ x \ \frac{C_{f\,t}}{C_{f\,i}} \ x \ SP$$

Where:	NSP	=	Normalized salt passage (%)
	NDP_i	=	Net Driving Pressure at initial conditions of operation (psi)
	NDP_t	=	Net Driving Pressure calculated at time t (psi)
	$C_{fb\,t}$	=	Feed-brine salt concentration at time t (see below)
	$C_{fb\,i}$	=	Feed-brine salt concentration at initial conditions of operation (see below)
	$C_{f\,t}$	=	Feed salt concentration at time t (mg/L)
	$C_{f\,i}$	=	Feed salt concentration at initial conditions of operation (mg/L)
	SP	=	Salt passage (%)

5.16 Feed-Brine Salt Concentration: The Feed-Brine salt concentration used in the calculation of Normalized salt Passage is defined by the following equation:

$$C_{fb} = \frac{\ln\left(\frac{C_b}{C_f}\right)}{1 - \left(\frac{C_f}{C_b}\right)}$$

Where:	C_{fb}	=	Feed-Brine salt concentration
	C_b	=	Brine (concentrate) salt concentration (mg/L)
	C_f	=	Feed salt concentration (mg/L)

6.0 TASK 1: CHARACTERIZATION OF FEED WATER

6.1 Introduction

This task involves a complete characterization of the raw water being fed to the treatment system. The information is required to determine the suitability of the water source as feed water for verification testing, and to document parameters which may be important in predicting the fouling and scaling tendencies of the water source.

6.2 Objectives

The objectives of this task are as follows:

- Obtain a complete chemical and physical characterization of the source water or feed water that will be subject to treatment.

- Identify potential membrane foulants and scalants (turbidity, bacteria, sparingly soluble salts, etc.) that will determine the type and degree of feedwater pretreatment and that must be monitored during system operation.

- Verify that the water as sampled is representative of the source water based on historical data (where available).

6.3 Work Plan

This Verification Testing Plan is based on the assumption that RO/NF for nitrate removal will be predominately applied to groundwaters that are not subject to significant seasonal changes in water quality. Application of membrane treatment systems to surface waters requires a significantly different approach than that outlined here in order to address seasonal variations in water quality.

Most water sources will not have pre-existing water quality data of sufficient detail to allow an evaluation of the proper application of RO/NF. Completion of this task involves the following:

- Analysis of grab samples for a detailed water quality analysis. The parameters evaluated will allow calculation of a complete cation/anion balance, in addition to general physical/chemical measurements and limited microbiological and organic analysis.

- A review of selected historical water quality data, where available. This will allow determination of trends in key water quality parameters such as nitrate and TDS or conductivity, as well as allowing verification that the water quality measured by the grab samples is representative of the recent historical data.

- Calculation of the scaling potential of the source water to be treated. This includes estimating the concentrations of the following salts in the membrane concentrate stream at the membrane system operating conditions proposed by the Manufacturer in Task 2 to the degree, if any, that these salts will be present in the concentrate stream in excess of their theoretical solubility:

    - calcium carbonate
    - calcium sulfate
    - barium sulfate
    - strontium sulfate
    - calcium fluoride
    - Silica

The FTO shall include in the PSTP guidelines for maximum percent saturation for each of the above salts during RO/NF system operation assuming the use of appropriate scale inhibiting chemicals.

6.4 Analytical Schedule

Parameters required for a complete evaluation of source water quality are presented in Table 1. Table 1 identifies required and optional parameters for evaluation by analysis of grab samples.

Table 1
Raw Water Characterization

Parameter	Grab Samples
General/Physical Parameters	
Temperature	Required
pH	Required
TDS	Required
Conductivity	Required
Silt Density Index	Required
Turbidity	Required
Particle Counts	Optional
Color	Optional
Taste and Odor	Optional
Inorganic Cation/Anion Balance	
Ca^{+2}	Required
Mg^{+2}	Required
Na^{+}	Required
K^{+}	Required
NH_4^{+}	Optional
Sr^{+2}	Required
Ba^{+2}	Required
Fe^{+2}	Required
Mn^{+2}	Required
CO_3^{-2}	Required
HCO_3^{-}	Required
SO_4^{-2}	Required
Cl^{-}	Required
NO_3^{-}	Required
F^{-}	Required
CO_2	Required
H_2S	Optional
SiO_2	Required
Organic/Microbiological	
Total Organic Carbon	Required
Total Coliforms	Optional
Heterotrophic Plate Count	Required
UV absorbance (@254 nm)	Optional
AOC/BDOC	Optional

(1) Report the mean and standard deviation of a mini-mum of two grab samples taken at least 10 days apart.

Parameters to be analyzed from grab samples should be taken from a minimum of 2 samples taken at least 10 days apart. Potential sources of historical data include the United States Geological Survey, US Environmental Protection Agency, and state and local laboratories.

Manufacturers intending to have their equipment verified for uses other than nitrate removal may wish to characterize the source water in terms of additional parameters besides those identified in Table 1.

6.5 Evaluation Criteria

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

The detailed water quality analysis results will allow an estimation of which sparingly soluble salts, if any, present a potential for scaling by mineral precipitation at the water temperature and recovery conditions to be tested. The analysis will allow proper selection of the chemical pretreatment (acid addition and/or antiscalant addition) and the design recovery of the RO/NF system. The water quality analysis will also determine if feedwater pretreatment is required to reduce fouling tendency. If turbidity or silt density index values exceed membrane-industry accepted criteria or if microbiological indicators suggest that biological fouling potential is significant, the Manufacturer will be required to provide pretreatment to adequately address these concerns.

7.0 TASK 2: RO/NF PERFORMANCE

7.1 Introduction

The purpose of this task is to verify that the RO/NF system, when tested in accordance with Manufacturer-selected operating conditions on the selected source water, can maintain performance as defined by:

- Productivity (product flow)
- Permeate nitrate concentration (and other salts, if applicable)
- Feedwater system recovery over a specified period of operation

A further purpose of this task is to demonstrate that changes in the level of these performance characteristics caused by membrane fouling or other interactions between the RO/NF system and the feedwater can be adequately managed through chemical cleaning of the membrane elements at an acceptable frequency.

In this task, the RO/NF system will be operated at conditions of constant permeate flux and recovery as specified by the FTO, and the normalized product flow, normalized salt passage (as measured by conductivity) and their changes with operating time will be measured. As fouling occurs and normalized product flow declines or normalized salt passage increases to pre-determined values (proposed by the FTO and agreed to by NSF), the RO/NF system will be chemically cleaned per Task 4 to remove foulants and if possible, scalants. The efficiency of cleaning will then be assessed by measuring the degree to which normalized product flow has been increased and/or normalized salt passage has been decreased upon subsequent operation of the RO/NF system.

In the event that fouling rates are judged to be excessive and/or chemical cleaning efficiency less than desired, the Manufacturer shall propose revised operating conditions to reduce fouling rate. The effect of the new conditions of membrane productivity will then be determined by additional testing.

Prior to the start of the Verification Testing Program, the operational conditions to be verified shall be specified by the FTO in terms of an average permeate flux (gfd), feedwater recovery, and maximum salt passage (or its converse, minimum salt rejection) at a reference temperature of 25°C.

The degree of fouling or scaling that occurs within a RO/NF system is a function of source water quality and operational conditions. Waters with high particle loads or greater concentrations of sparingly soluble salts generally produce increased fouling and scaling. Feedwater, permeate and concentrate streams will be sampled for water quality parameters critical to the assessment of membrane productivity as they relate directly to fouling or scaling potential. This sampling will be conducted in conjunction with sampling performed under Tasks 1 and 3. Flow, temperature, pressure and conductivity data shall be collected to quantify changes in the following parameters:

- Normalized product flow
- Normalized salt passage
- Feed-concentrate differential pressure

The testing runs conducted under this task shall be performed in conjunction with Tasks 3 and 4. With the exception of additional testing periods conducted at the FTO's discretion, no additional RO/NF test runs are required for performance of Tasks 3 and 4. This task shall be performed once (minimum) or twice (preferred, within a one-year period, with a minimum of 6 months between test runs).

7.2 Objectives

The objectives of this task are to document the following:

- Operational conditions for the RO/NF system.
- Feedwater system recovery achieved by the RO/NF equipment.
- The rate of change in normalized product flow, salt passage and feed-concentrate differential pressure and associated operating times between cleanings based on these rates.

Verification of RO/NF system operation shall also apply to operating conditions that are considered less stringent than those conditions tested; examples of less stringent conditions would include operation at lower membrane flux (lower permeate flow) and lower product water recovery.

7.3 Work Plan

The PSTP shall specify information concerning design and operation of the RO/NF treatment system being evaluated, using the following categories as specified in Table 2:

- System design criteria
- Operating conditions (including those for pretreatment and RO/NF systems)
- Written procedures for operation and maintenance
- Cleaning Criteria. Specify allowable changes to the following parameters, which indicate a need for cleaning of a stage of the array or the entire system:
  - Percent loss of normalized product flow

$$NPF\ \%\ Loss = \frac{NPF_{Original} - NPF_{Fouled}}{NPF_{Original}}$$

  - Percent increase in normalized salt passage

$$NSP\ \%\ Increase = \frac{NSP_{Fouled} - NSP_{Original}}{NSP_{Original}}$$

  - Percent increase in feed-concentrate differential pressure (across each stage and/or the RO/NF system)

$$\Delta P\ \%\ Increase = \frac{\Delta P_{Fouled} - \Delta P_{Original}}{\Delta P_{Original}}$$

After startup of the RO/NF equipment, membrane operation should be established at the permeate flux and recovery conditions to be verified. In the event the temperature of the feedwater differs significantly from 25°C, the Manufacturer shall provide a temperature-specific permeate flux (normalized to account for differences in temperature between Manufacturer-specified and actual). The RO/NF system may be operated for up to 24 hours to allow the membrane elements to come to equilibrium prior to the start of data used in the flux decline calculations (membrane setting).

Following the membrane setting period, the treatment system should be operated until one or more of the cleaning criteria specified in the PSTP are met or a total of 1,000 hours of run time is achieved (whichever occurs first). The objective of operation is to attain 1,000 hours or operation without the need for chemical cleaning. If the rate of change in normalized product flow, normalized salt passage or feed-concentrate differential pressure results triggers one or more cleaning criteria before the 1,000-hour operating period is complete, chemical cleaning shall be performed per Task 4 and adjustments to operation shall be made to reduce the rate of change in these performance parameters (such as a decrease in permeate flux or feedwater system recovery).

Decisions on operating condition adjustments shall be made based upon the Manufacturer's experience and consultation with the FTO responsible for performing the study. If subsequent operation at the new conditions results in the need for a second cleaning prior to the attainment of 1,000 operating hours, chemical cleaning shall again be conducted and cleaning efficiency determined. RO/NF system operating conditions shall then be further adjusted to provide for an acceptable rate of change to attain 1,000 hours of operation between cleanings. Each recommended change in operating conditions shall be first approved by NSF and the FTO.

During operation, data for the operational parameters identified in Table 3 should be monitored and recorded either continuously by means of on-line instrumentation, or at a minimum of twice daily by manual measurement. Requirements for water quality monitoring during operation are presented in Task 3.

Additional testing may also be included in the PSTP in order to demonstrate RO/NF performance under different feedwater quality conditions. The FTO shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 1,000-hour testing period, as required above for each additional set of operating conditions.

7.4 Analytical Schedule

A sample matrix of operation monitoring points, parameters, and frequency for a typical two-stage RO/NF treatment system with concentrate recycle (see Figure 2) is presented in Table 3. The manufacturer should adopt the operational data collection locations to the particular geometry of the RO/NF system. In general, adequate data must be documented to allow evaluation of each stage of the system independently, as well as documenting operation of the treatment system as a whole.

7.5 Evaluation Criteria

Provide tabular data for the parameters listed in Table 3.

Provide graphs of the following parameters versus elapsed run time:

- Temperature
- Flux
- Recovery
- Feed Pressure
- Normalized product water flow
- Normalized salt passage
- Feed-concentrate differential pressure (across each stage)

Table 2
Membrane Treatment System Information to be Provided in Manufacturer PSTP

Parameter, units		Comments
System Configuration		
	Number of stages	
	Number of pressure vessels in each stage	
	Number of membrane elements per pressure vessel	
	Surface area per membrane element, Ft^2	
	Acid addition	Type and dose
	Antiscalant addition	Type and dose
	Cartridge filtration, µm	Nominal rated pore size
	Other pretreatment	Describe if used
Operating Conditions to be Evaluated		
	Recovery per stage, %	
	Recovery for system, %	
	Design flux, gfd	
	Feed water temperature	
	Feed water pH	
	Feed water nitrate concentration	
	Feed water TDS	
	Concentrate recycle rate, gpm or %	
Operations and Maintenance Procedures		
	System startup	
	Normal operation	
	Temporary system shutdown (flush)	System shutdown < 48 hours
	Prolonged system shutdown (preservation)	System shutdown >48 hours
Cleaning Criteria		
	Allowable normalized product flow decline, %	Percent reduction from initial value
	Allowable increase in differential pressure, %	Percent increase from initial value
	Allowable normalized salt passage increase, %	Percent increase from initial value

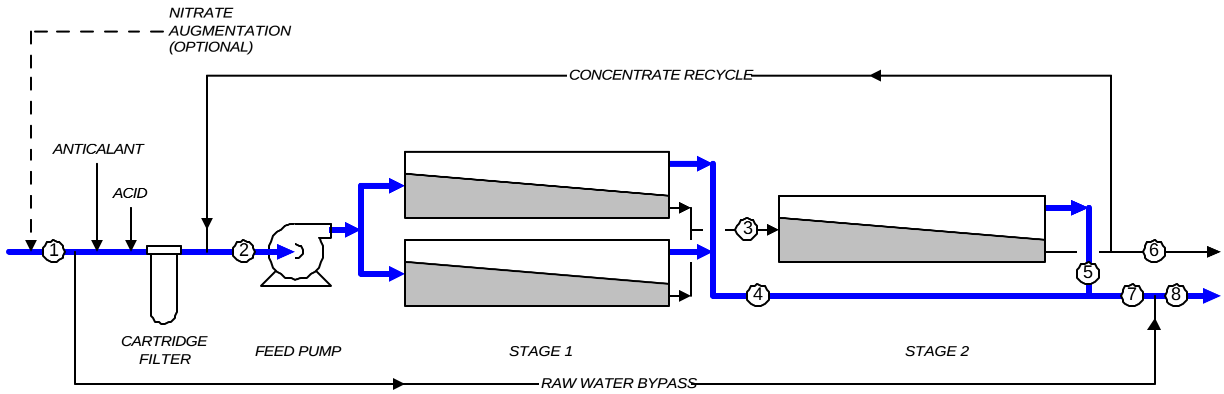

Figure 2 - Sample Monitoring Points for 2-Stage Treatment System with Concentrate Recycle and Raw Water Bypass

Table 3
Sample Operational Data Collection Matrix

	Monitoring Location (Refer to Figure 2)(1)	**Temper-ature**	**Flow**	**Pressure**	**Conduct-ivity**
1	Raw Water				
2	Membrane Feed Water				
3	Stage 1 Permeate				
4	Stage 1 Concentrate				
5	Stage 2 Permeate				
6	System Concentrate				
7	System Permeate				
7	Blended Product Water				

(1) Adopt the operational data collection locations to the particular geometry of the membrane system

(2) [shaded cell] indicates no monitoring requirement

7.6 (Optional) Nitrate Spiking

If the nitrate concentration at the test site does not challenge the treatment system to the limits of its performance objectives, an optional nitrate augmentation procedure may be used after the required 1,000 hour operating period is completed. Nitrate spiking would allow demonstration of product water quality under conditions of elevated nitrate in the feed water.

To spike nitrate, use of an appropriate spiking solution and metering pump will be required. A solution prepared from a monovalent nitrate salt (sodium nitrate, potassium nitrate) is preferred to avoid inadvertent addition of a cation that might increase the scaling potential of the test water. Use of nitric acid as nitrate source is not recommended because it would interfere with proper documentation of the acid dose required to prevent scaling.

Where nitrate spiking is proposed, the FTO must detail procedures for preparation of the spiking solution, and procedures for proper mixing of the spiking solution into the feedwater. The spiking solution must be added to the feed water prior to any other chemical addition (acid or antiscalant), prior to the point of concentrate recycle into the feed water (if used), and prior to raw water bypass for permeate blending. Refer to Figure 2 for an example of a proper spiking solution addition point.

Where nitrate spiking is proposed, the FTO may choose to operate over a range of feed nitrate concentrations. For each target nitrate concentration to be tested, the system should be operated for at least 5 days (120 hours) to allow steady-state performance to be achieved.

8.0 TASK 3: PRODUCT AND WASTE WATER QUALITY

8.1 Introduction

This task involves a characterization of product and waste quality during the system operation described in Task 2. Product water analysis will serve to document that the treatment system meets the nitrate removal performance criteria for which the manufacturer is seeking verification. Additional water quality information is required to identify performance of the treatment system relative to any potential foulants identified during the raw water characterization performed in Task 1.

The quality and quantity of concentrate produced by the RO/NF treatment system is a very important consideration in determining the efficacy and cost-effective use of the RO/NF treatment system. Regulators responsible for permitting the safe and environmentally acceptable disposal of the concentrate typically require precise information regarding physical, chemical and microbiological characteristics, along with other information relating to the biotoxicity of the concentrate. Costs for concentrate disposal can be significant based on the type of disposal option selected, particularly for those not utilizing a direct discharge to a surface water body.

8.2 Objectives

The objectives of this task are as follows:

- Assess the ability of the RO/NF equipment to meet the water quality goals specified by the Manufacturer.

- Monitor the concentrations of any potential foulants and sparingly soluble salts that may interfere with the long-term operation of the treatment system. Examples include turbidity, calcium, alkalinity, and bacterial plate counts in the feed water as identified in Task 1.
- Characterize the volume and composition of the wastewater (concentrate) produced by the process.

8.3 Work Plan

Water quality data shall be collected for the RO/NF treatment system feedwater, permeate and concentrate as shown in Table 4, during the RO/NF test runs of Task 2. At a minimum, the required sampling schedule shown in Table 4 shall be observed by the FTO on behalf of the Manufacturer. Water quality goals and target removal goals for the RO/NF equipment shall be clearly delineated in the PSTP.

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 4. The actual water quality parameters selected for testing and monitoring shall be stipulated in the PSTP. The limiting salt cation and anion listed in Table 4 shall be determined from source water analyses and estimation of concentrate stream concentrations of the sparingly soluble salts as required under Task 1. Each salt that has been determined to be present in the concentrate at levels exceeding theoretical solubility or for which chemical conditioning of the feedwater is required to control solubility shall be monitored per the requirements of Table 4.

The FTO shall identify the treated water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the Verification Testing Program. The statement of performance objectives prepared by the FTO shall indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater.

Although this Verification Testing Plan and the associated protocol are oriented towards removal of nitrate, the Manufacturer may desire to evaluate the treatment system's removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the FTO (refer to Table 5). Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA-accredited analytical laboratory.

The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are described in Task 6, Quality Assurance/ Quality Control (QA/QC).

Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both field and laboratory analytical procedures.

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing necessary 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 lab.

Table 4
Sample Water Quality Data Collection Matrix

Monitoring Location (Refer to Figure 2) (1)		Twice per Day		Once per Day					Once Every 5 Days		
		pH	**Nitrate**	**Turbidity**	**Silt Density Index**	**Other Potential Foulants** (2)	**Alka-linity**	**Calcium Hardnes s**	**Limiting Salt Cation** (3) (4)	**Limiting Salt Anion** (3) (4)	**Other Scalants** (3) (4)
1	Raw Water										
2	Membrane Feed Water										
3	Stage 1 Permeate										
4	Stage 1 Concentrate										
5	Stage 2 Permeate										
6	System Concentrate										
7	System Permeate										
8	Blended Product Water										

(1) Adopt the operational data collection locations to the particular geometry of the membrane system
(2) If identified from raw water quality analysis, Task 1
(3) As determined from raw water quality analysis, Task 1
(4) Limiting salts shall include one or more of the following: $CaSO_4$, $BaSO_4$, $SrSO_4$, SiO_2, and CaF_2

8.4 Analytical Schedule

The minimum monitoring frequency for the required water quality parameters is presented in Table 4. At the discretion of the FTO, the water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP; however, to the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

8.5 Evaluation Criteria

8.5.1 Nitrate Removal

The primary evaluation criteria will be the ability to meet the degree of nitrate rejection (expressed as a percentage) claimed by the manufacturer for the application being verified.

Provide a graph showing the RO/NF feedwater and permeate nitrate concentrations as a function of elapsed operating time.

