ACKNOWLEDGEMENTS

The USEPA and NSF International 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.

Generic Verification Protocol for Chemically Enhanced High-Rate Separation

Writer: George Zukovs - XCG Consultants Ltd.

Reviewer: Clyde Burnett – CDM

Technology Panel Members:

Ms. Meei-Lih Ahmad

Mr. Mervyn Bowen

Mr. Richard Field

Mr. Stephen Hides

Ms. Mary Stinson

Mr. Philippe Topalian

Mr. Randy West

Mr. Peter Young

Mr. Jim Zaccagnino

Mr. George Zukovs

GLOSSARY OF TERMS

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Core Parameter - a water quality parameter used to define test equipment performance. Core parameters shall be used at all testing sites and represent the minimum required.

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

Field Testing Organization (FTO) – an organization qualified to conduct studies and testing of chemically-enhanced high-rate separation technologies in accordance with protocols and test plans.

Manufacturer –a business that assembles or sells chemically-enhanced high-rate separation technology equipment.

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

Owner – a municipality, industry or other entity that would own and operate a full-scale chemically enhanced high rate separation facility.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, and scope of the verification testing of a technology category. The protocol defines the critical elements of the verification tests and serves as the basis for the development of site-specific test plan. A protocol shall be used for reference during Manufacturer participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for process conditions or an environmental condition.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Storm Event – a storm event is defined as a period of continuous or intermittent rainfall. It is differentiated from the previous and the following storm event by a minimum period with no precipitation. This period varies by climatic region.

Supplemental Parameter – a water quality parameter used to define test equipment performance. Supplemental parameters are additional to core parameters and are selected for a particular test site.

Test Plan – A written document that establishes the detailed test procedures for verifying the performance of a specific technology. It also defines the roles of the specific parties involved in the testing and contains instructions for sample and data collection, sample handling and preservation, and quality assurance and quality control requirements relevant to a given test site.

Treatability Parameter – a water quality parameter used to define testing conditions (e.g. pH, alkalinity) or maximum removal efficiency (e.g. soluble BOD_5).

Verification – a process to establish the evidence on the range of performance of equipment and/or device such as a chemically-enhanced high-rate separator under specific conditions following a predetermined study protocol(s) and test plan(s).

Verification Report – a written document prepared by the FTO containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Test Plan(s) shall be included as part of this document.

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

1. INTRODUCTION

This document contains the generic protocol to be employed for the verification testing of chemically-enhanced high-rate separation equipment used for the treatment of wet weather wastewater flows. Wet weather wastewater flows include: combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), and excess wet weather flow at wastewater treatments plants (WWTPs).

The goal of verification testing is to provide objective information to manufacturers, owners and staff of regulatory agencies regarding technology performance. Verification testing results in the issuance of a Verification Report documenting the procedures and outcomes of a Site Specific Test and the issuance of Verification Statement summarizing the site specific testing. More information about the ETV program can be found on the Internet at http://www.epa.gov/etv, or http://www.nsf.org/etv.

1.1 The Environmental Technologies Verification (ETV) Program

The purpose of the ETV Program is three fold. Specifically, the program is intended to:

1. Evaluate the performance of innovative and commercially available environmental technologies;
2. Provide objective information about technology performance to permit writers, buyers and users, among others; and,
3. Facilitate “real world” implementation of promising technologies.

The ETV Program is subdivided into twelve individual pilot projects, one of which is the Wet Weather Flow (WWF) Technologies Pilot concerned with technologies appropriate for the treatment of wet weather flows, among other issues.

The verification testing process established by the United States Environmental Protection Agency (EPA) and NSF International (NSF), is intended to serve as a template for conducting verification tests for various wet weather flow technologies. The goal of the verification testing process is to generate high quality data for verification of equipment performance.

The verification testing of chemically-enhanced high-rate separation equipment is being overseen by NSF International with the participation of manufacturers, under the sponsorship of the EPA Office of Research and Development with oversight by National Risk Management Research Laboratory’s Urban Watershed Management Branch (Edison, NJ) . NSF’s role is to provide technical and administrative leadership 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. Instead, the verification testing pilot projects are a formal mechanism by which the performance of equipment can be determined by these two organizations.

1.2 Verification Testing Process

The verification testing process consists of three phases as shown in Figure 1.1. They include:

Planning – The planning phase involves a number of characterization and testing activities culminating in the preparation of a site specific Test Plan.

Verification Testing – This phase includes an initial testing phase during which equipment operating parameters are optimized and the actual verification testing phase.