Provide a graph of nitrate rejection as a function of elapsed operation time, as defined by the following:

$$\textit{Nitrate Rejection (\%)} = \left(\frac{C_f - C_p}{C_f} \right) x\ 100$$

Where: C_f = Nitrate concentration in the feed water (mg/L)
C_p = Nitrate concentration in the product water (mg/L)

8.5.2 Fouling Indices

Provide graphs of RO/NF system feedwater turbidity and silt density index (SDI) as a function of elapsed operating time.

Provide a table showing maximum, minimum, and average RO/NF system feedwater turbidity and SDI values over the entire period of operation. The table shall include a listing of the RO/NF manufacturer's recommended maximum turbidity and SDI values to ensure satisfactory long-term operation of the RO/NF elements and to ensure that the element warranty is not voided.

8.5.3 Concentrate Stream Limiting Salts

Provide graphs of each limiting salt that was present in the system as a function of elapsed operating time. These graphs are required only where concentration of the salt is greater than theoretical solubility or where chemical conditioning of the feedwater was used to control solubility.

Provide a table showing maximum, minimum, and average concentrate stream scaling indices over the entire period of operation, or where the RO/NF system was operated at more than one feedwater recovery, for each distinct period of operation. Include in the table, percent saturation permitted by the manufacturer of the RO/NF elements used in the study and for which verification is being sought.

9.0 TASK 4: RO/NF CLEANING

9.1 Introduction

During or following the test runs of Task 2, the RO/NF equipment shall require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the RO/NF during each 1,000-hour test period. In the case where the rate of fouling is low and the decreases in normalized product flow or increases in normalized salt passage do not reach chemical cleaning criteria as specified by the Manufacturer in Task 1, chemical cleaning shall be performed after each 1,000-hour test of operation, with an evaluation of cleaning efficiency made by subsequent system operation for a period sufficient to determine cleaning impact.

9.2 Objectives

The objectives of this task are as follows:

- Evaluate the effectiveness of chemical cleaning for reversing losses in normalized product flow or increases in normalized salt passage to the RO/NF system.
- Confirm that Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity for the systems being considered under the conditions being evaluated.

9.3 Work Plan

The RO/NF systems may become fouled during the RO/NF test runs conducted for Task 2. These fouled membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce fouled membranes; cleaning will only be conducted if fouling causes performance losses to levels recommended by the Manufacturer and as listed in the PSTP. If losses are not sufficient, cleaning will be conducted at the conclusion of each 1000-hour test to assess the cleaning efficiency relative to the degree that such losses were incurred.

Each system shall be chemically cleaned using cleaning equipment (including chemicals) provided by the Manufacturer and cleaning solutions and procedures specified by the FTO in the PSTP. After each chemical cleaning of the membranes, the system shall be restarted at test conditions and operated for a period of 72 hours to monitor response to cleaning of the following productivity indicators:

- Normalized product flow
- Normalized salt passage
- Feed-concentrate differential pressure

Cleaning chemicals and cleaning routines shall be based on the recommendations of the Manufacturer. The PSTP shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the information in Table 5 shall be provided. In addition, a description of all cleaning equipment and its operation shall be included in PSTP.

9.4 Analytical Schedule

9.4.1 Sampling

The pH and temperature of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure, as indicated in Table 5. No other water quality sampling shall be required.

9.4.2 Operational Data Collection

RO/NF system performance data shall be collected immediately preceding cleaning and for 72-hours following return of the system to normal operation (following completion of cleaning). If the Manufacturer's procedures required cleaning with two separate cleaning formulations, the 72-hour operating period shall be performed following the completion of the entire cleaning event (final cleaning formulation).

9.5 Evaluation Criteria

At the conclusion of each chemical cleaning event and upon return of the RO/NF system to operation, system operating data (pressure, flow, conductivity, and temperature) shall be recorded four times per day for a 72-hour period and each performance parameter calculated (normalized product flow, normalized salt passage, and feed-concentrate differential pressure). The twelve data values for each performance parameter shall be averaged to obtain a "post-cleaning" value to be used in cleaning efficiency calculations described in this Task. The efficacy of chemical cleaning for each performance parameter shall be evaluated as noted below, with comparisons drawn from the cleaning efficacy achieved during previous cleaning evaluations (where applicable). Comparison between chemical cleanings shall allow evaluation of the potential for irreversible fouling and projections for usable membrane life.

Two primary measures of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, considering the value of the productivity indicator at the start of the run, at the end of the run, and after cleaning.

$$NPF\ Recovery(\%) = \frac{\left(NPF_{Cleaned} - NPF_{Fouled}\right)}{\left(NPF_{Original} - NPF_{Fouled}\right)}$$

$$NSP\ Recovery(\%) = \frac{\left(NPF_{Fouled} - NPF_{Cleaned}\right)}{\left(NPF_{Fouled} - NPF_{Original}\right)}$$

$$\Delta P\ Recovery(\%) = \frac{\left(\Delta P_{Fouled} - \Delta P_{Cleaned}\right)}{\left(\Delta P_{Fouled} - \Delta P_{Original}\right)}$$

2) The loss of productivity, considering the value of the productivity indicator at the start of the run and after cleaning:

$$NPF\ Loss(\%) = \left(1 - \frac{NPF_{Cleaned}}{NPF_{Original}}\right)$$

$$NSP\ Increase(\%) = \left(\frac{NSP_{Cleaned}}{NSP_{Original}} - 1\right)$$

$$DP\ Increase\ (\%) = \left(\frac{DP_{Cleaned}}{DP_{Original}} - 1\right)$$

Table 5
Data to be Recorded for Documentation of Cleaning Efficiency

Parameter[1]	Units	First Solution	Second Solution	Notes
Preliminary Flush				
Source				
Flow rate	gpm			
Volume or duration	gal or min			
Cleaning chemicals used				
Cleaning solution batch volume	gal			
Citric acid	lbs			
Sodium tripolyphosphate	lbs			
Trisodium phosphate	lbs			
Sodium EDTA	lbs			
Anionic surfactant	mL			
Hydrochloric acid	mL			
50% Sodium hydroxide	mL			
Other:____________________				Other solution components
Other:____________________				List Proprietary cleaning solution
Solution Recirculation/Soak/Recirculation				
pH				Note initial and final
Temperature	deg C			Note initial and final
Initial recirculation period	minutes			
Initial recirculation pH				
Initial recirculation temperature	deg C			
Appearance of solution				Note color, solids, clarity, etc.
Soak period	hours			
Final recirculation period	minutes			
Final recirculation pH				
Final recirculation temperature	deg C			
Appearance of solution				Note color, solids, clarity, etc.
Final Flush				
Source				
pH				
Flow rate	gpm			
Volume or duration	gal or min			

(1) Provide data for each stage if cleaned separately

10.0 TASK 5: DATA REDUCTION AND PRESENTATION

10.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software, manual recording methods, or both, for recording operational parameters of the RO/NF equipment on a daily basis.

10.2 Objectives

The objectives of this task are as follows:

- Establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes.
- Develop a statistical analysis of the data, as described in Test Plans for Equipment Verification Testing for Physical-Chemical Removal of Nitrate by Ion Exchange and RO/NF Processes.

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Microsoft Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a weekly basis at a minimum.

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

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

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

11.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

11.1 Introduction

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

11.2 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.

11.3 Work Plan

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

11.3.1 Daily QA/QC Verifications

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- On-line turbidimeter flow rates (verified volumetrically, if employed).

11.3.2 Weekly QA/QC Verifications

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- Recalibration of on-line pH meters and/or conductivity meters, if used.

11.3.3 Quarterly QA/QC Verifications

- On-line turbidimeters (clean out reservoirs and recalibrate, if employed)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

11.3.4 On-Site Analytical Methods

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

11.3.4.1 pH. 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.

11.3.4.2 Turbidity. Turbidity analyses shall be performed according to Standard Method 2130 with either an on-line or bench-top turbidimeter. On-line turbidimeters shall be used for measurement of turbidity in the permeate waters, and either an on-line or bench-top turbidimeter may be used for measurement of the feedwater (and concentrate where applicable).

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

11.3.5 Chemical and Biological Samples Shipped Off-Site for Analysis

Total organic carbon (TOC) and UV absorbance samples shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4ºC to the analytical laboratory within 8 hours of sampling. The TOC and UV absorbance samples shall be collected and preserved in accordance with Standard Method 5010B.

Table 6
Analytical Methods

Parameter	Analysis Type			Standard Methods [1] number or Other Method Reference	EPA Method[2]
	Field	On-Line	Lab		
General Water Quality					
pH	X	X		4500-H+ B	150.1 / 150.2
Total alkalinity	X		X	2320 B	
Total Hardness	X		X	2340 C	
Calcium Hardness	X		X	3500-Ca D	
Temperature	X	X		2550 B	
Conductivity	X	X	X		120.1
Total Dissolved Solids		X		2540 C	
Turbidity	X	X	X	2130 B / Method 2	180.1
Color	X		X	2120 B[3]	
Taste and Odor			X		
Inorganic Water Quality					
Calcium	X		X	3500-Ca D / 3111 B / 3120 B	200.7
Magnesium			X		200.7
Sodium			X	3111 B	200.7
Potassium			X		200.7
Ammonia			X		350.3
Strontium			X		200.7
Barium			X	3111 D / 3113 B / 3120 B	200.7 / 200.8
Iron	X		X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Carbonate, CO_3			X	Calculation	
Bicarbonate, HCO_3			X	Calculation	
Sulfate			X	4110 B / 4500-SO4= C, D, F	300.0 / 375.2
Chloride	X	X	X	4110 B / 4500-Cl- D	300
Nitrate	X		X	4110 B / 4500-NO3- D, F	300.0 / 353.2
Fluoride			X	4110 B / 4500-F- B, C, D, E	300
Carbon Dioxide			X	6211 M	
Hydrogen Sulfide			X		376.1/2
Silica, SiO_2			X	3120 B / 4500-Si D, E, F	200.7
Organic Water Quality					
Total organic carbon			X	5310 C	
UV254 absorbance	X		X	5910 B	
AOC/BDOC			X	9217	
Microbiological					
Total coliform			X	9221 / 9222 / 9223	
Heterotrophic Plate Count			X	9215 B	

Notes:

1) Standard Methods Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.

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

3) Hach Co. modification of SM 2120 measured in spectrophotometer at 455 nm.

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Inorganic chemical samples, including arsenic, alkalinity, hardness, aluminum, iron, and manganese, shall be collected and preserved in accordance with Standard Method 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples should be refrigerated at approximately 2 to 8ºC immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8ºC. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited Laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8ºC until initiation of analysis.

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 2 to 8°C to the analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

12.0 OPERATION AND MAINTENANCE

The FTO shall obtain the Manufacturer-supplied Operation and Maintenance (O&M) Manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommended criteria for evaluation of Operations and Maintenance (O&M) Manuals for equipment employing RO/NF treatment.

12.1 Operation

Provide clear and concise recommendations for procedures related to proper operation of the RO/NF treatment systems and equipment. Include as a minimum, information on the following:

- Startup
  - Initial startup of system
  - Restart of the system after prolonged shutdown
- Shutdown and membrane element preservation
  - Short term (less than 48 hours)
  - Intermediate term (48 hours to 1 week)
  - Long Term (more than one week)
- Chemical Feed Systems
  - Type of chemical to be used
  - Dose rate
  - Automation of chemical control system (e.g., pH control of acid feed)
- Tolerance of the system to operating conditions

    - Feed water temperature
    - pH
    - Oxidants (e.g., chlorine)
    - Maximum feed pressure and maximum allowable differential pressure across each stage
- Adjustment to operating parameters
    - Product water flux
    - Recovery

12.2 Maintenance

Provide clear and concise procedures for performing maintenance on the system and its components.

- Explicit instructions for in-situ cleaning of membrane elements
    - Chemicals to be used
    - Guidelines and limits for pH, temperature
    - Procedures for flushing before and after cleaning
    - Recirculation rates and durations
- Instructions for installing or replacing membrane elements into the system.
- Recommended or required maintenance schedules for each piece of equipment.
- A list of spare parts to be kept on hand.

12.2.1 Troubleshooting

- Provide an explicit list of alarm conditions that will be raised by the system.
    - Pressure
    - Temperature
    - pH
    - Pump Failure
    - Chemical feed low tank level
- Indicate which alarm conditions will cause automatic system shutdown and provide instructions for clearing each condition.
- Provide detailed procedures for verifying integrity of membranes, o-rings, etc. on a vessel-by-vessel basis.

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CHAPTER 3

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN NITRATE CONTAMINANT REMOVAL BY ION EXCHANGE

Prepared By:
NSF International
789 Dixboro Road
Ann Arbor, Michigan 48105

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1.0 INTRODUCTION

1.1 Need For This Verification Testing Plan

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing the ion exchange process for nitrate removal. The Safe Drinking Water Act and its state counterparts set standards for water quality regarding certain contaminants, which are known to occur in public water supplies. The frequency of testing for these contaminants is also specified. However, the Act does not set standards for the design, performance, testing or operation of treatment facilities for the regulated contaminants. To a certain extent, individual States place requirements on some of these areas not covered by the Act. For example, there are training and certification programs for operators of treatment plants and design reviews given to proposed treatment facilities followed by a plant operating permit procedure. However, in most cases, operator training and design reviews are not familiar with the variety of designs, which use the specialized ion exchange technologies. This ETV Testing Plan provides background information and testing procedures, which will be of service to owners, operators, state regulators and manufacturers who must deal with these unfamiliar technical subjects. The responsibility to make effective treatment rests with the States and the professional disciplines and organizations involved in the effort and in particular on the equipment designer and supplier or manufacturer of the treatment system.

Under the ETV testing program, it is the manufacturers responsibility to retain a qualified Field Testing Organization to conduct tests on the plant by following an NSF approved preset testing plan contained in the Product-Specific Test Plan (PSTP). Other subjects treated in the PSTP are set forth in the ETV Protocol Document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies." This Equipment Verification Testing Plan is applicable only to processes using ion exchange materials as the media in the nitrate removal processes.

1.2 Manufacturer's Responsibility

In order to participate in the equipment verification process for nitrate removal, the equipment Manufacturer shall retain a qualified Field Testing Organization to employ the terminology, procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of PSTP. The testing procedures shall generally follow the tasks that are outlined and described in this document. An attempt has been made to provide test descriptions to be appropriate to all processes using ion exchange rather than to a specific design of a process. However, variations in these tasks may be required to modify or adapt to specific process designs or plant situations. A suggested outline and format of the procedures written by the Field Testing Organization for each task is given. The outline for each task will usually contain the following sections:

- Introduction
- Objectives
- Work Plan
- Schedule

An overview of the Tasks is given in Section 4. A list of definitions and terms, which are peculiar particular to nitrate ion exchange, is given in Section 6. The specific Tasks to be included in each PSTP are described in Sections 7 through 13.

2.0 GENERAL BACKGROUND ON ION EXCHANGE PROCESSES

2.1 Description of Processes

This verification testing plan applies to a wide scope of equipment types which use ion exchange processes. There is no lack of creativity among ion exchange process designers who have had over fifty years since the availability of synthetic ion exchange materials to exercise their ingenuity. It is not the intention of a specifically defined test plan to limit this scope nor to discourage innovation. On the other hand, regardless of novelty, all ion exchange processes are governed by the same basic ion exchange reactions which constitute the various processes.

Among various ion exchange materials available for nitrate exchange, synthetic polymeric resins that carry exchangeable anions are most widely used. Regardless of exchange materials, the nitrate exchange process can be expressed in two steps, adsorption and regeneration as shown below:

$$(\text{Ion Exchanger})Cl^{-} + NO^{-}_{3(aq)} \rightarrow (\text{Ion Exchanger})NO^{-}_{3} + Cl^{-}_{(aq)} \qquad \text{Adsorption Step}$$

$$(\text{Ion Exchanger})NO^{-}_{3} + Cl^{-}_{(brine)} \rightarrow (\text{Ion Exchanger})Cl^{-} + NO^{-}_{3(brine)} \qquad \text{Regeneration Step}$$

The Adsorption Step consists of contacting the nitrate-laden water supply with a bed of Ion Exchanger in the chloride form. The nitrate ion is removed from the water and, in exchange, the chloride ion is added to the water. The opposite exchange occurs in the Regeneration Step where the Ion Exchanger is restored to its initial chloride condition where, after rinsing, it can be reused.

If the process were 100 percent efficient, only one chloride ion would be required to remove one nitrate ion from the water supply. In terms of energy demands, the Adsorption Step occurs with the equilibrium favoring the product side of the reaction, nitrate ion is much preferred by resins in preference to chloride. All resins are selective for nitrate over chloride. Therefore, for the Regeneration Step, an energy price must be paid by using an excess of chloride to drive the reaction to the right.

The nitrate exchange process can be represented by a single overall metathesis or exchange reaction, which is the sum of two reactions (adsorption and regeneration steps) with a resin giving a net result:

$$NO^{-}_{3(aq)} + Cl^{-}_{(brine)} \rightarrow NO^{-}_{3(brine)} + Cl^{-}_{(aq)} \qquad \text{Basic Nitrate Ion Exchange}$$

Wherein a chloride ion from a concentrated brine replaces a nitrate ion in the untreated water. The net result is removal of nitrate from the water supply and production of waste nitrate brine. The water softening process can be represented by a similar net exchange reaction:

$$Ca^{2+}_{(aq)} + 2Na^{+}_{(brine)} \rightarrow Ca^{2+}_{(brine)} + 2Na^{+}_{(aq)} \qquad \text{Ion Exchange Softening}$$

Superficially, the processes appear similar; but they are quite different because of the different stoicheometries which drastically influence process efficiency. In the nitrate/chloride exchange, the number of nitrate ions transferred to the brine is directly proportional to $Cl^{-}_{(brine)}$ according to the law of mass action. To drive the nitrate reaction to the right, an excess of chloride brine ions is required. However, in the softening case, the amount of waste calcium ions transferred to the brine is proportional to $(Na^{+}_{(brine)})^2$ according to the mass action law. In the case of waters of normal hardness, and the usual brine concentrations, the efficiency is nearly 100 percent, requiring relatively little excess brine. Process designs for efficient water softening, therefore, are not directly applicable to nitrate removal.

Because the basic process is carried out indirectly through a sequence of steps, efficiency is greatly dependent on the nature of the ion exchanger and the physical methods used to bring the water supply into contact with the Ion Exchange medium and then to carry out the regeneration. This situation invites a variety of process designs each employing specific chemical, hydraulic, and mechanical methods. In the softening case, both the adsorption and the regeneration reactions favor the right hand side of the two equations because of the divalent nature of the calcium ion. (This is probably the least understood aspect of comparisons between nitrate ion exchange and softening). The practical result is that near stoichiometric quantities of salt regenerant are required in softening, whereas in the nitrate case ten (or higher) to one are required for a complete regeneration.

The design must bring the water supply into close contact with the Ion Exchanger over a specific time period and in a three-dimensional uniform flow. Engineers have devised several ways to do this but it is usually done by placing the Ion Exchanger in a filter bed or columnar arrangement, distributing the untreated water over the bed and allowing water to flow through at uniform rates; then uniformly collecting the treated water near the exit of the bed. The same type arrangement is used for the Regeneration Step.

The competition between the major ions present in a water supply for taking over an ion exchange site is also great enough to be of concern in the design of the equipment and the process. After the Ion Exchanger is exhausted, the different ions will be concentrated in the resin bed according to the chemical equilibrium laws of chromatographic distribution. Consequently, the use of different ion exchange resins and different methods of adsorption and regeneration are employed to overcome any difficulties, which this may cause. For example, the regenerations will be conducted by flowing the regenerant through the bed in the same or opposite direction that the water flows in the adsorption step.

Rinsing and wasting the brine from the bed is also performed in different ways and gives rise to different rinsing efficiencies. In some cases sophisticated designs will reuse at least some of the rinse water, waste brine, or backwash water. Further variations in process designs are made to ensure that the resin bed is always in a uniformly packed condition to prevent channeling of fluid through the bed and reducing the physical contact time between the resin and the fluid.

In essence, each manufacturer has a large number of variables to deal with in how to accomplish the simple Basic Ion Exchange process with the particular design and operation of plant equipment. Each may claim some aspect of the design, which makes it superior to another, or make some claim regarding proprietary or breakthrough designs.

2.2 Classification of Nitrate Ion Exchange Processes

For the purpose of this verification testing plan the different process designs will be classified according to common characteristics and expected performance levels. For example, design Class 1 will usually be used for small units where process efficiency and waste production are of little concern, but high reliability, ease of operation and water quality objectives are important. In contrast, other design classes may be used where there is concern about waste disposal and may require more sophisticated regeneration procedures, adding to the complexity of operation. One cannot, therefore, state that one design is superior to the other, but only to the extent that the treatment and other related objectives are similar.

The verification testing program will verify manufacturer's objectives regarding the performance of the equipment. The manufacturer will classify the design according to the following design classifications, provide flow diagrams of the design and provide projected performance characteristics of the plant.

2.2.1 Fixed Bed Designs

Fixed bed designs employ the ion exchange resin placed in a vessel that is stationary and within which both the adsorption and regeneration steps are conducted. The contact between resin and the water (or regenerant) is accomplished by flowing the water (or regenerant) through the stationary vessel. This is the most common type design. (Some movement of the resin occurs within the vessel during the backwash, declassification, and rinsing procedures.) The placement and operation of a number of valves accomplishes the changes in the flow of fluids through the bed in a fixed bed design.

2.2.1.1 Class 1. Conventional Fixed Bed. This is the simplest type of design and uses the same equipment and regeneration method that is manufactured for water softener use. Instead of using a resin for softening water (cation exchange resin) this resin is replaced with an anion exchange resin. The specific gravity of anion exchange resins is much lower than cation resins. Therefore, the backwash step and the ion exchange vessel internal components may need to be modified for anion exchange processes. The bed is run to near exhaustion, then regenerated with excess salt to ensure regeneration in a down flow direction then rinsed. It is commonly thought, although erroneously, that nitrate ion exchange differs only from water softening in the kind of resin that is used and the chemical, physical, hydraulic, and regeneration processes are identical (see above). Although such designs may remove nitrate and operate reliably, they will also use excessive salt regenerant and may also produce excessive wastewater. A Class 1 design is likely to be low in capital cost because no special design considerations for nitrate removal chemistry are included and designs are made for the softening mass market. Normally, the sequence of steps for one cycle in a Class 1 design is adsorption, back wash, regeneration and finally, rinse.

2.2.1.2 Class 2. Up Flow Regeneration Fixed Bed. This fixed bed design employs regeneration in an up flow regeneration mode. Distributors within the vessel and valving are designed to accommodate this design feature. Again, this type of design is primarily used in softening where very low levels of contaminant ion are required to meet water quality objectives. Problems encountered are that when brine flows upward through the resin, the distance between resin particles tends to increase, as the bed tends to expand upward. The result is the regenerant will channel through the bed with reduced contact with the resin. Designers must somehow compensate for this problem, e.g., by employing a blocking flow.

The advantage of this design is that the resin at the bottom of the bed has virtually all nitrate removed so when the bed is placed in service, no nitrate appears in the initial portion of product water. However, continued production causes nitrate to gradually rise, with a rate dependent on amount of regenerant used. A second advantage of this design can be realized if the nitrate on the resin is concentrated at the top of the bed when regeneration starts. Large amounts of nitrate can be removed from the top of the bed by the regenerant and give good regeneration efficiency. The amount of nitrate at the top of the unregenerated bed varies with water composition. If sulfate is present, sulfate concentrates at the top of the bed and this advantage is diminished or can become a disadvantage. In the latter case, declassification of the resin before regeneration can move some nitrate to the top of the bed.

In general, a Class 2 design can give a product water very low in nitrate initially. The more nitrate removed from the treated supply, the more untreated water can be blended in to give an acceptable nitrate level. This in turn is translated into use of smaller sized vessels and amounts of medium (lower capital cost). However, greater salt demands are the trade off.

2.2.1.3 Class 3. Fixed Bed With Partial Regeneration And Declassification. This method was developed by the USEPA for demonstration in McFarland, California, and is employed in several locations in the U.S. where sulfate is present in the feed water. This design is more complex than the above systems to minimize the amount of brine and wastewater. The process uses modified vessel designs with efficient flow distributors and bifurcated collectors. Down flow adsorption is directly followed with down flow regeneration. This takes advantage of the concentrated nitrate at the bottom of the bed at the end of the adsorption cycle to give high nitrate removal efficiency. The bed is only partially regenerated, i.e. large amounts of brine are not used to remove all nitrate from the bed, only sufficient nitrate is removed to meet water quality objectives. The next step is to declassify the bed, (accomplished by a series of five uneven back washes via the bifurcated collector design, to mix the bed) and distribute the nitrate remaining on the bed uniformly throughout the bed. This is necessary to give a constant level of nitrate in the product water as the bed is exhausted.

The advantages of this design are more efficient use of brine and less wastewater production than the above designs especially if sulfate is present.

2.2.2 Moving Bed Designs

Moving bed designs require that the resin bed (or part of the bed) move from place to place at some part of the process cycle. An example is to use one vessel to perform the Adsorption Step, then remove resin and place it in a second vessel where the Regeneration Step is performed. Then move the regenerated resin back into the first vessel. One of the advantages of this type design is that less resin inventory is required.

2.2.2.1 Class 4. Loop Designs. These designs are also referred to as moving packed beds or by different names such as Higgins or Asahi and their variations and have a place in the history of nitrate treatment, being the first large-scale plant design used in the U.S. at Garden City Park, N.Y. Their common feature is the movement of resin from one vessel to another for different parts of the cycle.

In the Higgins Loop reactor, the adsorption occurs in a down flow mode through a first vessel. Then, the top portion of the bed is moved (pulsed) to a regeneration vessel and regenerated resin is pulsed back to the bottom of the first vessel. The adsorption and regeneration steps can be conducted simultaneously but in different vessels. Advantages depend on water quality. On Long Island, low sulfate water concentrated nitrate at the top of the bed, which is efficiently regenerated and the down flow mode in a separate vessel avoids the channeling problems encountered in the fixed bed Class 2 design. Further advantages claimed are that lower resin inventories are required making capital costs lower. Critics claim low resin life, because of resin attrition caused by pumping resin slurries from one vessel to another.

The Asahi design is quite complex. Some features are:

1) up flow adsorption and high flow rates, which pin the bed to the top portion of the adsorption vessel, while the lower portion of the bed is moved by fluidization to a regeneration vessel;
2) after exhaustion the flow stops, the bed falls and draws in regenerated, rinsed resin; and
3) absorption flow is started again, pinning the fresh resin against the top of the vessel and moving the spent lower portion to regeneration.

The advantages appear to be the same as the Higgins reactor except resin is moved by fluidization rather than mechanical pumping.

2.2.2.2 Class 5. Carousel Designs. In this design, the resin bed moves within several vessels within which resin is contained. The vessels are mounted in "merry-go-round" configuration and gradually step from position to position by rotation of the entire mechanism. The circular platform structure contains orifices through which the fluids enter and exit the individual vessels. When the vessels are in positions e.g. 1 through 10, they are in the adsorption section of the carousel. When they are in positions e.g. 11 through 15, they are in the regeneration section, and finally when they are in the last section, the vessels are rinsed. This design has potential to have the highest regeneration efficiency and lowest wastewater production because various piping arrangements can easily recycle brine and rinse water.

3.0 NSF QUALIFIED TESTING ORGANIZATIONS

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

4.0 OVERVIEW OF PHASES AND TASKS

The PSTP will include a Testing Plan with detailed tasks described and scheduled that will be followed by the NSF qualified field testing organization. The PSTP plan will be formulated by the Field Testing Organization to be effective for the particular plant design, operation and field situation. Wide variability in PSTP plans is anticipated because of these factors. The tasks listed below and detailed throughout this document are formulated to represent the content, vocabulary, organization and quality of testing and evaluation procedures anticipated by NSF to be included in any PSTP. The Field Testing Organization may add other tasks. If the tasks listed below are eliminated or substantially modified, a reason for doing so should be given.

Three phases of testing are to be included in the Verification and Testing Plan.

- The **first phase** consists of preparation and plant start up. The scope of this phase will depend on whether or not the equipment has already been installed at a treatment plant site and is already treating water or if the plant will be delivered to the site and will require set up and start up procedures.

  A meeting of testing personnel with the plant manufacturer will be held to review the material contained in the PSTP presented by the Field Testing Organization. Much material regarding the plant and its operation were provided in the PSTP as set forth in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies." This material will include, design classification, drawings and diagrams of the plant design, the start up and operating procedures. This meeting will allow any questions concerning the plant and the testing program to be addressed. The manufacturer will confirm the items which will be tested for during the program and present the objectives concerning operation, make projections of the plant performance characteristics, and review any critical or key measurements to be made.

  The meeting or a part of the meeting should take place at the treatment plant site where various features and components can be directly pointed out and demonstrated. If the plant is not yet started, the start up could take place at this time.

- The **second phase** is the field testing phase, which will evaluate performance of the equipment over a 60-day period.

- The **third phase** will be conducted throughout the testing period to ensure that the data are collected in a reliable and retrievable manner, properly and completely reported on a timely basis. A Data Manager will be responsible for these tasks.

The three phase Testing Plan outlined below is comprised of 8 separate tasks, which are outlined in the following sections.

4.1 Phase 1. Preparation

4.1.1 Task 1. Preparation, Coordination, Start Up

An orientation meeting will be held in preparation for the testing program. The manufacturer will meet with the field testing organization personnel to review the plant and process design and clarify the testing program and schedule. It is recommended that a field visit to the plant be made to acquaint the testing personnel with details of the plant site. Discussion of the program, its objectives, and responsibilities of each participant will be clarified. If the plant is not already operating, the plant will be started approximately 15 days before field tests begin.

4.2 Phase 2. Field Testing

4.2.1 Task 2. Initial Plant Characteristics

Initial tests will be conducted to measure the plant's basic capabilities and characteristics. These tests will be conducted to produce base line information, which can be used to evaluate changes, which occur as the plant ages. If the plant does not meet water quality objectives, the Field Testing Organization will be notified and adjustments made.

4.2.2 Task 3. Daily Testing and Data Collection

Routine measurements and data recording will be conducted on a daily basis for at minimum a 60-day test period.

4.2.3 Task 4. Cross-Connection And Mechanical Inspection

Two certified or registered professionals will perform inspections of plant equipment and operation:

1) a cross-connection specialist will inspect and test all cross-connection control and back flow prevention devices, and
2) a mechanical engineer will inspect all electrical and mechanical equipment for proper placement and operation.

4.2.4 Task 5. Evaluation of Secondary Data

Data obtained by the owner/operator the 60-day period during regular plant operation will be reviewed to evaluate the data collection, management and reporting system of the plant. The accuracy of the data and information as well as its adequacy will be evaluated. Data found to be accurate can be used to supplement the evaluation and testing program.

4.2.5 Task 6. Continuous Nitrate Analysis and Monitoring

In order to evaluate the reliability and stability of the plant operation. Frequent sampling and analysis of the three different streams (feed, treated and blended) for nitrate levels should be performed. High frequency sampling (at approximately six-minute intervals) is best done with modern nitrate measuring instruments. Because of recent improvements and the popular use of automatic nitrate monitoring instruments at several nitrate plant locations, it is highly feasible to do close monitoring of nitrate levels in multiple process streams. It is highly desirable that one nitrate monitor be used to monitor three different process streams over a period of 60 days. If an automatic monitor is not used, manual samples should be taken from the three different streams as frequently as feasible for analysis.

4.2.6 Task 7. Quality Assurance and Quality Control

A Quality Assurance and Quality Control (QA/QC) program will be followed to ensure adequate quality of the data collected.

4.3 Phase 3. Reporting

4.3.1 Task 8. Data Collection Methods, Management and Reports

Data collection, management and reporting will be tasks, which are closely integrated. The contents of the draft and final report will include specific summaries and items to complete the evaluation of the plant performance.

5.0 TESTING SCHEDULE

The PSTP will contain a Schedule of Tasks.

Task 1, Preparation, Coordination and Start Up, shall be performed before the plant testing program begins. The plant shall be operated for at least ten cycles before tests can begin.

Task 2, Initial and Final Plant Characterization, shall be performed at the beginning and end of the 60-day test program.

Task 3, Daily Testing and Data Collection, typical water quality and operational monitoring shall be performed at least three times per day and additional data collection shall be performed every two weeks.

Tasks 4, Cross Connection and Electromechanical Inspection, and 5, Operation Evaluation and Examination of Records, will be done near the end of the 60-day test period.

Task 6, Continuous Nitrate Analysis and Monitoring, shall be at least three times per day over the 60-day test period

Tasks 7, QA/QC, and 8, Data Collection Methods, Management, Reporting, will be conducted throughout the test program.

6.0 TERMINOLOGY FOR VERIFICATION TESTING AND EVALUATION

6.1 Perspective on Terminology

A uniform and consistent terminology shall be used for the evaluation, testing, and reporting of nitrate systems. This will allow potential users to make direct comparisons between different systems and be able to choose the most suitable system for their needs. Unfortunately, ion exchange technology is not consistent and varies with the application of interest. A set of terms will be used that are derived from the Safe Drinking Water Act (SDWA) itself, from standard chemical terminology, and which are specifically related to nitrate ion exchange. It is necessary to make distinct and precise definitions because the ion exchange process, as used for nitrate removal from municipal water, is a relatively new and highly specialized water treatment method. Ion exchange for nitrate removal is considerably different from older and widely used technologies of ion exchange for softening or ion exchange for demineralization. Because of these differences, a different terminology is used to be compatible with the SDWA and to represent the technological differences between nitrate removal and other applications such as softening. Although this discussion will appear superfluous to those skilled in ion exchange technology, it is believed to be useful to those who are not.

For example, the Safe Drinking Water Act specifies Maximum Contaminants Level (MCL) values in chemical concentration terms of **milligrams per liter** (mg/L) of the contaminant. Older technology conventions express concentrations in terms of mg/L of calcium carbonate equivalents or equivalent grains of calcium carbonate or electrical conductivity. This may be suitable terminology to describe hardness removal or demineralization, however, for nitrate or any other contaminant, it makes little sense to refer to nitrate as calcium carbonate or grains of calcium carbonate or conductance equivalents, especially when the SDWA avoids these terms.

Furthermore, the major differences between ion exchange for nitrate removal and ion exchange for softening relate to the basic chemistry differences between the two processes. It is appropriate to use a different terminology. The major differences are:

A. Inefficiencies Due to Presence of Other Ions

Sulfate ion interferes heavily in nitrate removal. Chloride and bicarbonate also interfere. Removal of calcium ion by softening resins is not as sensitive to these or other cations. Feed water composition of all major anions is important in nitrate treatment.

B. Process Efficiency

The nitrate removal process is less efficient than softening. (For example, at typical regeneration doses of 5 - 10 lbs/cubic foot of resin, the hardness leakage will be close to zero, whereas the nitrate leakage will be 10 to 20 mg/L depending on water quality.) Designing and operating a plant for minimum regenerant usage in nitrate removal is critical and process designs different from designs for softening are required. Use of salt in the softening process is of less concern because of the greater efficiency of regeneration. Use of salt in the nitrate removal process is a serious concern because of the relatively greater quantities of salt required and the cost of disposal.

C. Product Water Quality

In treatment for nitrate removal, processes can be designed to allow some nitrate to pass through the bed. In softening, only very small amounts of hardness ions are allowed to pass through. To hold nitrate removal to the same standards of removal as hardness ions can be counter-productive by increased complexity, lower efficiency and higher cost of the process.

The PSTP will use the following terminology when describing the plant equipment, its operation and the testing and evaluation procedures. The reports prepared in Task 8 will use also use the following terminology in describing the evaluation of the plant. This test plan also uses the terminology presented here.

6.2 Terms Defined

Adsorption - (Same as Ion Exchange Adsorption). The step in the ion exchange process which removes nitrate from water by chemical or physical attraction to a medium such as an ion exchange resin. It is also referred to as the SERVICE step or the EXHAUSTION step.

Adsorption Isotherm - A graph showing the amount of material adsorbed as a function of the equilibrium concentration at a fixed temperature per unit weight of ion exchange material.

Anion - A negatively charged ion. The major anions of concern are nitrate, sulfate, chloride and bicarbonate.

Anion Exchange Resin - A polymeric material in the form of granular particles or spheres within which positively charged ionic sites are chemically bound and which can adsorb anions from an aqueous solution by the ion exchange reaction.

Attrition - Breakage and wear of ion exchange resins.

Back Washing - The upward flow of water through an ion exchange bed to clean it of foreign material and reduce the compaction of the resin bed. Usually the bed is fluidized by the upward flow of water.

Batch Contact - A method of using ion exchange materials in which the resin and liquid to be treated are mixed in a vessel and the liquid is decanted off after equilibrium is attained.

Bead Count - The evaluation of an ion exchange material's physical quality by microscopic evaluation and determination of percent whole, cracked, and broken beads in a wet sample.

Bed - The ion exchange material contained in a column or vessel of an operating unit.

Bed Depth - The height of the resin material in the column after the exchanger has settled into a packed bed condition.

Bed Expansion - The effect produced during back washing: the resin particles become separated and rise in the column.

Bed Life - The time that a resin bed is allowed to remain in the adsorption step. With flow rate constant, the bed life equals the number of bed volumes which can be treated divided by the number of bed volumes treated per unit time.

Bed Volume (BV)- The volume of ion exchange resin material in a bed. The volume of the resin in the bed is referred to as one bed volume and is expressed in cubic feet, gallons or liters. (The volume of the resin includes the summation of the volume of each resin particle plus the void volume between the beads.).

Bed Volumes - (or BED VOLUMES TREATED) - A dimensionless ratio that refers to the amount of water, which can be treated, by a bed of resin. The ratio is volumes of water treated per volume of resin in the bed.

BreakThrough - The rapid increase in concentration in the effluent of a substance which signals that adsorption of the substance is near completion and further operation of the column will not be productive. During plant operation, the adsorption cycle is terminated prior to breakthrough of the ion of interest. (The **breakthrough point** can be defined in several different ways such as the point on the breakthrough curve where the concentration of the ion reaches a given value which is half the value of its feed water value**,** halfway between leakage and influent concentration, the MCL or points of inflection. Breakthrough can be gradual or sharp depending on several factors. Some of these points can be difficult to measure unless sharp breakthrough occurs. For example, if the influent nitrate is 10 percent over the MCL, the curve has a flattened or gradual slope when it is at the MCL and the point would be difficult to measure accurately. A consistent definition should be adopted for any given verification plan.)

Breakthrough Curve - Also referred to as EFFLUENT HISTORY or LEAKAGE CURVE. A curve showing the relationship between the bed volumes of water passing through a bed of ion exchange resin and the ionic composition expressed in milliequivalents of the ion per liter in the effluent from the bed over a range to show sharp or gradual changes in the composition of any ion which denotes its break through the resin bed. The BREAKTHROUGH POINT on this curve for nitrate ion is only well defined for fully regenerated resins as the point at which the concentration is one-half of its influent value. The term EFFLUENT HISTORY is also used in this context and is a more general term which denotes a curve of leakage over a treatment range, leakage curves may not show clearly defined breakthrough points.

Brine Use Factor (BUF) - A quantitative expression of salt used in practice to remove nitrate from water by the ion exchange process. The BUF is directly proportional to the salt costs required to operate the process and is also indicative of the amount of wastewater produced by the process. In theory, if the process of nitrate removal were 100 percent efficient, the BUF would be 1. The BUF changes with process and therefor useful in comparing different process designs. Its measured value depends on several other process parameters such as BV treated, nitrate leakage, salt loading, brine concentration, feed water composition, resin characteristics, direction of flow through the bed, method of regeneration or brine recycling etc.

$$\text{BUF} = \frac{\text{Average number of chemical eqivalents of salt used in regeneration}}{\text{Average number of chemical equivalents of nitrate removed by treatment}}$$

In practice and in actual plant operation, inefficiencies are experienced because of the inherent chemistry of the ion exchange process plus the imperfections in process and equipment design. Inefficiencies are introduced in the process design, the physical equipment, generation of wastewater, and operating procedures of a plant. The measured BUF is therefore a reflection of the entire plant operation rather than simply a ratio of two substances. The BUF of an operating system can be estimated by the following formula when the nitrate concentration is expressed as milligrams of nitrate ion per liter of water. (Not as milligrams of nitrogen per liter):

$$\text{BUF} = \left[\frac{\text{pounds of NaCl used per 1000 gallons of treated water}}{4.423(\text{untreated mg N/L - treated mg N/L})}\right]127.1$$

For example, if a plant treats one million gallons of water containing 18 mg-N/L and reduces the nitrate to 4.5 mg-N/L and uses 2000 pounds of salt in the process, the BUF is

$$\text{BUF} = \left[\frac{2}{4.423(18-4.5)}\right]127.1 = 4.26$$

Capacity - The number of chemical equivalents of exchangeable ion contained in one liter of an ion exchange material. The volume is measured when the material is wet and is fully saturated with adsorbed water.

Cation Exchange Resin - A resin to which negatively charged ionic sites are bound and which can adsorb cations from an aqueous solution.

Channeling - Cleavage and furrowing in the packed resin bed due to faulty operational procedures, or any condition in which the solution being treated follows the path of least resistance, runs through the channels, and fails to establish close resin contact.