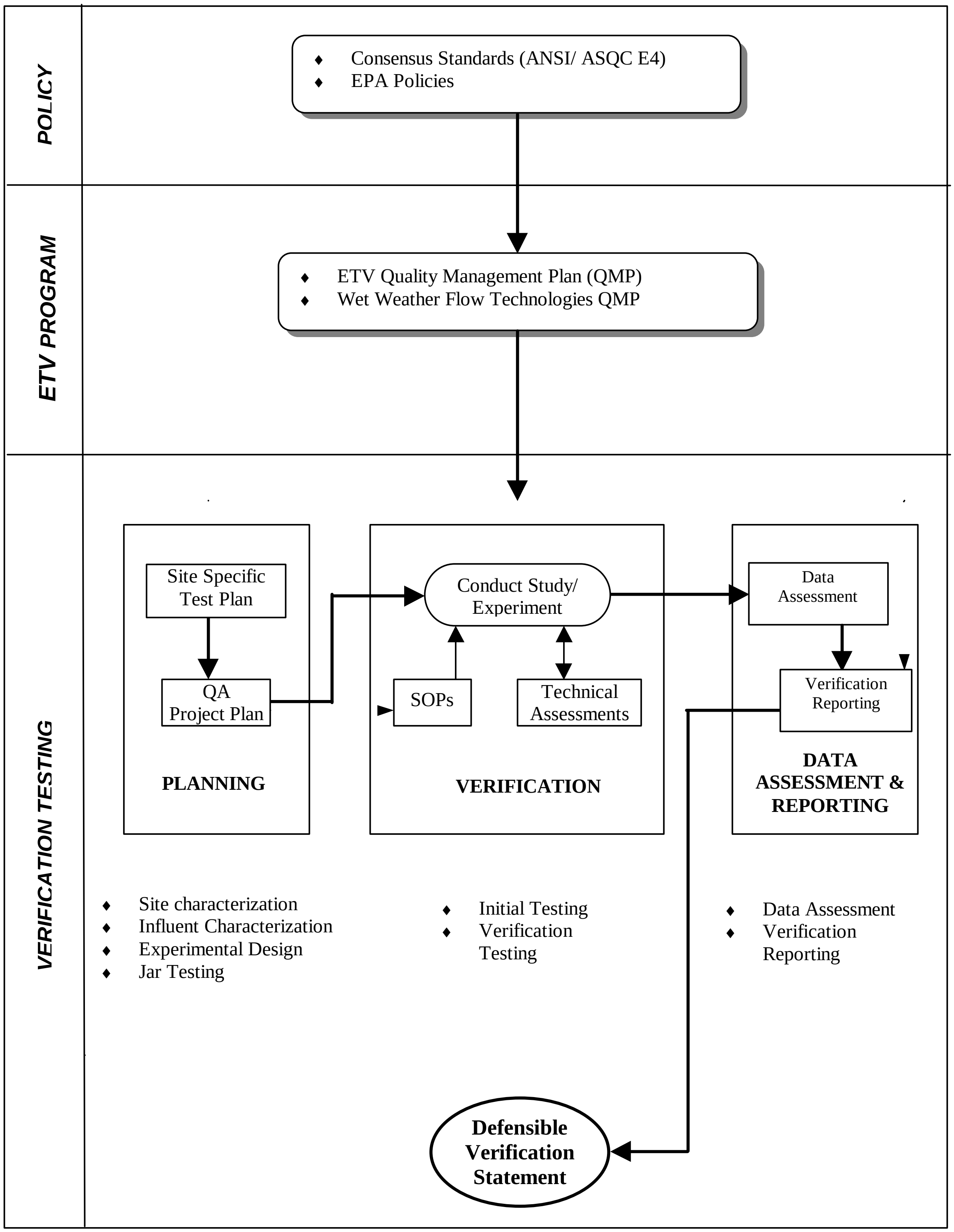
Data Assessment and Reporting – This last phase includes all data analysis and verification steps as well as Verification Report preparation.

Figure 1.1 also shows the relationship of the verification testing process to higher level quality management plans (QMPs), EPA policies and consensus standards such as ANSI/ASQC E4.