Chemical Equivalent - The amount of any ion, which contains Avogadro's number of ionic charges. The chemical equivalent is independent of the weight of an ion. Thus, one chemical equivalent of nitrate is chemically equivalent to one chemical equivalent of chloride although their equivalent weights differ. SEE EQUIVALENT WEIGHT.

Chemical Stability - The ability of an ion exchange material to resist changes in its properties when in contact with aggressive chemical solutions, such as oxidizing agents.

Chromatography - The separation of ions, molecular species, or complexes into highly purified fractions by means of ion exchange materials or adsorbents.

Clumping - The formation of resin agglomerations in an ion exchange bed due to fouling, chemical depositions, scaling, or admixture with highly cohesive substances, such as certain clays and silts.

Column Operation - The most common method of employing ion exchange materials, in which the liquid to be treated passes through a fixed bed of ion exchange resin held within a cylindrical vessel or column.

Counter Flow Operation - An ion exchange operation in which the direction of flow of water through a bed and the subsequent regenerant flow are in opposite directions.

Cross-Linking - Binding of the linear polymer chains in the matrix of an ion exchange material with an agent which produces a three-dimensional insoluble product.

Cycle - A complete series of operational steps. For instance, a complete cycle of nitrate ion exchange would involve; the complete adsorption step, followed by completion of all other steps and return to the start of the next adsorption step.

Declassification - A resin mixing operation performed on a resin bed. This is used to evenly distribute the nitrate adsorbed on a bed of resin to prepare the bed for the following adsorption step. The operation is performed by using an uneven backwash technique developed at the McFarland, California EPA demonstration plant.

Degradation - The physical or chemical reduction of ion exchange properties due to type of service, solution concentration used, heat, or aggressive operating conditions. Some effects are capacity loss, particle size reduction, excessive swelling, or any combination of the above.

Down Flow - Conventional direction in which water and brines flow through an ion exchange bed during processing, inlet at the top, outlet at the bottom of the bed or column.

Dumping - Refers to removal of large amounts of nitrate, or any other substance, from an ion exchange column as detected by its appearance in the effluent in concentrations exceeding its concentration in the feed water. Nitrate dumping from a resin can occur if sulfate is present in the feed water and if the adsorption cycle is run beyond nitrate breakthrough. This occurs because sulfate ion is able to displace nitrate from the downstream portions of the resin column where nitrate is absorbed. Nitrate dumping does not occur if nitrate selective resins are used or if the concentrations of sulfate and chloride are high such as in regeneration brines.

Effluent - The solution which emerges from an ion exchange column. Synonymous with PRODUCT or TREATED water. The regenerant emerging from the column after regeneration is referred to as the ELUENT or ELUATE.

Elution - The stripping of ions or complexes from an ion exchange material by passing through the bed solutions containing other ions at specific known concentrations.

Empty Bed Contact Time (EBCT)- The time it would take for water to pass through the volume of the column occupied by the resin bed. It is calculated as though the resin is not present, hence "Empty Bed" Contact Time. For example if the one Bed Volume is 700 gallons and the flow rate is 350 gal/min, the EBCT is 2 minutes. Or 0.5 BV per minute.

Entering Ion - The ion involved in an ion exchange reaction which is adsorbed by the resin and which displaces a different ion.

Equivalent - See Equivalent Weight.

Equivalent Weight - The sum of the atomic weights in a chemical formula (the formula weight) for an ion divided by the absolute value of the charge on the ion. This concept is used to compare relative weights of ions, which can interchange or combine with each other as expressed in a balanced chemical equation. For example, the equivalent weight of nitrate ion is 62. The equivalent weight of chloride ion is 35.5 and the weight of sulfate ion is 48. If the weights are expressed in grams, 35.5 grams of chloride ion is chemically equivalent to 62 grams of nitrate ion (or 48 grams of sulfate ion) in an ion exchange reaction. The equivalent weight of sodium ion is 23; thus, 23 grams of sodium is combined with 35.5 grams of chloride ion in 58.5 grams of NaCl. MILLIEQUIVALENT WEIGHT is EQUIVALENT WEIGHT expressed in milligrams of ion per liter. One equivalent weight of nitrate ion is 62 grams. One milliequivalent weight of nitrate ion is 62 mg/L.

Exhaustion - The state of the resin at the end of the adsorption step and when the capacity of the resin for adsorbing the ion of interest is used up. The resin is exhausted.

Fouling - Any deposit or concentration of foreign material on or in an ion exchange material which interferes with the chemical and physical processes. Typical foulants are lubricating oil from pump lubricants, clays, silts, bacteria, algae etc. Fouling can cause reduced efficiency, channeling, loss of resin in back wash and many other plant malfunctions.

Freeboard - The space provided above the resin bed in a vessel or column to accommodate the expansion of the resin bed during the backwash cycle.

Headloss - The loss of liquid pressure head resulting from the passage of water through a bed of ion exchange material.

Hydraulic Loading Rate - The volume of water passing through a given quantity of resin within a given time. Flow rate is usually expressed in terms of gallons per minute per square foot of bed cross sectional area and as gallons per minute per cubic foot of resin. In nitrate treatment these can be 10 to 15 gals/min/sq ft and 3 to 5 gals/min/cu ft.

Influent - The untreated water entering an ion exchange column.

Interstitial Volume - The space between the particles of an ion exchange material in a column or an operating unit (see Void Volume).

Leakage - The presence of a substance, usually nitrate, in the treated water exiting from an ion exchange column before its breakthrough has occurred giving the impression that the substance has "leaked" through the resin bed. Leakage of nitrate from a resin bed is purposely allowed, but controllable, in all process designs because it is virtually impossible to regenerate the resin completely. Leakage is different from Breakthrough.

Leaving Ion - The ion involved in an ion exchange reaction, which is displaced from the resin by a different ion.

Milliequivalent Weight - One one thousandth of the amount in one EQUIVALENT WEIGHT. See EQUIVALENT WEIGHT.

Nitrate Selective Resin same as NITRATE-TO-SULFATE SELECTIVE (NSS) RESIN An ion exchange resin which will adsorb nitrate ions in preference to sulfate from water. The following generalizations obtain: All resins are selective for nitrate over chloride, but may not be NITRATE SELECTIVE. Only special resins (NSS RESINS) are selective for nitrate over sulfate in the range of drinking water concentrations. Also, all resins are selective for nitrate over sulfate at brine concentrations.

Nitrate Concentration - The units of nitrate concentration in the protocol and verification test plan documents must be clearly stated and defined as such in the introductory sections. Nitrate will be expressed as milligrams of the element nitrogen (N) per liter of solution (As opposed to milligrams of NO_3 per liter). The conversion factor is 4.423 times mg-N/L = mg- NO_3/L. California prefers the use of mg- NO_3/L as the expression of nitrate concentration. (Note: The N as the symbol for nitrogen should not be confused with the N representing solution "Normality" which is the expression of concentration in terms of the number of chemical equivalents of a substance per liter of solution.)

Operating Cycle - A single completion of all steps in the process consisting of adsorption, regeneration, rinsing, back wash, stand by.

Osmotic Stability - The ability of an ion exchange material to resist physical degradation due to volume changes imposed by repeated, alternate application of dilute and concentrated solutions.

Partial Regeneration - The regeneration process which is terminated before all of the ions are removed from the bed and replaced by regenerating ions. This is practiced in nitrate removal cases because higher regeneration efficiency can be realized. Regeneration efficiency decreases rapidly with decreasing amounts of applied regenerant. In practical cases for nitrate removal, even complete regenerations will leave some nitrate on the bed because of the strong tendency for nitrate to remain attached to the resin. Processes, which require removal of all nitrate ions (or nearly all), from the bed will require very large amounts of salt and generate large quantities of wastewater.

Physical Stability - The ability of an ion exchange material to resist breakage caused by mechanical manipulation.

Presaturant - The ion adsorbed on the resin by saturating the resin with the ion prior to a column operation. In nitrate treatment the PRESATURANT is chloride ion

Preferred Ion - The one of at least two different ions having equal concentrations that will be adsorbed on the resin to the greatest extent.

Recontamination - The process of removing a contaminant from one point in a water supply and then adding the same and/or other contaminant into the supply at a different point. A problem encountered in ion exchange systems. For example, by incomplete rinsing of resin beds nitrate, chloride, bicarbonate, sulfate and sodium can be added to the supply. Also, by running beds beyond their bed life, nitrate ion can be "dumped" from the bed into the treated water.

Regenerant - The solution used to convert an ion exchange material from its exhausted state to the desired regenerated form for reuse.

Regeneration - The displacement from the ion exchange material of the ions removed during the adsorption (service) run. In nitrate treatment, the regeneration is performed by passing a sodium chloride brine slowly through the bed.

Regeneration Level - The amount of regenerant chemical used per unit volume of ion exchange bed, commonly expressed as lb/ft^3. Also See SALT LOADING.

Resin - Refers to a synthetic ion exchange material. Resins are composed of polymeric water insoluble organic substances, which have been chemically treated to contain chemically charged ionic sites. In nitrate treatment, the resin contains quaternary amino groups, each bearing a positive charge. The quaternary amino groups contain either trimethyl (Type 1), trihydroxyethly (Type 2), or tributyl (NSS, Nitrate Selective) structures.

Rinse - The passage of water through an ion exchange material to remove excess regenerant. Some rinsing action also occurs during BACK WASH and DECLASSIFICATION.

Salt Loading - Salt loading is the amount of regenerant applied to a resin during the regeneration step. It can be expressed in terms of pounds of NaCl per cubic foot of resin, grams of salt/L of resin, equivalents of salt/L of resin or, more conveniently, in terms of bed volumes of brine (volumes brine/ volumes resin) having a specified concentration of NaCl.

The latter method allows expression of salt loading as Bed Volumes (BV) of 1 equivalent NaCl/L of brine. This is equivalent to a salt loading of 3.65 lb. of NaCl/cu. ft. of resin (Derived from 58.5 g/L x 3.781 gal/cu ft/453.6 g/lb). This method allows a direct comparison to the resin capacity expressed in chemical equivalents. For example 1.3 BV of regenerant at 1 equivalent of salt per liter will be chemically equivalent to 1 liter of resin having an exchange capacity of 1.3 equivalents per liter of resin.

The expression of salt loading in terms of BV of brine is a practical consideration. Operation of an ion exchange plant requires some metering of the salt during the regeneration step. This is conveniently accomplished by metering the volume of a saturated brine. The amount of salt can be measured from the volume and brine concentration as determined from specific gravity tables. Salt loading can be expressed in terms of BV of brine in weight percent NaCl. For example, six percent brine contains 3.901 lb/ft^3 and is slightly more concentrated than a brine containing one equivalent of NaCl/L. Salt loading expressed in BV of 6% brine is 1.068 (or 3.901/3.65) times greater than salt loading expressed in equivalents NaCl/L.

Volumetric and Salt Loading Interconversion Factors @ 60°F (Note: 1 BV = 1 L)

Volumetric Conversions:

1 Volume of (6% brine) = 1.068 Volumes of (1 equivalent NaCl/L)

Therefore: 1 BV of (6% brine) = 1.068 BV of (1 equivalent NaCl/L)

1 Volume of (1 equivalent NaCl/L) = 0.936 Volumes of (6% brine)

Therefore: 1 BV of (1 equivalent NaCl/L) = 0.936 BV of (6% brine)

1 Volume of (1 equivalent NaCl/L) = 1 Volume of (5.61% brine)

Therefore: 1 BV of (1 equivalent NaCl/L) = 1 BV of (5.61% brine)

Salt Loading Conversions:

1 BV of (1 equivalent NaCl/L) = 3.65 lb NaCl/cu ft resin

1 BV of (1 equivalent NaCl/L) = 58.5 g NaCl/L resin

1 lb NaCl/cu ft resin = 16.03 g NaCl/L resin

Service Run - The step in the operating cycle during which the water is being treated; i.e., nitrate exchange for chloride. The same as an ADSORPTION RUN.

Set Points - The values of settings, which control the process. These are, Length of Bed Run, Amount of Brine, Amount of Rinse Water, Amount of Backwash and Declassification, Percent Treated in Blend (see "Percent Blend" definition on next page). All are set by controller devices reading totalizing flow meters. If controlled on a time basis, report BOTH time and totalized flow as the setting.

Slow Rinse - That portion of the rinse which follows the regenerant solution and is passed through the ion exchange material at the same flow rate as the regenerant.

SR-6 Resin - A manufacturer's product identification for a strong base ion exchange resin which has three butyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin. The resin is an NSS resin and is highly nitrate selective.

Strong Base Resin - A resin that contains quaternary ammonium ions as the functional group in an ion exchange resin. These groups provide the positive charge sites, which adsorb and hold negatively charged ions such as nitrate, chloride, and sulfate ions.

Throughput Volume or VOLUME TREATED or BV TREATED- The amount of water passed through an exchange bed during the service run before.

Type 1 Resin - A strong base resin which has three methyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin.

Type 2 Resin - A strong base resin which has one hydroxyethyl and two methyl groups as part of the quaternary ammonium ions in a styrene divinyl benzene resin.

Up Flow - The operation of an ion exchange unit in which solutions are passed in at the bottom and out at the top of the vessel.

Void Volume - See INTERSTITIAL VOLUME.

Voids - The space between the resinous particles in an ion exchange bed.

The following terms were defined in *EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies* (Chapter 1) and will be used in this testing program.

Financing Cost - The cost to finance the purchase of the equipment based on the rates of inflation, borrowed capital, and amortization period. To standardize cost calculations, these factors will be set by the NSF/EPA.

Untreated Water - The raw water that is delivered or available at the site for treatment by the equipment for nitrate removal.

Treated Water - The water stream that has passed through treatment (and post treatment) and is available from the equipment either for direct discharge into a distribution system or for blending with untreated water before injection into the water supply system. The PRODUCT WATER is the water that is injected into the distribution system. It contains TREATED WATER and can also contain UNTREATED water if a portion bypasses the ion exchange vessels.

Blended Water - A mixture of treated and untreated water that is suitable for injection into the distribution system. This is the same as the distributed water. The blending system may or may not be a part of the equipment.

Percent Blend - The percent of treated water that is in the blend. Thus a 75 percent blend will refer to water composed of 75 percent treated and 25 percent untreated water. A 100 percent blended water is equal to treated water.

Maximum Distribution Flow Rate - The maximum flow rate (gallons per minute) of blended (distributed) water which the equipment can cause to be injected into the distribution mains on a continuously operating basis with a nitrate level at or below 80 percent of the MCL.

Maximum Treatment Flow Rate - The maximum flow rate (gallons per minute) of treated water which the equipment can produce on a continuously operating basis while maintaining the Maximum Distribution Flow Rate.

Plant Factor - A factor used in computing water treatment cost. It is the fraction of total time the plant operates or is projected to operate during its period of amortization. NSF will determine this factor to standardize cost computations.

Percent Waste - 100 times the ratio of the annual wastewater production to the annual amount of treated water production.

7.0 TASK 1. PREPARATION, COORDINATION AND START UP

7.1 Introduction

A meeting will be held between the manufacturer and the NSF qualified testing organization regarding the tasks and scheduling of tasks described in the NSF approved PSTP. This task will also include the plant start up if it is not already in operation.

7.2 Objective

The objective of the meeting will be to provide an opportunity for the manufacturer and the field testing personnel to reach a common understanding of the objectives and execution of the testing plan and provide an opportunity to clarify any areas of concern by either party. Initial start up data will be collected if the plant is not already in operation. A tour of the test site can be a helpful part of this meeting. Other personnel associated with the plant should attend if possible, such as the owner/operator and the plant operator and local or state health officials.

7.3 Work Plan

The following items will be covered in this meeting:

- The manufacturer will review the material that was included in the PSTP; in particular, the plant design, operations, outstanding and distinguishing features and especially the treatment objectives and other secondary performance goals claimed for the plant performance. The treatment objectives will be reviewed as stated in the PSTP.

The objectives must include the following:

- The nitrate levels in blended water will be 80 percent of the MCL or less at all times. No nitrate level should occur higher than this level.
- Any secondary standard for any other constituent will not be exceeded at any time.
- Any other objective the manufacturer wishes to include. It is desirable that objectives such as the following be included.
    - a) The BUF will average less than 5.0 during the operation period,
    - b) The amount of wastewater produced during the operation of the plant will be less than 1.5 percent of the blended water, or

c) The Operations and Maintenance (O & M) cost of producing blended water will be under 10 cents per thousand gallons.

The Field Testing Organization will use diagrams, drawings, plans or on site locations to: Point out the physical limits of the system to be tested, the source water supply, the blending facility and the distribution lines.

- Point out the location of the plant control mechanism, pressure gauges, all control valves, their function, and all instrumentation.
- Point out the alarm system and alarm/shutdown devices and their functioning.
- Point out all safety valve and cross-connection control devices and illustrate how they are tested.
- Walk the testing personnel through the complete operation of the plant, describe the set up and start up procedures and indicate positions of sampling valves and any automatic data collection and recording devices. Indicate where set points are set and what their current values are.

The Field Testing Organization will:

- Review the Schedule for the Testing Plan
- Prepare the Product-Specific Test Plan
- Present the Evaluation Criteria. The plant will be evaluated based on its performance regarding the following:
  - Ability to consistently meet water quality treatment objectives
  - Ability to meet other stated objectives regarding water quality, plant efficiency and wastewater production etc.
  - Sufficiency of cross-connection devices and their reliability
  - Ability to produce product water with acceptable and constant nitrate levels
  - Material balances for water, nitrate, chloride, and sulfate must be established during plant operation test periods
  - Wastewater production
  - Plant Efficiency (BUF)
  - Time and effort required for plant set up and start up
  - Operator time and skills required
  - Maintenance time required
  - Quality of parts and construction
  - Reliability of operation.
  - Functioning of safety devices and alarms
  - Reports of plant inspections

- Quality of the plants data collection and reporting system.
- Costs

- Observe and participate in the plant start up procedures. Record the steps of the start up procedure, note initial set points for the following:

  1) amount of water treated by a single vessel,
  2) amount of brine set for each regeneration,
  3) amount of water used per each rinse,
  4) amount of water used for each backwash, and
  5) percent blend.

The initial set points will be set at the recommendations of the manufacturer.

7.4 Schedule

Before the meeting is held, the Field Testing Organization will provide the Manufacturer with the PSTP containing the Test Plan and any other drawings, plans, site plans operation manuals and similar helpful materials. Sufficient time should be allowed prior to the meeting to allow the testing organization to develop their testing procedure plans and methods to quantify the evaluation criteria. The orientation meeting will be held immediately prior to the first field test period.

8.0 TASK 2. INITIAL PLANT CHARACTERIZATION

8.1 Introduction

Tests will be conducted to get an initial characterization of the plant and to determine if the water quality objectives are being met early in the program. These field tests and data collection activities will be conducted at the start of the testing program to provide a base line for other field tests conducted in Task 3 and at the termination of the test program to see if any operating characteristics change over the test period.

8.2 Objective

The objectives of this task are to establish the initial plant performance characteristics and provide benchmark data which can be referred to for evaluation of long term changes in plant performance when future similar data are obtained. The tests can be repeated at intervals throughout the test program if desired but will be repeated at the end of the test plan.

8.3 Work Plan

At the beginning of the test period, data will be collected from the operating plant, which will characterize the plant performance (e.g., regeneration level, flow, etc.). These tests will be started only after the beds have gone through several cycles at the same settings to allow the plant to reach a steady state of operation. Steady state will be confirmed from nitrate measurements by achieving a material balance of nitrate removed from the treated stream and nitrate removed in the waste brine.

From the following chemical analyses, it shall be determined if the water quality performance objectives are being achieved. If they are not, the manufacturer shall be notified, as they may change the settings on the plant. If changes in settings are significant, the tests should be suspended to allow the beds to reach a steady state. It shall be determined if the objectives are being met from the following analyses:

Samples of Feed Water, Treated Water, and Blended Water will be collected for chemical and biological analyses. The following must be included in the analyses.

- Total Alkalinity
- Bicarbonate
- Chloride
- Nitrate
- TDS
- Electrical conductivity
- Fe
- Mn
- Temperature
- TOC
- HPC
- Algae
- Sulfate
- Sodium
- Calcium
- pH

All analytical data should be reported as mg/L and equivalents per liter of the ion. The nitrate will be reported as both mg-N/L and mg-NO_3^-/L.

The following data shall be measured or observed and recorded from the operating plant.

- Record all set points: Length of Bed Run, Brine, Rinse, Back Wash, Percent Blend, (in units of time, flow rate and total gallons for each)
- Number of vessels in service, regeneration, and standby
  - Flow rate of treated water.
  - Flow rate of blended water.
  - Amount of regenerant (pounds of salt) being used for each regeneration.
  - Inspect the plant equipment including piping for any leaks and scale build up.
  - With help from the operator, at least one vessel should be opened and inspected for piping integrity, dirt, bacterial slime, algae, oil or other foreign material.
  - Estimate the amount of resin in each vessel either by direct inspection or through site glass observations. Use external vessel measurements, corrected for internals and wall thickness. Record the values of one Bed Volume for each vessel.
  - Take a small sample of the resin for resin tests. See section on resin tests below.

While one vessel is in service, the effluent history curves shall be obtained for each major ion (bicarbonate, chloride, nitrate, sulfate) from the start of service to its termination. This is done by collecting grab samples of the treated water at a sample port at or near the exit end of the vessel. (Be sure no other water is mingled with the treated water at the sample point). Flow meter readings and time of collection of each sample or take readings shall be obtained directly from a cumulative flow meter to determine BV of water treated by the vessel at the time of sample collection. At least 20 samples should be collected. The data shall be plotted as mg/L of each ion vs. BV of water treated. The data shall be plotted mg-N/L vs. BV treated.

Any changes in these curves which have occurred since the last measurements shall be noted.

While one vessel is in regeneration, the Field Testing Organization shall:

- Obtain a sample of the undiluted brine and a sample of diluted brine.
- Obtain data for a brine elution curve. This is done by taking grab samples at appropriate intervals of the brine exiting the regenerating vessel. Approximately 20 samples should be taken. Each sample should be analyzed for the four major ions and electrical conductivity. Also from a brine inlet flow meter, determine the amount of brine entering the vessel. Plot the concentration of each ion and the electrical conductivity versus the amount of brine entering the vessel.
- Continue the sample collection after the regeneration from the exit end of the vessel during the rinse period. These samples should be analyzed for the four major ions and the electrical conductivity. During the rinse period, record the amount of rinse water used each time a grab sample is taken. Plot the concentration of each ion and the electrical conductivity versus the amount of rinse water used.
- Estimate the amount of sodium chloride added to the water supply as a result of regeneration and rinsing. This is done as follows: When the above vessel is returned to service, take grab samples of the product water at one minute intervals for ten minutes to twenty minutes. Analyze each sample for the four major ions and the electrical conductivity. Plot the concentration of each ion and the electrical conductivity versus the amount of water treated.
- During the regeneration and rinsing process, record flow meter readings to determine the total amount of waste water produced.
- From the above collected data, make plots (as already mentioned) and calculations as follows:
  - The effluent history curves
  - The brine elution curves
  - The rinsing curves
  - The amount of resin in one BV
  - The amount of salt applied per regeneration in pounds per cubic foot of resin
  - The amount of product water produced per service run
  - The amount of rinse water used
  - The total amount of wastewater (brine, rinse, back wash) produced per vessel per cycle
  - The gallons of saturated brine used per each regeneration
  - The percent blend

  - The percent of wastewater produced
  - The brine use factor, BUF
- From the data collected, determine if the water quality objectives are being met. If they are not, notify the manufacturer. The set points may require readjustment.
- The general appearance and condition of the plant will be noted. Note the general appearance of equipment, new construction etc.

Any changes in this data from the measurements made during the previous test periods shall be noted.

- Resin Tests. Samples of resin will be regularly tested. These tests may be conducted by the testing organization or may be submitted to the resin manufacturer who may do such tests on a routine basis for customers using their products. Tests include, bead integrity or breakage tests done by counting the number whole and partial beads, capacity determinations, and fouling tests made by observation of foreign material and chemical analyses.

8.4 Schedule

The above tests will be conducted at the beginning of the field test period after the plant has reached steady state performance. The tests will be repeated at the end of the field testing period and compared to previously collected data. The field testing organization should coordinate the timing and nature of the tests with the plant owner/operator to be sure the plant is being operated and the proper tools are available for opening the ion exchange vessels for internal inspections.

9.0 TASK 3. DAILY TESTING AND DATA COLLECTION

9.1 Introduction

The plant will be operated and tested on a daily routine basis during the 60-day testing period. Data will be collected to evaluate operator requirements and activity and reliability of equipment.

9.2 Objective

The objective of routine daily testing is to make close observation of plant operation and to provide experience and data to evaluate operational characteristics of the plant such as, ease and reliability of operation, start up and shut down routines, noise production and alarm setting and resetting, reliability of instruments, flow meters, valve operations and similar day to day operator tasks.

9.3 Work Plan

One or more Daily Plant Data Forms will be prepared to include specific data obtained directly from the plant's instrumentation, flow meters and gauges. Each manufacturer will provide a sufficient number of flow meters and instruments for these measurements. Data should be collected daily as described below.

The data which should be collected daily, at the same time each day, includes the following:

- Cumulative flow and gpm of source water and cumulative flow and gpm of treated water
- Cumulative flow and gpm of blended water
- Cumulative flow and gpm of wastewater
- Salt Inventory Estimate

For each ion exchange vessel collect the following data:

- Cumulative flow and gpm of treated water
- Cumulative flow and gpm of brine
- Cumulative flow and gpm of rinse water
- Cumulative flow and gpm of back wash water

Grab samples of raw and finished water streams will be collected once per week for nitrate, chloride, sodium, sulfate, alkalinity, total hardness, calcium hardness, iron, manganese, color, total organic carbon, algae, heterotrophic plate count and electrical conductivity. The samples shall be sent to an analytical laboratory for analysis to reduce cost and increase accuracy. These samples may also be duplicated with on-site field testing kits for immediate results during treatment process adjustments, particularly with the rinse water stream. On-site determination of bed exhaustion and regeneration using conductivity meters is recommended.

Record all instrumentation readings for each stream. Readings will be made each hour from 8 a.m. to 5 p.m. from each vessel.

For each operating ion exchange vessel, the following will be measured and recorded:

- The number of gallons of treated water produced each time the vessel is in Service Mode.
- The number of gallons of brine, and its concentration, used each time the vessel is in regeneration mode as measured at the point of entry into the vessel.
- The number of gallons of rinse water used each time the vessel is in Rinse Mode.
- The number of gallons of back wash water and declassification water used each time the vessel is in Back Wash.

Sufficient data must be collected to enable the calculation of a material balance of total water entering and leaving the vessel and the total solid regenerant entering and leaving the vessel per each cycle.

Summaries of the data collected during the eight hour period will be made and will include the following:

- Total daily water treated by the plant
- Total daily untreated water blended with treated water
- Total daily blended water sent to distribution

- Percent blended water (i.e. Percent of the blended water that is treated.)

Daily summaries for each vessel will include:

- Number of completed cycles
- Total daily water treated
- Total rinse water used
- Total back wash water used
- Total pounds of solid regenerant used
- Total water used to make the regenerant solution

From the above data and chemical analyses, the following will be estimated:

- Material balances for salt and water
- Material balances for nitrate, sulfate, bicarbonate, chloride
- Average untreated water nitrate
- Average treated water nitrate
- Average blended water nitrate
- Amount of salt entering the water supply as a result of incomplete rinsing.
- Brine Use Factor (BUF). Include both completed and incomplete cycles.
- Percent wastewater produced (Percentage of the total water supplied for treatment AND blending that becomes wastewater)
- Cost of regenerant chemical per 1000 gallons of water distributed

9.4 Ion-Exchange Removal Efficiencies

9.4.1 Operational Data Collection

Removal efficiencies of nitrates from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and pressure and finished water flow and pressure shall be collected each hour from 8 a.m. to 5 p.m. per day from each vessel. Table 1 is an example of on-line readings for a daily operational data sheet for an ion-exchange system for 3 shift readings. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific.

TABLE 1: Daily Operations Log Sheet for an Ion-Exchange System

Date:

Parameter	**Shift 1**	**Shift 2**	**Shift 3**
Time			
Initial			
Raw Water			
Q_{raw} (gpm)			
Nitrate (before pretreatment) (mg/L)			
Nitrate (after pretreatment) (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm), (before pretreatment)			
TDS (mg/L)/ Conductivity (μmhos/cm), (after pretreatment)			
P_{raw} (psi)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Ion-exchange Vessel			
Q (gpm)			
Nitrate (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm)			
P (psi)			
Finished			
Q_{fin} (gpm)			
Nitrate (mg/L)			
TDS (mg/L)/ Conductivity (μmhos/cm)			
Regeneration (@ what % brine or NaCl)			
Q_{regen} (gpm)			
TDS (mg/L)/ Conductivity (μmhos/cm)			

Table 2 presents operational sampling and sample frequency for on-line, field and laboratory analysis. On-line meters and probes should be available for instantaneous recordings. Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 2 at a certified laboratory, except for nitrates, which will be monitored prior to start-up and then weekly. Field sampling should be performed weekly, if samples can not be analyzed in the field then they should be sent to the certified laboratory once a week. Power costs for operation of the ion-exchange equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

9.4.2 Feedwater Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of ion-exchange performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished nitrate concentrations over time for each 60-day test period.
- Plot graph of removal of nitrate over time for each 60-day test period.

TABLE 2: Operating and Water Quality Data Frequency for Ion-Exchange Processes

Parameter	Frequency		
Raw Water Flow	Daily		
Finished Water Flow	Daily		
Regenerant Flow	Daily		
Raw Water Pressure	Daily		
Finished Water Pressure	Daily		
Regenerant Pressure	Daily		
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average		
Hours Operated Per Day	Daily		
Hours Operator Present Per Day	Monthly Average		
Power Costs (kWh/Million Gallons)	Monthly		
Independent check on rates of flow	Weekly		
Independent check on pressure gages	Weekly		
Verification of chemical dosages	Monthly		
Feed Water and Finished Water Characteristics	**On-line**	**Field**	**Lab**
Nitrate	Continuous	Daily	Weekly
Temperature	Continuous	Daily	---
pH	Continuous	Daily	---
TDS/Conductivity	Continuous	Daily	Weekly
Chloride	---	Weekly	Weekly
Sulfate	---	Weekly	Weekly
Sodium	---	Weekly	Weekly
Total Hardness	---	Weekly	Weekly
Calcium Hardness	---	Weekly	Weekly
Total Alkalinity	---	Weekly	Weekly
Iron	---	Weekly	Weekly
Manganese	---	Weekly	Weekly
True Color	---	Weekly	Weekly
Total Organic Carbon	---	---	Weekly
Algae, number and species	---	---	Weekly
Heterotrophic Plate Count	---	---	Weekly

10.0 TASK 4. CROSS-CONNECTION AND MECHANICAL INSPECTION

10.1 Introduction

Professionals will participate in the evaluation and testing program. Testing and inspection of all of the cross-connection prevention devices will be conducted. A professional will also inspect and test all meters, gauges, valves, instrumentation, motors, compressors and similar devices for proper placement and functioning.

10.2 Objective

The objective is to evaluate mechanical, safety and qualitative features of the plant including cross-connection control devices, quality of components, to test cross-connection prevention devices and operation. Assistance of a registered mechanical engineer and a certified cross-connection specialist will be required.

10.3 Work Plan

A Physical Testing and Inspection Schedule and Checklist will be prepared. The checklist will contain the location of all cross-connection prevention devices, air gaps, check valves, block and bleed valves, back flow preventers and similar devices and all electrical and mechanical equipment. The testing will be performed over a time interval to evaluate effects of long term usage.

A site visit by a person certified for inspection and testing of cross-connection prevention devices will be made. A separate report will be prepared by the certified inspector after completing the two following steps.

- All cross-connection prevention devices included in the plant and blending system will be inspected and tested. A piping plan will be supplied and all such devices will be indicated for easy location. The detectors to set off alarms or indicators in event of failure of these devices will also be inspected and tested by simulating failure conditions.
- The piping plan will also be inspected to locate potential trouble spots, where valve leakages, loss of pressure or back siphoning could result in the transfer of waste nitrate and waste salt into the drinking water supply and where safety would be enhanced by providing additional safety devices.

An engineer with specific experience in dealing with ion exchange field equipment will inspect the brine pumps, valves, controllers, compressors, motors, probes, gauges, flow meters, alarms, level controllers, electronic controllers, vessels, storage tanks and similar items on the checklist of mechanical electrical equipment for functional operability, wear, leaks, corrosion, scale build up, and any damages and general suitability. The accuracy and range of gauges and flow meters should be tested or estimated from experience and manufacturer's literature. The performance of valves should be inspected and valve manufacturer data sheets critically reviewed to determine if sufficient closure and sealing is accomplished for the application and for low maintenance operation. The valve type should be noted and if the location and function is appropriate for the type of valve being used. Particular attention should be paid to devices which are subject to corrosion and wear such as brine pumps, other brine system parts and waste brine pumps and storage tanks. All findings will be included in a special reports prepared by the certified mechanical engineer listing those items inspected and an assessment of the condition and an estimate of the lifetime of the item if current usage is extended. The reports should include any specific items, which would require high maintenance, or be particularly costly. The reports will also include an estimate of annual maintenance cost to maintain, service and replace all mechanical and electrical items to allow the plant to operate without interruption.

10.4 Schedule

As stated above, two inspections will be performed; the first inspection will occur at the start of the testing program and the second inspection will be performed after the plant has been in operation for approximately one year. Each inspector will prepare reports after the first inspection and after the second inspection.

11.0 TASK 5. OPERATION EVALUATION AND EXAMINATION OF RECORDS

11.1. Introduction

The direct collection of field data by the Field Testing Organization is considered in this test plan as PRIMARY data. Data collected by others and provided to the testing organization is considered to be SECONDARY data. This task deals with the latter. This other data can be collected by the owner/operator as a part of the regular operating procedures of the plant. This data can be valuable in the evaluation testing program to show consistency of plant performance and to fill in any data gaps which may occur during the brief test periods of primary data collection.

11.2 Objective

The objective is to make an evaluation of the reliability and accuracy of the plant's data collection, management and reporting system used in the regular or routine plant operation and maintenance. If the data collection are found accurate, they can supplement the primary data obtained by the NSF Qualified Testing Organization and will support the evaluations made using primary data. These data can be valuable in the evaluation testing program to show consistency of plant performance and any data missed related to rare incidences of operating and maintenance problems. The secondary data will be obtained with cooperation of the owner/operator from the daily operating logs and records kept by the owner/operator and other reports on plant operation.

11.3 Work Plan

Preparation. At the beginning of the testing program, the testing organization personnel will meet with the plant owner/operator and review the daily or weekly plant operating records and logs used for normal plant operation. The frequency, type, location of recorded data (notebooks, instrument recordings, lab reports etc) should be noted. The records should include the data listed below for easy recall. If appropriate and agreeable, the owner/operator may be requested to provide data on special forms or modem transferable computer files provided by the testing organization.

Secondary Data. The data which should be reviewed will be the following:

- Daily and Weekly data:
  - Total gallons of blended water delivered into the distribution system
  - Total gallons of water treated for nitrate removal
  - Total untreated gallons blended with treated water
  - Percent treated in blended water
  - Total gallons of saturated brine used in the regenerations
  - Total pounds of salt used
  - Total number of regenerations performed
  - Total amount of wastewater produced
  - Percent of water delivered to plant for treatment and blending that becomes wastewater.
- Daily and Weekly records of :
  - Nitrate in treated water
  - Nitrate in untreated water
  - Nitrate in blended water
  - Electrical conductivity of treated water
  - Equipment and parts deliveries
  - Salt deliveries to the plant
- Number of occurrences of the following will be recorded:
  - Nitrate levels in distributed water exceeding 80 percent of the MCL value
  - Electrical conductivity of rinse water exceeding normal levels
  - Alarms and their cause
  - Normal maintenance procedures
  - Unscheduled maintenance activity
  - Unscheduled plant shut downs and their causes

Use of Secondary Data. The above data will be reviewed by the testing organization and a Summary of Secondary Data will be prepared. The following will be estimated on a daily or monthly basis from the Secondary Data:

- Material balances for salt and water

- Average untreated water nitrate
- Average treated water nitrate
- Average blended water nitrate
- Amount of salt entering the water supply as a result of incomplete rinsing
- Brine Use Factor (BUF). Include both completed and incomplete cycles
- Percent wastewater produced. (Percentage of the total water supplied for treatment AND blending that becomes the wasted water.)
- Cost of regenerant chemical per 1000 gallons of water distributed
- Agreement or disagreement with primary data and conclusions based on primary data

An evaluation of the plant's data collection, recording, management and reporting system will be made by comparing the data with that obtained by the NSF Qualified Testing Organization. A general evaluation of the data collection and reporting system should also be made from the standpoint of accuracy, sufficiency, and reliability. Is the system giving enough data to tell if the manufacturer's performance objectives are being met? Is too much data being obtained and is the interpretation confusing? Are alarms recorded? Is there enough and accurate data for the operator to determine if the plant is operating efficiently? Is the data recall system reliable and is the data easy to find and well organized?

11.4 Schedule

The secondary data for this task will be the normal operating data collected by the owner/operator throughout the 60-day test period concurrent with the test program. The secondary data will be made available to the testing organization on a weekly basis. If additional secondary data are required, the testing organization will make a request for it at the initial meeting.

12.0 TASK 6. CONTINUOUS NITRATE ANALYSIS AND MONITORING

12.1 Introduction

Consistency, reliability and stability of the operation of an ion exchange plant to produce water of acceptable quality should be tested on a continuous basis, during a 60 day uninterrupted period in the testing program. Consistency and reliability relate to the long-term operation, while stability relates to absence of spiking and fluctuations which may occur during a relatively short term and which may cause plant disruptions or maladjustments. Nitrate analysis by occasional grab samples say one or two per day, is not frequent enough to detect fluctuations which may occur in the product water or other streams.

Fluctuations or swings in nitrate levels may be expected to some extent because of the cyclic nature of the ion exchange processing. When a resin bed is placed into service, the water quality may change throughout the bed run up to the regeneration. Any given bed may undergo up to about five regenerations per day. For example, after regeneration, some nitrate remains on the bed. If the bed is improperly rinsed or declassified, high nitrate spikes can occur at the start of the run. Also, if nitrate increases during the run, or the end of run set point malfunctions or is set too long, an over run may occur which is the cause of "dumping" high nitrate into the product water. Malfunction of equipment during regeneration or rinsing can also cause high nitrate levels to rapidly rise in the product when the vessel is returned to service. Malfunctioning, slow operating, or stuck valves may also cause similar problems.

If the fluctuations become extreme the plant is described as "unstable" and can be the cause of two major problems.

1) The water quality standard and treatment objective may be violated, and
2) The plant may be thrown into an upset, which could cause serious water supply and water quality violations.

These upsets would be caused by set point changes which either the instrumentation or the operator is basing on grab sample analyses, which are not typical or average. For example, if a high nitrate analytical result is obtained, an automatic instrument may cause a vessel to go off line and regenerate prematurely. This in turn can cause a water supply failure and an excessive use of salt.

The above plant malfunctions can best be detected by doing continuous, on stream analysis. Strictly speaking, the best and most reliable analyzers can only do grab samples in rapid succession. Ion chromatography instruments or instruments using ultraviolet detectors can make analyses at a frequency of about 12 analyses per hour. One or more of these instruments should be employed in this testing procedure.

12.2 Objective

The objective is to test the consistency, reliability and stability of the plant to produce water meeting the water quality nitrate objectives. This will be done by monitoring the nitrate levels in three different streams and one monitoring stream by using automatic, continuous, on site, 24 hour per day sampling and analysis for a period of 60 days.

12.3 Work Plan

Preplanning: The most active season of nitrate plant operation should be determined prior to the start of the testing program. Some plants operate only during summer periods of high water demand others are most active during the growing season when fertilizers are used. A site plan will be prepared to show, housing, location of equipment, benches, sinks, sample taps, sample lines, electrical power and drainage. Location of computer and/or recording instruments will be shown. If modems are used, show locations of telephone access lines. More than one analyzer may be needed.

Set Up: Allow one month for set up and testing the analyzer. The nitrate analyzer will be set up in an enclosed area at the plant site and separate sample lines will be connected to supplies of treated, untreated, blended, and a monitor supply, for delivery to the analyzer. The monitor supply will be provided from a batch container and will be prepared from chemical standards having a nitrate composition of 10 mg N/L and the approximate composition of bicarbonate, chloride and sulfate in the product water. Flow of sample will be regulated or delivered via timed sample pumps to prevent sample contamination from other water sources. A calibration standard will be used as recommended by the manufacturer of the analyzer.

Operation of Analyzers: Continuous nitrate analyses will be performed for a period of 60 days on each of the three streams of blended water, treated water and untreated water. The analyzers will be programmed to sample each stream in succession. A sample from the monitor solution will also be analyzed to allow corrections to the nitrate data to be made.

Automatic analyzers usually have provisions for chart recording or serial ports for transfer to computer files. The latter can be stored in the computer and also delivered to remote locations vial modem transfers. The latter would have the advantage of low cost data management and collection by the testing organization.