1.3 Purpose of Protocol

This document contains explicit guidance to Field Testing Organizations (FTOs), Manufacturers and Owners for verification testing of chemically-enhanced high-rate separation equipment. This protocol contains instructions for the preparation of Test Plans, as well as guidance on execution of testing, data reduction and analysis, and reporting. The following protocol is organized according to the three phases of verification testing. Specific details addressed in each phase are as follows:

Figure 1.1 Verification Testing Process



1.4 Chemically-Enhanced High-Rate Separation

Chemically-enhanced high-rate separation devices are a class of physical-chemical treatment technology that employs coagulants in a variety of reactor and clarifier configurations. These devices can be multi-purpose in that they may be capable of gross and particulate solids removal, colloid destabilization and agglomeration, and soluble contaminant (e.g. phosphorus and selected heavy metals) precipitation. In some cases, an inert particulate is added as a ballasting agent. In other cases, sludge is conditioned and recycled to enhance coagulation and settling. In general, the devices incorporate the following elements:

- Pre-treatment including screening and degritting. (Screening equipment is generally not supplied by the Manufacturer but may be required nonetheless to protect the device. Degritting may or may not be included as part of a Manufacturer's device.);
- Primary coagulant and coagulant aid addition;
- Ballasting agent addition (only in selected devices);
- Flash mixing;
- Flocculation;
- Clarification
- Sludge concentration (only in selected devices);
- Sludge (underflow) removal;
- Ballast agent and/or sludge recovery and recycle; and,
- Sludge (underflow) disposal.

A typical operating cycle for chemically-enhanced high-rate separation equipment is as follows:

- Fill-up of equipment - at this time feed of chemical coagulants, coagulant aids and/or ballasting agents may be initiated;
- Initial operating period during which time full equipment removal efficiency has not been achieved. The initial operating period is termed the start-up phase. In some instances, the effluent produced during the start-up phase may be diverted to a sewer or WWTP;
- Subsequent operating period during which time full equipment removal efficiency has been achieved. This period is termed the dynamic operations phase; and,
- Finally, the shutdown phase when no effluent is produced but equipment is allowed to drain and is then cleaned.

1.5 Considerations in Verification Testing

1.5.1 Simulated Influents

Ideally the verification testing of chemically-enhanced high-rate separation devices should occur under a wide range of storm events and corresponding influent quantity and quality conditions. The test equipment should also be operated for each verification test through a full operating cycle. Clearly the use of actual storms under real operating conditions is strongly preferred. Verification testing under these conditions is the least constrained and therefore produces the most meaningful Verification Statement.

As a practicality, availability of test equipment, lack of wet weather and the high cost of multi-storm testing often place significant limitations on verification testing. It has been the practice of FTOs and the Manufacturers to employ some type of "simulated" influent to undertake testing in a more controllable and predictable manner. Different approaches have been used or proposed for creation of a representative simulated influent, including blending of raw sewage with effluent from a primary sedimentation tank. It has also been suggested that if storage facilities are available at the test site, that "actual flows may be captured and subsequently used for testing. If a storage capture strategy is employed, the FTO shall ensure that the stored flows are adequately mixed during use and that quality characteristics have not changed significantly during storage, mixing and pumping (if needed).

The Generic Protocol presented in this document addresses the use of both actual storms and simulated flows for verification testing. The guidance for each of the testing phases presents various details and considerations associated with the use of simulated influents. In addition the following general guidance regarding the use of simulated flows is presented to aid the FTO, Manufacturer and Owner in developing an appropriate verification-testing program:

- Verification testing by preference should employ a wide range of actual storm events and corresponding influent flowrate and pollutant concentration conditions.
- The use of simulated influent for verification testing shall be acceptable.
- The FTO shall determine through site and actual influent characterization and jar testing, the flowrates, pollutant concentrations and coagulation chemistry characteristics of the actual influent.
- The FTO shall determine the degree to which simulated influents must match actual influents in flow, pollutant concentrations and coagulation chemistry.
- The FTO shall justify and shall document the bases upon which simulated influent was prepared in the Test Plan and Verification Report.

- Equipment treatment performance results shall be separately stated for actual and simulated influents.
- The Verification Statement will clearly identify the use of simulated influent in testing.

1.5.2 Performance Indicators and Quality Parameters

The performance evaluation of chemically-enhanced high-rate separation devices is based on the assessment through site specific testing of the following:

- Treatment performance measured by test equipment effluent concentrations and test equipment removal efficiencies for selected water quality parameters.
- Operations and maintenance performance measured by a number of quantitative and qualitative O&M indicators including use of consumables (i.e., chemicals and power), ease of operation among other factors.