Data Interpretation: The data collected on the three different streams can be rapidly and easily examined in the form of computer data files and spreadsheet graphics. The following data should be obtained:

- Total number of nitrate analyses obtained from each stream
- Average nitrate level obtained over each 24 hour period, each week, and for 60 days
- Standard deviation for each stream
- Number and frequency of exceeding water quality objectives
- Number and frequency of nitrate spikes
- Duration of nitrate spikes
- Relation of spikes to daily time
- Relation to diurnal temperature as obtained from local weather data
- Relation to vessel cycles as recorded by plant operator
- Relation to operator activities as reported by operator
- Relation to maintenance operation as reported by operator
- Relation to water production as reported by operator

12.4 Schedule

Task 6 will be conducted over a continuous 60 day period which can coincide with other scheduled tasks.

13.0 TASK 7: QUALITY ASSURANCE AND QUALITY CONTROL

13.1 Introduction

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

13.2 Objective

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program to provide accurate data from which reliable conclusions and evaluations can be made. Maintenance of strict QA/QC procedures and records is important, in that if a question arises when analyzing or interpreting data collected for a given test or experiment, it will be possible to verify exact conditions at the time of testing through procedure and record recall.

13.3 Work Plan

13.3.1 Plant Metering Devices

Metering devices, flow meters, pressure gauges, thermometers, sensors, analyzers, probes, and associated electronic signals should be inspected and verified to be working or not on a routine basis. A daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with other meters registering the same flow stream and that the signal being recorded is correct. Accurately calibrated flow meters may be attached to the plumbing to aid calibration.

Accuracy of readings need be verified at least once per week.

13.3.2 On-Site Analytical Methods

Use of portable field test equipment will be used unless regular laboratory wet chemical capabilities are available for the on-site measurements. Accuracy of calibrated field kits should be determined by comparison with split sample analysis by a certified lab. For all sample collections, preservation and storage for later analysis and the analyses themselves should be done according to recognized procedures listed as acceptable for drinking water in Standard Methods or EPA Methods.

13.3.3 Nitrate Grab Samples

Nitrate analyses will be the most frequently performed analysis. It is very convenient to use the field test kits commercially available for drinking water samples such as Hach NI-11 and similar kits. A variety of kit types are available ranging in price and sophistication. The procedures for using the kits should be carefully followed. In addition, it has been found that results can vary with the individual preferences and practices. Colorimetric comparators are particularly troublesome. The nitrate measurements should be made by one person who has practice and proven competence with the method.

If a color comparator using a color graduated circular disk is used the following precautions should be made.

1) Read against light reflected from a white panel lit by a good white light dispersed light source such as a fluorescent bulb.

2) Never use sky light or sunlight.
3) Use the same light source and position for all readings.
4) Calibrate against known standards.
5) Make a new calibration if the analyst changes, the light source changes, the color wheel changes, at least once per week in any case.

In any case, regardless of the kit used, a calibration should be performed against known standards once per week and every tenth sample should be a sample of known concentrations.

13.3.4 Continuous Nitrate Sampling and Analysis

The use of continuous sampling nitrate analyzers was discussed under a separate section of this test plan. These instruments can be programmed for calibration at set intervals. The use of a monitor solution is also recommended to save calibration solution and time. The monitor solution should be a batch source of known concentration containing representative concentrations of the other major ions. Corrected readings will be based on both the monitor readings and the standard solution readings.

13.3.5 Chloride, Sulfate, Alkalinity

Laboratory and field test kits are also available for doing analyses for these ions. The kit selected should use methods listed in Standard Methods. Each method should be field calibrated over a range of concentrations available in the various streams subject to analysis. Split samples should also be submitted to a state certified laboratory for checking accuracy of the field kit analysis.

13.3.6 Off-Site Analyses

Inorganic chemical samples shall be collected and preserved in accordance with Standard Method 3010B. The samples should be refrigerated at approximately 2 to 8°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8°°C. Samples shall be processed for analysis by a state-certified, third party accredited or EPA accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of analysis.

14.0 TASK 8. DATA COLLECTION METHODS, MANAGEMENT AND REPORTING

14.1 Introduction

It is important to give considerable thought prior to the start of any data collection regarding the collection methods and management of data. Data management and the reporting and evaluation of the data should be integrated with each other because of the limited time allowed for the testing plan.

The data collection methods used in the verification testing program shall involve the use of manual field note books, logs, field forms and/or computer files of software programs. Any software used must be compatible with NSF software preferences. It is particularly important that data from the continuous nitrate analysis instrumentation be kept on computer files, as this provides a convenient method of collection, transfer, storage and evaluation.

It should be considered from the outset, that the method of data collection and management employed by the plant owner/operator was designed in response to plant operation and regulatory reporting and should not be a primary source of the data required by the testing plan. Plant testing is not an objective of plant operation. The primary objective is to provide safe drinking water to the public. Consequently, it is preferred that the field testing organization remain as independent as possible from the data system adopted by the owner/operator. The data collection and management system used for daily plant operation is itself a part of the plant and is evaluated in Task 5 above. Valid testing should therefore be done using independent methods of data collection and management.

14.2 Objective

The objective of this task is to implement methods of data collection, management, and evaluation which are consistent with the testing plan and prepare the final report product.

14.3 Work Plan

14.3.1 Manual Methods

The field testing organization will prepare data forms or log forms to be used by their personnel to collect the data required for each of the specific tasks as described above. One individual, the Data Manager, will be assigned the data management task. All original completed data forms and logs will be submitted to the Data Manager for filing and transfer. The Data Manager will be an engineer or scientist experienced in water treatment and testing and will be closely involved in the testing plan on a daily basis. The Data Manager will compile the manually obtained data into computer files for use in spreadsheets or other data management software and retained for data evaluation. The Data Manager will also review data and make evaluations regarding water quality objectives and plant characteristics based on current data. The Data Manager will also organize the data according to the outlines of the quarterly and final reports and be active in the preparation of the reports.

14.3.2 Automatic Methods

Data from automatic recording devices may be transferred to electronic files for storage and recall either with field computers or by remote transfer to the Data Manager for the project. If available, the Data Manager shall download the files once a day during automatic data collection periods. The data from the automatic nitrate analyses is an example of this application.

14.3.3 Secondary Data

The data collected by the plant owner/operator is considered as secondary data in this testing plan. The Data Manager will coordinate the collection of secondary data with the owner/operator.

14.3.4 Data Interpretation

The data will be interpreted in light of the water quality objectives and other operational objectives to verify the plant performance.

14.3.5 Report Preparation

The report will be organized by task number plus other sections appropriate for the 60-day test period and will contain a description of all data obtained during the test program. The report will include an executive summary, data summaries, data charts, data tables, and conclusions, which can be drawn concerning the plant performance and the achievement of performance objectives.

The final report will contain an Executive Summary that will include the following information given in brief tabular form:

- Plant Identification:
  - Design classification of the equipment
  - Location of the test site
  - Maximum flow rate, g.p.m.
  - Duration and dates of testing period
- Achievement of Objectives:
  - Whether or not the water quality and secondary objectives were achieved
  - Cases, if any, where the plant failed to meet objectives
- Performance Characteristics:
  - The amount of salt used per day, per month, per year
  - The amount of salt used to produce blended water, pounds per 1000 and million gallons
  - The average BUF of the operating plant
  - The cost of regenerant per 1000 gallons of blended water
  - Percent of wastewater produced
  - Instances of operational problems or difficulties
  - Evaluation of equipment quality, construction and service

  - Evaluation results of cross-connection devices
  - Number of shut down alarms during operation
  - Maintenance level required
  - Overall rating and evaluation
- Estimated Cost:
  - Annual maintenance cost
  - Annual operating cost including capital amortization
- Projections:
  - The performance characteristics of the plant and costs will be projected for various representative compositions of feed water with (1) greater and (2)lesser amounts of each of the four major anions.

14.3.6 Report Submission and Comments

A draft final report will be submitted to the manufacturer for comments. The final report will address the comments of the manufacturer.

14.4 Schedule

The data collection methods and data management will be in effect throughout the test program. A draft final report will be submitted after the 60-day test period followed by a final report.

15.0 OPERATIONS AND MAINTENANCE

The following are recommendations for criteria for O&M Manuals for ion exchange equipment and should be evaluated by the Field Testing Organization during verification testing.

15.1 Maintenance

15.1.1 Component Maintenance

The maintenance section will include references to equipment manuals, which describe maintenance procedures and calibration procedures. Refer to manuals prepared by each manufacturer of each component, which requires maintenance. The manufacturer's manuals must be provided in an appendix. Summarize the maintenance and calibration procedures, which are recommended by the manufacturer of each of the major components, valves, meters, instruments and controllers.

Provide a Maintenance and Calibration Schedule or Table indicating recommended frequency of maintenance and the specific maintenance activity for each maintained component.

15.1.2 Plant Maintenance

The following items must be addressed regarding general plant maintenance:

- Testing resin samples for capacity and breakage.
- Inspection and cleaning of vessel interiors and ion exchange resin.
- Inspection of all piping connections for leakage.
- Keeping the plant area clean and free of debris.
- Inspection and renewal of painted surfaces such as vessels, piping, housings, etc.
- Inspection of sample lines for free flow samples.
- Inspection of all valves for leakages.
- Inspection and maintenance of all back flow preventors and cross connection devices for leakages and/or malfunctioning.
- Inspection and maintenance of air pressure throughout the system for automatic valves.
- Inspection of all electrical cables, voltages, and heat production areas and devices.
- Inspection of brine pumps and brine leakages in brine maker area.
- Inspection of fire extinguishers, air packs, showers, eye washes and other safety devices.
- Inspection of controller cables, cabinet interiors, relays, heat generation and functioning.
- Inspection and routine tests of computer components, printers, modems, etc.
- Supply of salt for brine making.
- Chemical supplies for analytical devices and procedures.
- Supply of analytical sampling bottles.
- Supply of recording paper and computer printer paper.
- Any other items required for proper plant operation.

15.2 Operation

The operation manual section should be prepared by a person who has field experience and has actually operated the equipment and can give a clear description of theory and practice of operation. Input from design engineers or other office-confined personnel should be minimized. The material must be presented from the plant operator's point-of-view and should not be highly technical or engineering oriented. The operation of each major component must be addressed without reference to equipment brochures supplied by subcomponent suppliers.

- **Water Quality Objectives**: These shall be of primary importance.
- **Theory of Operation**: Text and diagrams shall be provided, as well as a section on

terminology. These materials shall be at a level understandable by plant operators.

- **Description of the Process**: Text and diagrams shall be provided, as well as a section on terminology.
- **Flow Diagram**: Normal operating flow rates and daily cumulative amounts shall be shown.
- **Piping and Instrumentation Diagram**: A non-engineering presentation that can be understood by non-engineer plant operator shall be provided, referencing all valves and components according to ID labels placed on all components (valves, piping, flow direction, etc.). An ID label and a clearly marked indicator of OPEN or CLOSED status shall be provided for each valve.
- **Automatic Controller(s)**: The principle of operation shall be described and the start up and shut down procedures, reagents required, calibration procedure, accuracy and interface and plant shall be given.
- **Manual Operation**: Method of operation if controllers fail to function shall be described.
- **Data Collection and Recording Devices**: A section for each device shall be provided, describing the operation and accuracy and calibration procedure.
- **Location and Operation of Meters and Instruments**: Each item shall be specified and an ID label given.
- **Alarms**.

A section on each of the following shall be included:

- Start-up procedure
- Plant settings, service batch, blend percent, brine batch, rinse and backwater water
- Plant monitoring procedure
- Expected typical performance
- Manual shutdown of the plant
- Restarting the plant after manual shut down alarms
- Restarting the plant after automatic shut down alarms
- Alarm removal procedure
- Reinitializing and restarting
- Adjusting the plant settings to lower nitrate levels
- Adjusting the plant to increased nitrate levels
- Adjusting plant to reduce salt consumption
- Adjusting plant to reduce waste production
- Adjusting plant in response to changes in untreated water composition

16.0 REFERENCES

Anderson, R.E., **Estimation of Ion Exchange Process Limits by Selectivity Calculations.** *AIChE. Symposium Series*, 71(152):236, 1975.

Clifford, D.A. and Weber, W.J., **Nitrate Removal From Water Supplies by Ion Exchange**. EPA-600/2-78-052, June 1978.

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Guter, G.A. **Nitrate Removal From Municipal Water Supplies**. Chapter2 in *Ion Exchange Technology, Advances In Pollution Control* Edited by Arup Sengupta, Technomic Publishing Inc,Lancaster, PA, 1995.

Higgins, I.R. **Continuous Ion Exchange Equipment**, *I&EC* , 53:336, 1961 EPA-600/S2-82-042, August, 1992.

Guter, G.A. **An Estimation of Effects of Resin and Water Composition on Column Performance in Nitrate Ion Exchange**. *AWWA Annual Conference Proceedings,* Dallas, Texas, June 10-14, 1984 also see **Computer Simulations of Nitrate Removal by Ion Exchange**, *AWWA Annual Conference Proceedings*, Washington, D.C. June 23 - 27, 1985 p. 1293.

Guter, G.A. **Removal of Nitrate from Contaminated Water Supplies for Public Use, Final Report**, EPA-600/S2-82-042, August, 1992.

Guter, G.A.,Hunt, K.,and Paliska, S., **Evaluation of Automatic Nitrate Monitoring by Ultraviolet Absorption at a Nitrate Treatment and Blending Facility**, AWWA Water Quality Technology Conference, Boston Mass., Nov 17-21, 1996.

Lauch, R.P. and Guter, G.A., **Ion Exchange for Removal of Nitrate from Well Water**, Journal AWWA (May):83-88, 1986.

Simon, G.P., **Ion Exchange Training Manual**, Van Nostrand Reinhold,New York, 1991.

Cross-Connection Control Manual, EPA Publication No EPA 570/9-89-007, June 1989.

Recommended Practice for Backflow Prevention and Cross-Connection Control. AWWA Manual M14.

Distribution Valves: Selection, Installation, and Field Testing. AWWA Manual M44.

Regulations Relating to Cross-Connections, California Administrative Code, Title 17, Public Health, 1956.

Table 3. Analytical Methods

Parameters	Laboratory *Standard Methods*[1] number or Other Method Reference	Laboratory EPA Method[2]
General Water Quality		
pH	4500-H^+ B	150.1 / 150.2
Total alkalinity	2320 B	
Temperature	2550 B	
Conductivity	2510B	120.1
Total Dissolved Solids	2540 C	
Color	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Inorganic Water Quality		
Nitrate	4110 B / 4500-NO_3^- D, F	300.0 / 353.2
Chloride	4110 B / 4500-Cl^- D	300.0
Sulfate	4110 B / 4500-$SO_4^=$ C, D, F	300.0 / 375.2
Sodium	3111 B	200.7
Calcium Hardness	3500-Ca^{+2} D	
Total Hardness	2340 C	
Alkalinity	2320 B	
Iron	3111 D / 3113 B / 3120 B	200.7/200.8/ 200.9
Manganese	3111 D / 3113 B / 3120 B	200.7/200.8/200.9
Bicarbonate, HCO_3	Calculation	
Organic Water Quality		
Total organic carbon	5310 C	
Microbiological		
Algae, number and species	10200 F	
Heterotrophic Plate Count	9215 B	

Notes:

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

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CHAPTER 4

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
HETEROTROPHIC BIOLOGICAL DENITRIFICATION FOR REMOVAL OF NITRATE

Prepared By:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

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1.0 INTRODUCTION

1.1 Application of This Test Plan

This document is the ETV Testing Plan for the Biological Denitrification Process for the Removal of Nitrates from Contaminated Water. This Testing Plan is to be used as a guide in the development of Product-Specific Test Plan (PSTP) procedures for testing biological denitrification (BD) treatment equipment, within the structure provided by the EPA/NSF Environmental Technology Verification (ETV) Protocol Document for nitrate removal. Refer to the "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies" as well as the Test Plans for Equipment Verification Testing Plan for Reverse Osmosis and Nanofiltration Processes for further information.

This document is applicable only to heterotrophic carbon-based fixed-film denitrification systems and not to suspended-growth systems. This document is not applicable to autotrophic denitrification systems including hydrogen and sulfur-based processes.

Post-denitrification treatment systems for the removal of residual soluble and suspended carbonaceous materials may be required to bring the biologically denitrified water to drinking water standards. Such equipment is considered to be a separate treatment module whose performance and operation are outside the scope of this document. Where such post-treatment is required to reduce the fouling potential of the BD throughput as measured by turbidity, suspended solids, and residual Total Organic Carbon (TOC), the reader should consult other NSF publications related to residual contaminant removal including the ETV document *Protocol for Physical Removal of Microbiological and Particulate Contaminants, and Test Plans for Membrane Filtration, Coagulation and Filtration, Bag and Cartridge Filters, and Precoat Filtration*. These documents should be useful in determining post-denitrification treatment needs.

In order to participate in the equipment verification process for BD processes, the Equipment Manufacturer shall retain a Field Testing Organization (FTO) that is NSF-qualified to employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the PSTP. The procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific equipment. A recommended format of the procedures written for each Task should consist of the following sections:

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

1.2 Objectives of Verification Testing

Testing of equipment covered by this Verification Testing Plan shall be conducted by an NSF-qualified FTO. Water quality analytical work to be carried out as a part of this Verification Testing Plan shall be contracted with a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA. The FTO shall provide full details of the procedures to be followed for each task in the PSTP. The FTO shall specify the operational conditions to be evaluated during the Verification Testing.

The Manufacturer shall define the verification testing objective(s). These specific objectives of the equipment verification testing should be different for each Manufacturer, depending upon the statement of objectives of the specific equipment to be tested. The testing 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:

- Verifying the performance of the equipment by generating field data in support of meeting a specific contaminant level in the treated water;
- Evaluating new advances in equipment and equipment design;
- Verifying the performance of the equipment used in a specific environment such as a coastal region where ocean disposal is available;
- Verifying the performance of the equipment operating within a specific range of untreated water quality;
- Verifying the performance of the equipment used for specific modes of operation such as continuous or interrupted operation.

Multiple testing objectives may be included in the PSTP. An important aspect in the development of the verification testing is to describe the procedures that will be used to verify the statement of performance objectives made for water treatment equipment. A verification testing plan document incorporates the Quality Assurance/Quality Control (QA/QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Verification testing conducted at a single site may not represent every environmental situation which may be acceptable for the equipment tested, but it should 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 and/or accepted by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

1.3 Scope of the PSTP

Specifically, the PSTP shall include at least the following items:

- Roles and responsibilities of verification testing participants;
- A brief statement of the objectives of the test plan;
- A brief statement of the water quality treatment objectives;
- 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;
- Quality assurance and quality control (QA/QC) procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing;
- Health and safety measures relating to biohazard (if present), chemical, electrical, mechanical and other safety codes.

2.0 BACKGROUND

Heterotrophic biological denitrification is a well-established process in the realm of wastewater treatment. However, this process has not been used on a full-scale basis in the field of water treatment in the U.S., but there are several full-scale plants being operated in Europe (Dahab et al., 1998; Gayle, et al., 1989). The primary reason behind the slow transfer of technology from the wastewater treatment to potable water treatment is the obvious concern over potential contamination of the treated water by bacteria and residual organics from the bio-denitrification process. This is a legitimate concern that must be kept in mind when designing such treatment processes for water treatment.

Numerous studies (Dahab and Woodbury, 1998 and Dahab and Kalagiri, 1996) reported on the potential for using biological denitrification for nitrate reduction in groundwater supplies in laboratory-scale experiments. The results indicated that fixed-film denitrification can be expected to reduce the nitrate concentration in the influent water supply from as high as 100 mg/L (as N) to levels within the 1.0 mg/L (as N) range. These removals translate into an efficiency of nearly 100 percent, which is generally not matched by other processes available for nitrate reduction. However, some residual soluble as well as insoluble organic matter should be expected in the denitrified water supply. Further treatment can reduce these solids to levels sufficient to meet prevailing drinking water standards.

In heterotrophic biological denitrification, facultative microorganisms are contacted with the water supply containing nitrates and an added carbon source in an anoxic (oxygen-free) environment. Under these conditions, the bacteria utilize nitrates as a terminal electron acceptor in lieu of molecular oxygen. In the process, nitrates are reduced to nitrogen gas, which is harmless and can be directly discharged to the atmosphere. The extraneous carbon source is necessary since it supplies the energy required by the microorganisms for respiration and synthesis while serving as an electron donor. Most denitrification studies have used methanol (CH_3OH) as the carbon source. If a simple carbon source is chosen such as ethanol or acetic acid, then the biomass produced during the process should be correspondingly low; a useful characteristic in that the overall excess biomass production is minimized.