The water quality parameters used to assess treatment performance include two categories or groups of parameters as follows:

- Core parameters which are water quality parameters used to define equipment treatment performance and are used in testing at all sites. The core parameter list is the minimum required to define performance.
- Supplemental parameters which are water quality parameters additional to the core parameters selected for a particular test site. Supplemental parameters are selected by the FTO in conjunction with the Manufacturer and Owner.

In addition to the core and supplemental parameters used to evaluate test unit treatment performance, verification testing shall require measurement of other parameters termed treatability parameters at various stages of the testing process. Treatability parameters include water quality parameters such as soluble BOD_5 that help define the maximum removal efficiency of the test unit as well as parameters such as alkalinity and pH that help establish test conditions.

Details of performance indicators and quality parameters are presented in Section 2.0 of this protocol.

2. PLANNING

2.1 Development of the Test Plan

The FTO shall prepare a Test Plan specific to each location where testing is proposed. The Test Plan shall be prepared in consultation with the facility Owner and equipment Manufacturer, and shall be reviewed by NSF prior to implementation. This Protocol provides guidelines for developing the Test Plan.

The specific contents of the Test Plan will vary from site to site; however, at a minimum, the Test Plan shall address the following elements:

- Scope and Purpose of Verification Test
- Roles and responsibilities of Verification Testing Participants
- Site Characteristics
- Influent Characteristics
- Technology Description and Capabilities
- Jar Testing
- Experimental Design
- Field Operations Procedures
- Quality Assurance Project Plan
- Data Management, Analysis and Reporting
- Health, Safety and Environmental Plan
- References

The following sections of this protocol establish guidelines for preparing each required section of a Test Plan.

2.2 Purpose of Verification Testing

The Test Plan shall define the general and specific objectives of the proposed verification testing. The testing objectives should support the desired Verification Statement; so for example, if testing is completed using simulated influent, the objectives should reflect this decision. In general, the objectives of verification testing shall be to determine the:

- Performance of specific chemically-enhanced high-rate separation equipment relative to the Manufacturer's stated range of equipment capabilities;

- Resources and costs required to operate the equipment;
- Range of operating conditions and the ease of operation of the equipment;
- Impact of influent characteristics on the performance of the equipment; and,
- Impact of the equipment operating cycle, including start-up, dynamic operation, and shut-down on treatment and operations and maintenance performance.

2.3 Equipment Verification Testing Responsibilities

Management of wet weather wastewater discharges such as CSOs, SSOs and excess wet weather flow at WWTPs is generally a municipal or metropolitan sewerage agency responsibility. Hence, the testing of chemically-enhanced high-rate separation equipment will involve multiple parties, each with responsibilities during Verification testing. They include:

- Field Testing Organization
- Manufacturer
- Municipality or sewerage agency (Owner)
- NSF International
- US Environmental Protection Agency

The general responsibilities of each party are presented in the following sections. The Test Plan shall, wherever possible, identify the specific individuals who will fulfill the responsibilities of the respective party.

In addition to the parties listed, regulatory agencies because of their approval and permitting powers, can have an important role to play following verification testing. It is therefore recommended that the appropriate authorities be advised of proposed testing and be requested to indicate their particular requirements or issues. In turn, the FTO in conjunction with the Manufacturer and Owner should in so far as possible, incorporate agency requirements and issues within the site specific Test Plan.

2.3.1 Responsibilities of Field Testing Organization (FTO)

The FTO shall prepare the site specific Test Plan for each site where testing is to take place. The FTO will have responsibility for the development of the Test Plan(s) and the implementation and completion of verification testing.

The FTO shall have the following responsibilities:

- Preparation of the site-specific Test Plan;
- Evaluation and reporting on the performance of the equipment;

- Scheduling and co-ordinating all the activities of all verification testing participants including establishing a communication network and providing logistical support on an as needed basis;
- Selecting locations as test sites that can provide influent water appropriate for verification testing;
- Managing, evaluating, interpreting and reporting on data generated by verification testing.
- Preparation and review of the Draft Verification Report
- Operation of equipment with on-site assistance as needed from the Manufacturer.

2.3.2 Responsibilities of Manufacturer

The Manufacturer shall have the following responsibilities:

- Initiate application to ETV for testing;
- Selection of the FTO (in co-operation with the Owner);
- Provision of complete, field ready equipment for verification testing;
- Provision of logistical and technical support as required for the installation and operation of the equipment being tested, including the designation of at least one staff person as the point of contact;
- Provision of assistance to the FTO on the operation and monitoring of the equipment during the verification testing; and,
- Review of site specific Test Plan.