Since heterotrophic denitrifying bacteria require an organic carbon source for their respiration and growth, a wide variety of organic compounds have been used. These organics include methanol, ethanol, acetic acid, glucose, and other more complex organics. While the types of organic compounds may affect the biomass yield, the choice is generally based on economic comparison. The availability of ethyl alcohol from agricultural sources could make this carbon source a strong candidate for denitrification systems. It should be noted that methanol toxicity is such that it is not recommended as electron donor and carbon source for drinking water denitrification.

Another important factor is the presence of dissolved oxygen in the waters and its inhibiting effects. To effect denitrification, the oxygen concentration must be reduced to a level low enough to avoid inhibition or repression of nitrate reductase. Unless dissolved oxygen is removed by chemical addition, the amount of electron donor (organic carbon) added must be equal to that needed to remove the oxygen as well as the nitrate.

Biological denitrification can be carried out in suspended or attached growth systems. In suspended growth systems, the bacterial culture is “suspended” within the contents of the reactor vessel by constant mixing or agitation. In these systems, sedimentation is required to settle out the bacterial biomass so it can be returned to the reactor vessel, or otherwise removed by wasting. Such systems are common in wastewater treatment applications. The principal advantages of suspended growth systems include the ability constantly return biomass into the system and small tankage requirements. However, suspended growth systems are subject to damage or washout by hydraulic transients and influent shock loads. They are generally not suited for handling periods of extended shutdown.

In fixed-film (also known as biofilm) systems, the bacterial biomass is physically attached to a solid matrix, which serves to support the bacterial mass by providing surface area on which the bacteria can grow in a film-like layer. Attached growth systems can be of the static media type or the expanded-bed (i.e. fluidized) type. In static media systems, the solid matrix typically is made up of synthetic modules that are stacked in some fashion (or simply dumped, depending on their size and configuration) in the reactor vessel. These media can have high porosity, light weight (when synthetic materials are used) and high specific surface area (i.e. surface area per unit volume of medium). Static media attached growth systems are operated in either downflow or upflow regimes although upflow systems are more common due to the reduced chance of plugging associated with their operation and the fact that the bacterial biomass is constantly submerged.

Fluidized-bed systems are operated in an upflow manner so that the bacterial growth matrix bed is expanded hydraulically as the water is pumped from the bottom to the top of the reactor. In expanded-bed systems, the support media are generally of the granular type (both natural and synthetic) to facilitate expansion of the bed. As the bed is expanded the entire surface of the granular material is made available for bacterial support. Because of this fact, expanded-bed systems have been reported to be loaded at rates exceeding static-bed systems. However, the additional costs associated with pumping to maintain bed expansion or fluidization must also be considered during design evaluation. With no known exceptions, all full-scale biological denitrification systems designed for potable water treatment have been of the static-bed fixed film type.

3.0 OVERVIEW OF TASKS

This ETV Testing Plan is divided into 6 tasks. A brief overview of the tasks to be included in the verification testing program is presented below:

3.1 Task 1: Characterization of Feed Water

A full characterization of the source water must be made prior to initiating operation so that the potential for fouling and mineral precipitation (scaling) and other possible interferences can be defined and/or predicted. Results of this analysis shall be used to define feed water pretreatment requirements, chemical doses and system operating conditions, and to identify potential foulants in the source water for monitoring during operation.

3.2 Task 2: BD Start-up and Initial Performance

The objective of this task is to evaluate BD start-up and subsequent steady-state operation. Start-up conditions including the need for bacterial seed (inoculum) must be characterized. Furthermore, the usability of the biological denitrification process and potential fouling (including excess biomass and potential hydrogen sulfide production) shall be evaluated in relation to feed water quality.

3.3 Task 3: Product and Residual Management

The objective of this task is to evaluate the quality of water produced by the BD system, referred to as product water or BD effluent. Multiple water quality parameters shall be monitored during each operational period. A basic goal of this Task is to confirm that BD-treated waters meet the manufacturer's performance objectives for nitrite. BD effluent quality shall be evaluated in relation to feed water quality and operational conditions to determine if additional treatment is required. Any wastewater or sludge streams shall also be characterized and management plans for the proper disposal of BD residual biosolids are to be identified.

3.4 Task 4: Process and Equipment Maintenance

An important aspect of BD operation is the maintenance of the system so that an adequate inventory of biological (bacterial) mass (i.e. biomass) is maintained while avoiding excess biomass conditions that may lead to impaired effluent quality or to system support matrix clogging. Another intent of this task is to provide procedures and methods for insuring the continued integrity and operability of all equipment and associated appurtenances.

3.5 Task 5: Data Reduction and Presentation

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

3.6 Task 6: Quality Assurance/Quality Control

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 Verification Testing.

4.0 TESTING PERIODS

On the assumption that the source water is a groundwater, which normally exhibits minor or no significant changes in seasonal water quality, the required operational tasks in the Verification Testing Plan (Tasks 1-4) shall be performed at least once during a 1-year period, not including mobilization, start-up, and Initial Operations.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary if feed water quality is known to be seasonally variable. If one verification testing period is selected, the feed water should represent the worst-case concentrations of nitrate concentration, which can verify the manufacturer's objectives. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions. Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined through feed water characterization. Verification test periods shall last a minimum of 3000-hours. The purposes of the 3000-hour test period are: 1) to provide a data base for a long period of time to demonstrate start-up (establishment of biomass in system) and steady-state conditions; 2) to assess the system recovery after short periods of shutdown; and 3) to provide opportunity for the treatment of feed water having variable quality.

5.0 DEFINITIONS

5.1 Biological Denitrification: a bacteria-mediated (i.e. biological) process in which nitrate is reduced into nitrogen gas by denitrifying bacteria (typically facultative heterotrophes) under anoxic (oxygen-free) conditions. The process requires that an electron donor (typically an organic carbon source) be present for the reaction to go to completion.

5.2 BD Effluent: Product water produced by the biological denitrification (BD) treatment system.

5.3 Denitrified Effluent: The same as BD Effluent.

5.4 System Feed Water: Source water introduced into the BD process for treatment.

5.5 Reactor Feed Water: Influent feed water introduced into the BD reactor system, consisting of raw system feed water, and in rare occasions, a combination of raw system feed water and recycled reactor effluent being returned for further treatment.

5.6 Fouling: A condition in which the BD effluent quality is impaired by the presence of excess biological solids being discharged by the BD reactor or fouling resulting from extraneous reactions including sulfate reduction to produce traces of hydrogen sulfide. Fouling in this case also is referred to as "biofouling". Fouling could also be the result of other contaminants that might be present in the feed water.

5.7 Carbon Source: The material to be used as a source of elemental carbon for heterotrophic bacterial denitrification to proceed. The organic carbon serves as an electron donor in the heterotrophic biological denitrification reaction as well as a source of energy for bacterial metabolism. This carbon source can be one (or a combination of) several organic substances including alcohols (such as methyl alcohol or ethyl alcohol), organic acids (such as acetic acid) or other similar organic substances including sugars.

5.8 Electron Donor/Electron Acceptor: The term electron donor generally refers to the organic carbon source to be used in the heterotrophic denitrification process whereas the electron acceptor refers to substances being reduced in the denitrification process, principally nitrate, but it also may include sulfate, if present in the raw feed water being denitrified.

5.9 Bacterial Seed (Inoculum): This term refers to the bacteria that must be added to the denitrification reactor to accomplish the conversion of nitrate biologically into nitrogen gas. Such bacteria must be inoculated into the reactor system for immobilization on the reactor bacterial support matrix. Bacterial inoculums can be of a pure culture or a mixed culture variety.

5.10 Reactor: The term reactor refers to the vessel in which the denitrification process is to be accomplished. The combination of the reactor vessel, bacterial support matrix and other related appurtenances are referred to as the "Reactor System."

5.11 Start up: The period of time following the installation of the reactor system, addition of bacterial seed and the commencing of operation. During this period, the product water may contain excess biomass and excessive nitrate concentrations indicating that the treatment process has not stabilized yet. Generally, start-up should be in the order of 3 to 5 weeks.

5.12 Steady-State Operation: Steady-State Operation begins after the reactor system had gone through a successful start-up with nitrate concentrations in the reactor effluent approaching the targeted concentrations and with minimal occurrence of fouling.

5.13 Biofilm: Biofilm is the structural appearance of bacterial mass (biomass) on the surface of the reactor support matrix. Ideally, the biofilm should be a consistent and uniform accumulation of bacterial solids that appear like a gelatinous and slime-like layer that can be put into contact with the water being treated for the removal of nitrate contamination.

5.14 Support Matrix: The porous material to be used as reactor column packing to support the growth and accumulation of denitrifying bacteria. These materials typically consist of small individual packing modules that can be randomly packed into the reactor or large modular blocks that can be stacked inside the reactor column. These matrices must be made of materials that are known to be non-reactive and non-leachable and non-biodegradable and be lightweight with high specific surface area and high porosity.

5.15 Specific Surface Area: The amount of surface area (e.g. square feet) provided by a unit volume (e.g. one cubic foot) of packing material.

5.16 Porosity: The extent of open space provided by the biological denitrification reactor packing material; generally computed as the volume of voids per unit volume of packing material.

5.17 Post-denitrification Treatment: Refers to all treatment methods that are required to bring biologically-denitrified water to drinking water quality and likely to include filtration and disinfection.

6.0 TASK 1: CHARACTERIZATION OF FEED WATER

6.1 Introduction

This task involves a complete characterization of the raw water being fed to the treatment system. The information is required to determine the suitability of the water source as a feed water for verification testing, and to document parameters which may be important in predicting the treatability of the water source and treatment efficiency of the treatment process.

6.2 Objectives

The objectives of this task are as follows:

- Obtain a complete physical, chemical, and biological characterization of the source water or feed water that will be treated.
- Determine the degree of nitrate removal needed and the amounts of the organic carbon source and other chemicals required to carry out the denitrification process.

- Identify potential process contaminants (foulants) such as sulfates, bacterial solids, etc., that might affect the treatment process, and to determine potential and degree of feed water pretreatment, if any, that may be needed during system operation.
- Verify that the water, as sampled, is representative of the source water based on historical data (where available).

6.3 Work Plan

This Verification Testing Plan is based on the assumption that biological nitrate removal will be predominately applied to groundwater which is not subject to significant seasonal changes in water quality or temperature. Water sources with significant variability in nitrate contamination, including surface waters, require a significantly different approach to address seasonal variations in water quality. With the exception of "effluent" streams that receive a significant component of their base flow from nitrate-contaminated groundwater sources, surface water supplies typically have not historically exhibited nitrate contamination that would require treatment.

In cases where the feed water quality is known to vary seasonally, sufficient information shall be obtained to illustrate the variations that are expected to occur in the parameters that will be measured during Verification Testing for a period of time long enough to demonstrate such variability. This information shall be compiled and provided to NSF, so NSF and the FTO can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. The initial characterization is important to the success of the testing programs, as failure to adequately characterize the feed water (source water) could result in testing at a later site deemed inappropriate. Therefore, the initial characterization is important to the success of the testing program.

A brief description of the aquifer system that provides the feed water shall be provided in the PSTP to aid in interpretation of feed water characterization results. In addition to water quality parameters, this description should include aquifer hydrogeologic characteristics that may influence the groundwater quality. Furthermore, a brief description of watershed(s) hydrologic characteristics that may have an influence on the aquifer water quality should also be provided. The watershed description should include a statement of the approximate size of the watershed, a description of its soils (i.e. clays, silts, sand, etc.) and their hydrogeologic characteristics as well as a description of it topography (i.e. flat, gently rolling, hilly, mountainous, etc.). A description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality should also be provided. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

Most water sources will not have pre-existing water quality data of sufficient detail to allow an evaluation of the proper application of biological denitrification. Completion of this task involves the following:

- Analysis of grab samples for a detailed water quality analysis. The parameters evaluated shall allow for the calculation of a complete cation/anion balance, in addition to general physical, chemical and biological measurements and limited organic analysis.
- A review of selected historical water quality data, where available. This should allow for the determination of trends in key water quality parameters such as nitrate, sulfate, alkalinity and

total dissolved solids (TDS) (or conductivity), as well as allowing for the verification that the water quality measured by the grab samples is representative of recent historical data.

- Calculation of the amounts of nitrates to be removed to meet existing drinking water quality standards as well as the amounts of organic carbon needed to satisfy the stoichiometric needs of denitrifying microorganism.

- Calculation of the buffering capacity of the feed water and the need to control pH. Assessment of the viability of the biological denitrification process as well as other potential interferences that may lead to biofouling. This includes estimating the concentrations of the following salts and species in the feed water stream:

  - carbonate/bicarbonate,
  - total alkalinity,
  - sulfate,
  - phosphates, and
  - iron and manganese.

The FTO shall include in the PSTP guidelines for maximum concentrations for each of the above salts during BD system operation, assuming the use of appropriate water pretreatment and conditioning chemicals, when needed.

6.4 Analytical Schedule

Parameters required for a complete evaluation of source water quality are presented in Table 1. This table identifies all required parameters for evaluation in the field or in the laboratory by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA. In order to ensure that the source water supply is of consistent quality, it is recommended that the feed water be re-evaluated periodically (monthly basis is recommended) according to Table 1 during ETV testing. Parameters in Table 1 that are found to be constant after repeated testing over time can be removed from periodic testing. Table 1 also identifies the recommended Standard Methods (APHA, 1992) or U.S. EPA-approved procedures.

Parameters to be analyzed from grab samples shall be taken in duplicates, as a minimum, or more, at least one week apart. Potential sources of historical data include the United States Geological Survey (USGS), US Environmental Protection Agency, and state and local approved laboratories.

Manufacturers and suppliers intending to have their equipment verified for uses other than biological nitrate removal may wish to characterize the source water in terms of additional parameters besides those identified in Table 1.

Table 1. Feed Water Characterization Parameters

Parameter	Analysis Options			*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
	Field	On-Line	Lab		
General Water Quality					
pH	X	X		4500-H^+ B	150.1 / 150.2
Total alkalinity			X	2320 B	
Total Hardness			X	2340 C	
Calcium Hardness			X	3500-Ca D	
Temperature	X	X		2550 B	
Conductivity	X			2510	120.1
Total Dissolved Solids			X	2540 C	
Total Suspended Solids			X	2540 D	
Turbidity	X	X		2130 B / Method 2	180.1
Color			X	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Taste and Odor[3]			X	2150-2160	
Inorganic Water Quality					
Sodium			X	3111 B	200.7
Potassium			X		200.7
Ammonia, NH_4			X		350.3
Strontium			X		200.7
Barium			X	3111 D / 3113 B / 3120 B	200.7 / 200.8
Iron			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Oxygen, Dissolved	X			4500-O	
Manganese			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Carbonate, CO_3			X	Calculation	
Bicarbonate, HCO_3			X	Calculation	
Sulfate, SO4	X		X	4110 B / 4500-$SO4^{=}$ C, D, F	300.0 / 375.2
Chloride	X		X	4110 B / 4500-Cl^- D	300.0
Nitrate, NO_3	X		X	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Nitrite, NO_2	X		X	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Fluoride			X	4110 B / 4500-F^- B, C, D, E	300.0
Carbon Dioxide, CO_2			X	6211 M	
Hydrogen Sulfide, H_2S	X				376.1/2
Organic Water Quality					
Total organic carbon			X	5310 C	
Electron Donor[4]	X		X	TBD	
UV_{254} absorbance			X	5910 B	
AOC/BDOC			X	9217A/5310	
Microbiological					
Total coliform			X	9221, 9222, 9223	
Heterotrophic Plate Count			X	9215 B	

1) Standard Methods Source: APHA (1999).
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water (1996).
3) Taste and Odor measurements are optional.
4) Residual electron donor (i.e. carbon source) concentration; TBD = To be determined by the FTO. See Section 5.7, FTO must identify Standard Method for their carbon source of interest (i.e. alcohols, organic acids, or sugars). Note that the choice of electron donor could interfere with ion chromatography-based measurements.

6.5 Evaluation Criteria

Feed water quality shall be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment with respect to nitrate concentration, but should not be beyond the range of water quality parameters suitable for treatment for the equipment in question.

The detailed chemical analysis should lead to a detailed determination of chemical doses required to support and maintain the biological process including organic carbon, pH control, dissolved oxygen control, and other process maintenance measures. Furthermore, the detailed water quality analysis results should allow for the determination of feed water constituents that may cause interferences, or potential biofouling, during biological denitrification. The analysis should lead to the proper selection of the chemical pretreatment options (i.e. chemical addition), if needed, to control and minimize such interferences.

If the feed water does not contain the level of nitrate concentration required to verify the manufacturer's removal objectives, nitrate spiking may be employed. The nitrate spiking procedure must be a peer-reviewed and published procedure and it must be reviewed by NSF and the EPA prior to implementation. Manufacturers and FTOs should also be aware that there are professional opinions that are opposed to nitrate spiking for verification testing.

7.0 TASK 2: BD START-UP AND INITIAL PERFORMANCE

7.1 Introduction

The purpose of this task is to verify that the BD system, when tested in accordance with Manufacturer-selected operating conditions using the selected source water, can reach and maintain performance as defined by:

- Productivity (product flow)
- Nitrate concentration (and other salts, if applicable)
- Concentrations of residual dissolved and suspended organic solids in the BD effluent
- Degree of post-denitrification treatment required to elevate the water quality to drinking water standards.

Another purpose of this task is to demonstrate that changes in the level of these performance characteristics caused by biofouling or other interactions between the BD system and the feed water can be adequately managed through conventional process modifications, chemical addition, or through conventional post-denitrification treatment.

The start-up of biological treatment systems requires the selection and enrichment of a non-pathogenic biological culture capable of efficiently and selectively removing nitrate from water. This biological culture must be accumulated within the reactor packing material to provide constant and steady-state nitrate removal. The accumulation of such solids will require careful operation during the start-up period to avoid the sudden washout of biological solids due to hydraulic transient conditions. Furthermore, the biological system will require careful monitoring to assure that minimum trace elements and buffer are provided and that excess nitrate loading is avoided. Additionally, suitable environmental conditions including moderate temperature and pH levels must be maintained. Although biological denitrification can be carried out at all normal temperatures above freezing, the maintenance of moderate temperature (i.e. 50 – 80 F) is conducive to desirable denitrification rates.

Beyond start-up, the BD system must be operated under steady-state operating conditions as specified by the FTO. While product flow is maintained, measures shall be taken to optimize (i.e. reduce) the concentrations of residual soluble and suspended organic materials (including bacterial numbers) in the denitrified effluent to minimize post-denitrification treatment needs.

As the biomass inventory in the system increases to the point where it is measurably impacting the BD system effluent quality, this biomass inventory will need to be managed as described in Task 4 to reduce the concentrations of residual suspended organic matter in the system effluent.

In the event that biofouling is judged to be excessive and unacceptable, the Manufacturer shall propose revised operating conditions to reduce such fouling. The effect of corrective measures on water productivity and BD effluent quality water shall then be determined through additional testing.

Prior to the start of the Verification Testing Program, the operational conditions to be verified shall be specified by the FTO in terms of an average water production rate (gallons per day [gpd]), nitrate removal efficiency, and organic carbon use rates.

7.2 Objectives

The objectives of this task are to document the following:

- Conditions for the BD system start-up and long-term operation.
- Performance of the BD system when operated under variable loading conditions.
- Effluent quality achieved by the BD system.
- Chemicals use and their impact on the treated water supply

7.3 Work Plan

7.3.1 Operational Conditions and Start-up

The PSTP shall specify information concerning the design and operation of the BD treatment system being evaluated in the following categories: 1) system design criteria; 2) operating conditions; 3) written procedures for operation and maintenance; and 4) maintenance criteria. To achieve and maintain successful long-term biological denitrification, numerous considerations need to be kept in mind during the various phases of reactor selection, design, start-up and operation. These considerations are discussed briefly below:

1. **Reactor selection and configuration:** To provide an acceptable level of system reliability, care must be taken during the BD system reactor selection and configuration. For example, the use of single-stage systems can be acceptable provided that more than one reactor is provided to meet minimum reliability requirements. When economically justifiable,

two-stage systems can provide a crucial degree of reliability to ensure long-term operation and maintenance. This level of reliability can yet be increased by utilizing multiple trains of two stage systems. Work by numerous researchers has demonstrated that two-stage reversible-flow reactor configurations are extremely efficient in providing increased levels of operational reliability beyond that provided by once-through two-stage systems (Siddique, and Young, 1995; Dahab and Kalagiri, 1996; Dahab and Woodbury, 1998). The PSTP should justify the use of single-stage systems, or single-stage systems with recycle over two-stage systems based on process as well as economic considerations.

Furthermore, the type of packing media should be specified based on expected hydraulic flow regime, packing media porosity, specific surface area and other pertinent considerations including materials of construction of packing media, density and chemical characteristics. Packing materials that are known to be non-reactive, non-leachable and non-biodegradable should be selected.