2.3.3 Responsibilities of the Owner

The Owner shall have the following responsibilities:

- Selection of the FTO (in co-operation with the Manufacturer);
- Provision of a suitable test site;
- Provision of logistical and technical support as may be agreed upon by the FTO, Manufacturer and Owner;
- Provide assistance during testing as may be agreed upon by the FTO, Manufacturer and Owner; and,
- Review of the Test Plan and Verification Report.
- Operation of the equipment with or without on-site assistance by the Manufacturer.

2.3.4 Responsibilities of NSF

It is understood that NSF as an ETV partner, is acting on behalf of the EPA, and in this capacity NSF shall have the following responsibilities:

- Approval of the FTO;
- Review of the site specific Test Plan;
- Approval of Test Plan in conjunction with the Technology Test Panel;
- On-site audit of test procedures;
- Review and dissemination of the Verification Report; and
- Approval of the Verification Report in conjunction with the WWF Technologies Pilot Stakeholder Advisory Group
- Preparation and dissemination of the Verification Statement.

2.3.5 Responsibilities of US EPA

- Review and approval of Test Plan
- Review and approval of Verification Report
- Review and approval of Verification Statement
- Posting of Verification Report and Statement on the EPA website
-

2.4 Site Characterization

Site characteristics are unique to each test site. Site characterization is necessary to support development of an appropriate Test Plan. An accurate description of site characteristics allows the reader of a Verification Report to assess the context within which testing was carried out. In turn, this knowledge facilitates a better understanding of the transferability of a Verification Statement from one site to another.

The Test Plan shall clearly identify details of the Test Site including the following:

- Plan and profile of test equipment, including its layout on the site;
- Location of influent to the test equipment;
- Details of any pre-treatment of influent prior to entry into the test equipment;
- Underflow discharge location;
- Effluent discharge location;
- All proposed monitoring and sampling locations;
- Chemical storage location(s) (if any); and,

- Other relevant or unique features of the test site.

Other site related information may provide additional useful details on factors that influence test unit influent quantity and quality characteristics. For example, knowledge of rainfall patterns and characteristics can be useful in developing verification experimental design and field operation procedures (e.g., sampling duration and sub-sample frequency). This information, if available, should be considered during Test Plan development. It is not, however, a requirement of this protocol that these data be presented either in the Test Plan or the Verification Document.

2.5 Influent Characterisation

The purpose of influent characterisation is first to obtain an understanding of the actual storm influent flow behavior and quality characteristics. If it is proposed to employ simulated influent for testing, then influent characterisation of the flow behavior and the quality characteristics of the simulated influent shall also be carried out.

For actual storm influent, influent characterisation shall address both the quality and quantity characteristics of the range of expected wet weather flows. Sampling during characterisation may also provide adequate sample volume for jar testing.

Sufficient information shall be assembled to establish the actual wet weather flow and simulated flow quantity and quality characteristics to ensure proper structuring of subsequent test phases.

In some cases, sufficient existing data from NPDES monitoring or other sources may be available such that the FTO can forego either actual storm influent or simulated influent characterisation or both, as part of verification testing.

The Test Plan and the subsequent Verification Report shall characterise the influent with respect to flow and water quality. In the event that existing data are employed, the FTO shall present details of the data collection procedures, including monitoring and sampling methods, QA/QC and data analysis and reporting procedures.

Influent characterisation shall include two components:

- Flow
- Quality Characterisation

2.5.1 Flow Characterisation.

Flow monitoring for characterisation of actual storm influent to the treatment unit shall be carried out at a representative location. It may not be necessary to flow monitor simulated flows for initial characterisation unless some variation is expected. Flow data shall be obtained using industry standard procedures appropriate to the site. Details of flow monitoring methods, calibration procedures, and data editing and evaluation procedures, shall be documented. As noted above, sufficient flow data shall be collected to assess a range of influent flow conditions.

If possible, rainfall data should be collected coincident with the flow and quality data. Rainfall data provides a useful context for assessing influent characteristics (e.g. small storm vs. large storm inter-event period, etc.). Collection of rainfall data is not, however, a mandatory element of this Generic Protocol.

2.5.2 Quality Characterization

Sampling for quality characterization of the raw actual storm influent (prior to any pre-treatment) shall be carried out at a representative location. Simulated influent flows shall be monitored at a suitable location determined by the FTO. Industry standard procedures shall be employed for sample collection, preservation, storage and subsequent analysis. Details of sampling methods, storage and preservation techniques, analytical methods, and field and laboratory QA/QC procedures, shall be documented.