2. **Operational Controls:** The PSTP shall delineate the BD process and its controls based on kinetic as well as process hydraulic considerations, reactor dimensions, flow rates, influent nitrate concentrations, and proposed detention times. The PSTP shall also delineate steps to optimize the BD system by consideration of split (partial) treatment to provide for sufficient, yet flexible, denitrification capacity to meet the nitrate and nitrite standards while minimizing the total flow requiring actual biological treatment (i.e. treating a portion of the flow and blending it with the remaining untreated portion).

3. **Reactor Seeding and Seed Selection:** The PSTP shall specify how the BD system is to be seeded with denitrifying culture and how such non-pathogenic culture is to be obtained. There are many species of non-pathogenic bacteria that are capable of denitrification which are found in soils and natural waters. Such bacteria can be harvested and enriched for inoculation of the BD reactors. Many such bacterial cultures also can be obtained from commercial suppliers.

4. **Carbon Source Selection:** The most efficient species of denitrifying bacteria are typically facultative heterotrophs that require organic carbonaceous material be added as a source of energy for growth and multiplication. The PSTP shall specify the type of carbon to be provided for metering into the feed water. Typically, simple organic carbon sources are the most efficient from the standpoint of minimizing the amount of biosolids production as well as being fully utilized during the biodenitrification reaction. Additionally, the organic carbon source selection is typically based on cost as well as public health considerations. For example, while being a fully biodegradable simple organic molecule, methyl alcohol may not be acceptable because of potential toxicity implications. Based on economic and kinetic considerations, ethyl alcohol is an ideal denitrification carbon source, but it may, or may not be desirable from the standpoint of public acceptance.

5. **Dissolved Oxygen (DO) Control:** Dissolved Oxygen (DO) control is important to maintain anoxic conditions for optimum denitrification in the reactor system. The PSTP shall specify the methods by which dissolved oxygen would be reduced, if present in significant concentrations. DO can be removed by the addition of a reducing agent (e.g. sodium sulfite) or by relying on aerobic carbonaceous bacterial reaction to consume the DO in the feed water.

The latter method implies that additional organic carbon would need to be provided to satisfy the dissolved oxygen demand. Subsequent to biological denitrification, it may be desirable to restore the DO concentration in the treated water. This measure generally should contribute to the improvement of the chemical and aesthetic quality of the treated water as DO will be helpful in the oxidation and removal of residual dissolved and suspended organics in the treated water as well as help reduce potential malodorous conditions. The PSTP should address this important issue by examining the need for post-denitrification oxygen addition.

6. **Product Gas Removal:** The PSTP shall indicate how gases produced during denitrification will be exhausted from the reactor system. These gases are typically made of nitrogen gas and carbon dioxide and thus, need to be properly vented to the atmosphere.

7. **Control of pH:** The PSTP shall specify methods to monitor and control pH levels in the treated water supply, if necessary. Typically, biological denitrification will result in increasing the water pH. Depending on the influent nitrate concentration in the feed water and the available buffering capacity of the water, pH control might be necessary. Fortunately, most groundwater supplies will contain sufficient alkalinity to counteract this phenomenon, assuming that nitrate contamination is moderate.

8. **Excess Biomass Production:** During biological denitrification, a certain amount of biomass is produced and accumulated in the reactor as either attached biofilm or suspended biomass floc, biomass granules, or similar agglomerations. The PSTP shall specify methods of biosolids control including wasting frequency and reactor backwash procedures, if necessary.

7.3.2 Response to Transient Loading Conditions

The ability of the BD System to respond to changes in loading conditions shall be determined after steady state operation is reached and maintained for a period of about 3-4 weeks. Measures shall be taken to challenge the system's ability to respond to transient increases in nitrate concentration and/or hydraulic loading rates. This can be accomplished by altering the loading rates to the BD system for a duration equal to at least 3-4 hydraulic detention times. If the nitrate concentration in the water supply is not sufficiently variable, then this can be accomplished by gradually increasing the hydraulic loading rate by at least 50 percent (ideally in increments spanning about 1-2 hydraulic detention times). The BD reactor system performance shall then be monitored throughout the transient test period. If the water supply nitrate concentration is known to be variable, then the system can be operated at a constant flow rate while observing and documenting the reactor performance for a period of time of sufficient length such that a 40-50% change in nitrate concentration, if possible, is observed.

7.3.3 Response to Extended Periods of Shutdown

The ability of the BD System to respond to periods of dormancy, or shutdown, shall be determined after steady state operation is reached and maintained for a period of about 3-4 weeks. The ability of the system to respond to extended shutdown can be accomplished by gradually turning the flow to the system off, keeping it off for a period of 5-6 days, and then gradually restarting the system. The BD reactor system performance shall then be monitored throughout the restart-up period and until normal performance is re-established.

7.3.4 Product Effluent Water Quality

The key parameters in measuring the quality of the biologically treated water are the effluent nitrate concentration and the concentration of other substances, organic and inorganic, that can result from the biological treatment process. These byproducts are generally considered to be foulants and thus must be reduced to acceptable levels. The PSTP shall address this issue by providing detailed product water analysis and specifying steps to reduce, or remove foulants resulting from water treatment. These issues are further detailed in Task 3.

7.3.5 Chemical Use

Successful biological denitrification requires the use of chemicals that can facilitate the vitality of the biological culture that removes nitrate from water as well as re-condition the treated water quality to meet prevailing drinking water quality. Typical chemical additives are listed in Table 2 below. The PSTP must address the need for chemical addition either as pre-denitrification or as post-denitrification additives and specify chemical addition rates, metering and dosing systems and provide for proper storage and handling facilities for these substances.

Table 2. Typical Chemical Additives Required for Biological Denitrification.

Chemical	Purpose	Use/Addition
Organic Carbon sources including Ethanol, Acetic Acid, Acetate, and Others	Organic Carbon Source	Pre-denitrification
Hydrochloric acid	pH control	Denitrification
Bicarbonate	pH control	Denitrification
Phosphate	P-source	Pre-denitrification
Phosphoric Acid	P-Source	Pre-denitrification
Sulfite, Sodium	DO Control	Pre-denitrification
Oxygen	DO Control, Oxidant	Post-denitrification

7.3.6 Power Use

In an attempt to calculate power costs for operation of the system, power usage shall be measured by meter readings or quantified by the following measurements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor.

7.3.7 Operator Hours

In an attempt to calculate labor hour costs for operation of the system, operator hours shall be recorded during the verification testing.

7.4 Analytical Schedule

During Verification Testing of the BD system equipment, the feed water and treated water quality shall be characterized by measurement of the "Field" water quality parameters listed previously in Table 1. These data are to be collected and analyzed to enhance the usefulness of the Verification Testing data.

The sampling schedule and sampling frequency shall conform to sampling schedule and sampling frequency defined in Task 3 (Product and Residuals Management) and Table 3.

7.5 Evaluation Criteria

Where applicable, the data developed from this task should be compared to statements of equipment performance objectives. If no relevant statement of performance capability exists, results of operating and performance data should be tabulated for inclusion in the verification report.

8.0 TASK 3: PRODUCT AND RESIDUALS MANAGEMENT

8.1 Introduction

Under normal conditions, BD involves the production of minor amounts of wastewater; most of which is associated with the flushing and periodic backwash of the denitrification reactors. This task involves a characterization of product and waste water quality during the system operation described in Task 2. Product water analysis shall serve to document that the treatment system meets the nitrate removal performance criteria for which the manufacturer is seeking verification. Additional water quality information is required to identify performance of the treatment system relative to any potential fouling identified during the raw water characterization performed in Task 1.

The quality and quantity of wastewater produced by the BD treatment system is an important consideration in determining the appropriate methods of management and disposal of this wastewater. The cost of wastewater disposal typically is not a large component of the total system cost, but it can be significant depending on the type of disposal option selected, particularly for those not utilizing a direct discharge to an existing wastewater treatment system.

8.2 Objectives

The objectives of this task are as follows:

- Assess the ability of the biological treatment system equipment to meet the water quality goals specified by the Manufacturer.
- Assess the amount and concentrations of any potential foulants which may interfere with the long-term operation of the treatment system. Examples include excessive sulfate concentrations that can lead to the production of sulfide and other dissolved and suspended solids that can interfere with the biological treatment process.
- Characterize the volume and concentration of the wastewater produced by the process.

8.3 Work Plan

Water quality data shall be collected for the BD treatment system feed water and product during the BD test as outlined in Task 2. As a minimum, the required sampling schedule identified in Table 3 shall be observed by the FTO on behalf of the Manufacturer. Water quality goals and target removal goals for the BD equipment shall be clearly delineated in the PSTP.

When necessary, excess solids must be removed from the reactor system to maintain a suitable and adequate solids inventory in the reactors. When solids removal is implemented, characterization of the amount and quality of wastewater that needs to be removed must be completed. The biological solids (biosolids) to be removed from these reactors are non-toxic, but they must be handled and managed in an approved manner in consultation with the requisite regulatory agencies. The most appropriate method of disposal might be the discharge of these solids and wastewater to a nearby municipal biological wastewater treatment system with adequate capacity to handle the solids load. Otherwise, solids concentration (i.e. thickening and/or dewatering) might be needed before disposal of these solids to land as a soil conditioner. Additional disposal methods might be available. The PSTP must specify, based on local conditions and regulations, the method(s) of solids handling and ultimate disposal.

8.3.1 Sampling Schedule:

The sampling schedule outlined in Table 3 applies to the biological denitrification system raw feed water and treated water streams. Some parameters identified in Table 3, including nitrate and nitrite, should be analyzed on a continuous basis, or on a multiple daily measurement basis, as appropriate. However, when continuous analysis is not possible, these parameters shall be analyzed at least once every four to six hours.

The FTO shall identify the treated water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the Verification Testing Program. The statement of performance objectives prepared by the FTO shall indicate the range of water quality under which the equipment can be challenged while successfully treating the feed water.

Many of the water quality parameters described in this task shall be measured on-site by the FTO or by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA.

The methods to be used for measurement of water quality parameters in the field are summarized in Table 3. The analytical methods utilized in this study for on-site monitoring of influent and product water qualities are described in Standard Methods (APHA, 1992) and/or the U.S. EPA. Methods and are governed by their respective QA/QC measures. 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 by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA, water samples shall be collected in appropriate containers (using recommended sample preservatives techniques, as applicable) prepared, or otherwise approved, by the laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with recommended procedures and holding times, as specified by the analytical lab.

TABLE 3. BD SYSTEM SAMPLING SCHEDULE DURING ETV TESTING

Parameter	Sampling Frequency[1]	Analysis Options	*Standard Methods*[2] number or Other Method Reference	EPA Method[3]
Nitrate, NO3	Multiple Daily (or continuous)	Field or Lab	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Nitrite, NO2	Multiple Daily (or continuous)	Field or Lab	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
pH	Multiple Daily (or continuous)	Field or On-line	4500-H^+ B	150.1 / 150.2
Temperature	Daily	Field or On-line	2550 B	
Dissolved Oxygen	Multiple Daily (or continuous)	Field	4500-O	
Turbidity	Multiple Daily (or continuous)	Field or On-line	2130 B Method 2	180.1
TDS	Weekly	Lab	2540 C	
Conductivity	Weekly	Field	2510	
Sulfate, SO4	Daily	Field or Lab	4110 B / 4500-$SO4^=$ C, D, F	300.0 / 375.2
Sulfide	Daily	Lab	4500-$S^=$ F, D	
TSS	Daily	Lab	2540 D	
VSS	Daily	Lab	2540 E	
TOC	Daily	Lab	5310 C	
DOC	Daily	Lab	5310 C	
Carbon source (electron donor)	Daily	Field or Lab	TBD	
Total Coliform	Weekly	Lab	9215 B / 9221 / 9222 / 9223	
E. Coli	Weekly	Lab	9221 / 9222 / 9223 (Colilert)	
UV Absorbance (254 nm)	Daily	Lab	5910 B	
Alkalinity	Daily	Lab	2320 B	
Total Hardness	Weekly	Lab	2340 C	
Color	Weekly	Lab	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Taste and odor[4]	Weekly	Lab	2150-2160	
Iron and Manganese	Weekly	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Chloride	Weekly	Field or Lab	4110 B / 4500-Cl^- D	300.0

1 Grab samples unless continuous sampling.
2 Standard Methods Source: APHA (1999).
3EPA Methods Source: EPA Office of Ground Water and Drinking Water (1996).
4Taste and Odor measurements are optional.

8.4 Analytical Schedule

The minimum sampling frequency for the required Task 3 water quality parameters is presented in Table 3. At the discretion of the FTO, the water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling. As indicated earlier in Section 6.4, periodic (e.g. monthly) extensive re-evaluation of the feed water supply is recommended using all parameters listed in Table 1 to ensure that the feed water is of consistent quality. Such extensive evaluation is prudent to guard against possible sudden changes in feed water quality.

Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP. However, to the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

8.5 Evaluation Criteria

- **Nitrate Removal**

  The primary BD system evaluation criterion is the nitrate removal capacity expressed as the amount of nitrate removed per unit reactor volume per unit time (e.g. lb NO_3-N/ft^3-hr) claimed by the manufacturer for the application being verified.

  Provide a graph showing the BD influent and product water nitrate concentrations as a function of elapsed operating time.

- **Fouling**

  As indicated earlier, depending on raw water quality, biological denitrification can result in additional byproducts of nuisance and/or fouling potential. Detail must be paid to careful operation to minimize the occurrence and production of such materials. Optimizing the BD reactor operating conditions should result in minimization of these substances in the reactor effluent.

  Provide graphs showing the levels of contaminants in the raw water and treated water supplies as a function of elapsed time including dissolved and suspended solids, residual organic carbon source concentrations, and hydrogen sulfide.

9.0 TASK 4: PROCESS AND EQUIPMENT MAINTENANCE

9.1 Introduction

Under this task, the FTO shall demonstrate that adequate steps are being taken to insure the continued maintenance of both the biological denitrification process as well as the BD process equipment. The process maintenance schedule shall delineate steps to be taken to preserve process stability while maximizing the nitrate removal rate and minimizing the extent of potential fouling of the product water quality. Process maintenance must involve at minimum:

- Target nitrate removal rates are met while maintaining potential nitrite concentration at desired levels,
- Production of minimal concentrations of residual organic carbon,
- Production of minimal concentrations of suspended and dissolved organic solids of cellular or extracellular origins, and

- Minimization of the production of substances that can cause, or contribute taste, color, and/or odor in the treated water.

The process equipment schedule shall outline steps to be taken to insure the continued optimum functioning of all process equipment including chemical dosing, process control and monitoring equipment.

9.2 Objectives

The objectives of this task are as follows:

- Outline steps to evaluate and maintain the continued effectiveness of the biological process in removing nitrate while reducing the potential production of fouling substances.
- Confirm that Manufacturer-recommended equipment management schedules (Manufacturer Operations and Maintenance [O&M] Manual) are sufficient to maintain the continued functional integrity of all process control and monitoring, and that procedures and methods to restore the integrity of such equipment upon malfunction, are current.

9.3 Work Plan

9.3.1 Process Maintenance

The FTO shall ascertain that:

1. Organic carbon dosing equipment is set to correspond to stoichiometric limits dictated by the influent feed water nitrate concentration and the influent water DO concentration.
2. Reactor environmental conditions are maintained at optimal levels with respect to pH, temperature, and adequate supply of essential trace elements and nutrients.
3. The attached and suspended solids inventories in the reactor system are monitored on a regular and continuous basis and that excess biological solids are removed by draining or backwashing, or both. A reactor backwash procedure based on the type(s) of biomass support matrix characteristics (packing density, porosity, and specific surface area) should be maintained. When possible, the frequency of backwash should be established to allow for better process automation.

9.3.2 Equipment Maintenance

Regular schedule and O&M manuals for equipment testing, calibration mechanical maintenance and replacement and/or repair are required. The following are recommended criteria for evaluation of O&M manuals for BD treatment systems.

9.3.2.1 Operation. Provide clear and concise recommendations for procedures related to proper operation of the BD treatment system and equipment. Include as a minimum, information on the following:

- Startup

  Initial startup of system including reactor seeding
  Establishment of steady state operation
  Restart and possible reseeding of the reactor system after prolonged shutdown

- Shutdown and biomass inventory management

  Short term shut down (one day or less)
  Intermediate term (one day to one week)
  Long term (more than one week)

- Backwash Procedures

  Backwash cycle details including duration
  Backwash frequency

- Chemical Feed Systems

  All chemicals with anticipated use
  Dosing rates
  Automation of chemical control system (e.g., pH, control of carbon source feed)

- Tolerance of the system to operating conditions

  Feed water temperature
  pH
  Oxidants (e.g., dissolved oxygen, chlorine, etc.)
  Maximum feed pressure and maximum allowable differential pressure across each stage of the reactor system

- Adjustment to operating parameters

  Influent water flow rates
  Influent water nitrate and DO concentrations

9.3.2.2 Maintenance. Provide clear and concise procedures for performing maintenance on the system and its components.

- Instructions for installing or replacing system control and process monitoring equipment and components.
- Recommended or required maintenance schedules for each piece of equipment.
- A list of spare parts to be kept on hand.

9.3.2.3 Troubleshooting. Provide clear and concise procedures for troubleshooting.

- Provide an explicit list of alarm conditions that the system must respond to:

  Pressure
  pH
  Pump Failure
  Chemical feed low tank level

- Indicate which alarm conditions will cause automatic system shutdown and provide instructions for clearing each condition.

- Provide detailed procedures for verifying integrity of the reactor system, back-flow prevention, all flow control and check valves, etc. on a vessel-by-vessel basis.

10.0 TASK 5: DATA REDUCTION AND PRESENTATION

10.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software, manual recording methods, or both, for recording operational parameters of the BD equipment on a daily basis.

10.2 Objectives

The objectives of this task are as follows:

- Establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for verification purposes.

- Develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies" (Chapter 1).

10.3 Work Plan

The following protocol has been developed for data handling and data verification 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 a spreadsheet software as a comma delimited file. These specific database parcels should be identified based upon discrete time spans and monitoring parameters. In spreadsheet format, the data should be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases should be performed on a daily basis, if possible.

In the case when a SCADA system is not available, field testing operators shall record all data and calculations by hand in laboratory notebooks (daily measurements shall be recorded on specially-prepared data log sheets, as appropriate). The laboratory notebook should provide carbon copies of each page.

The original notebooks shall be stored on-site; the carbon copy sheets should be forwarded to the project engineer of the FTO at least once per week. This protocol should not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the BD 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 should be conducted on-site by the designated field testing operators. All recorded calculations should also be checked at this time. Following data entry, the spreadsheet should be printed out and the printout is 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 should 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 (e.g. each test run) 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 analytical laboratories that are certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA, 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.

11.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

11.1 Introduction

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

11.2 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 would be possible to verify exact conditions at the time of testing.

11.3 Work Plan

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

11.3.1 Daily QA/QC Verifications

- Chemical feed pump flow rates (verified volumetrically over a specific time period).
- On-line turbidimeter flow rates (verified volumetrically, if employed).
- On-line turbidimeter readings checked against a properly calibrated bench model, if employed.

11.3.2 Weekly QA/QC Verifications

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- Recalibration of on-line pH meters and/or conductivity meters, if used.

11.3.3 QA/QC Verifications Performed Before Each Test Period

- On-line turbidimeters (clean out reservoirs and recalibrate, if employed).
- Differential pressure transmitters, if used (verify gauge readings and electrical signal using a pressure meter).
- Tubing (verify good condition of all tubing and connections, replace if necessary).

11.3.4 On-Site Analytical Methods

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

11.3.4.1 pH. 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.

11.3.4.2 Turbidity. During each verification testing period, 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 Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to 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 verify 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. For 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 operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments, the readings should be comparable. Should the comparison suggest inaccurate readings, then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

11.3.5 Chemical and Biological Samples Shipped Off-Site for Analysis

TOC and UV absorbance samples shall be collected in glass bottles supplied by the laboratory (certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA) and shipped at 4°C to the analytical laboratory within 8 hours of sampling. The TOC and ultraviolet (UV) absorbance samples shall be collected and preserved in accordance with Standard Method 5010B

Inorganic chemical samples, including alkalinity, hardness, iron, and manganese, shall be collected and preserved in accordance with Standard Method 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples should be refrigerated at approximately 2 to 8°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8°C. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of analysis.

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied (or approved) by the qualified laboratory and shipped with an internal cooler temperature of approximately 2 to 8°C to the analytical laboratory. Samples shall be processed for analysis by the qualified laboratory within 24 hours of collection. TC densities are reported as most probable number per 100 milliliters (MPN/100 mL) and HPC densities are reported as colony forming units per milliliter (cfu/mL).

12.0 REFERENCES

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