The actual storm and simulated influent shall be characterised for the following:

- Core performance parameters including: total suspended solids (TSS), turbidity, total 5-day biological oxygen demand (BOD_5), total chemical oxygen demand (COD) and total phosphorous (TP);
- Supplemental performance parameters as may be selected by the FTO. The FTO is encouraged at this stage to evaluate the influent for a range of heavy metals including: copper (Cu), lead (Pb), Zinc (Zn), selected organic pollutants such as petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), and Total Organic Carbon (TOC). If these parameters are present in sufficient concentration in the wastewater, they should be considered for inclusion in the site specific Test Plan as supplemental performance parameters; and,
- Treatability parameters such as: alkalinity, pH, soluble BOD_5, soluble COD, temperature, total soluble phosphorus, ortho phosphorus, dissolved solids, particle size distribution (PSD), settleable solids, UV transmittance and VSS which will give indication of expected level of performance of test equipment, as well as supporting an understanding of coagulation chemistry. "Soluble" parameters are in this case defined as the BOD_5, COD and phosphorus concentrations in samples previously filtered through a 0.45 µm filter.

Table 2.1 provides a list of representative references/methodology for testing for core, supplemental, and treatability parameters.

Table 2.1 Testing Reference/Methodology for Core and Supplemental Parameters

CEHRS

Parameter	Reference or Methodology
TSS	EPA 160.2
Settleable solids [1]	EPA 160.5
BOD_5	EPA 405.1
pH	EPA150.1
Temperature	EPA 170.1
Zn	EPA 200.7
Pb	EPA 239.2
Cu	EPA 220.2
Tp	EPA365.2
COD	EPA 410.1
Alkalinity	EPA310.2
VSS	EPA 160.4
Turbidity	EPA180.1
UV Transmittance	SOP Required
PSD	SOP Required
TOC	SM 5310C

[1] Use of Gravimetric test preferred with presence of chemical floc in CEHRS technology.

Again, sufficient quality data should be collected to assess a range of influent conditions.

The quality data shall support the following:

- Assessment of the variation of actual storm influent quality (core and supplemental) throughout storm events. It is particularly important to examine the incidence of peak concentration periods that may challenge the test equipment, including so called "first flush" or highly polluted segment phenomena;
- Assessment of the variation of parameters potentially influencing treatment behavior throughout actual storm events. These parameters will provide insight into expected treatment unit behavior (e.g. coagulation/flocculation effectiveness) throughout the course of the storm event;
- Assessment of actual storm influent quality averaged for a number of storm events including event averages and an overall (multi-event) average;
- Correlation (where possible) of actual storm influent quality variation with flow and rainfall characteristics. This will aid in developing sampling strategies;
- Assessment of the flow variation (if any) in simulated influent; and,
- Assessment of average simulated influent quality characteristics for core, supplemental and treatability parameters.

As noted previously, flow and influent quality characterisation characterisation characterisation data for actual storm events may in some instances be obtained from the Owner's NPDES permit monitoring sites or from the wastewater treatment plant records.

2.6 Equipment Description

A simple schematic of a typically chemically enhanced high rate separation process for wet weather flow treatment is provided in Figure 2.1. Also outlined in Figure 2.1 are the major design elements which must be specified by the Manufacturer for each piece of equipment to allow interpretation of operating conditions by the NSF/EPA**.**

All equipment used in verification testing shall be provided by the Manufacturer, along with technical assistance and technical support on an as-needed basis to the FTO during the operation and monitoring of the equipment.

The Test Plan(s) shall include the following information on the equipment to be tested:

- Full description of each unit process along with relevant photograph perspectives or schematics;

- A description of the scientific concepts on which the design of the equipment was based;
- A detailed description of physical condition of the equipment including its weight, ruggedness, and size;
- A detailed description of requirements of the equipment including general environmental requirements, limitations, and consumables. The description shall include typical consumption rates for all consumables including power and chemicals and an estimate of the underflow and overflow volumes;
- Definition of the range of flows for which the equipment is suitable for use;
- Identification of any special licensing requirements associated with the operation of the equipment;
- Discussion of the factors which impact the performance of the equipment;
- Instrumentation and control requirements.

In addition to providing the equipment, the Manufacturer shall attach data plates to each piece of equipment in an accessible location. The data plates shall, at a minimum, contain the following information:

- Equipment name;
- Model number; and,
- Manufacturer’s name and address.

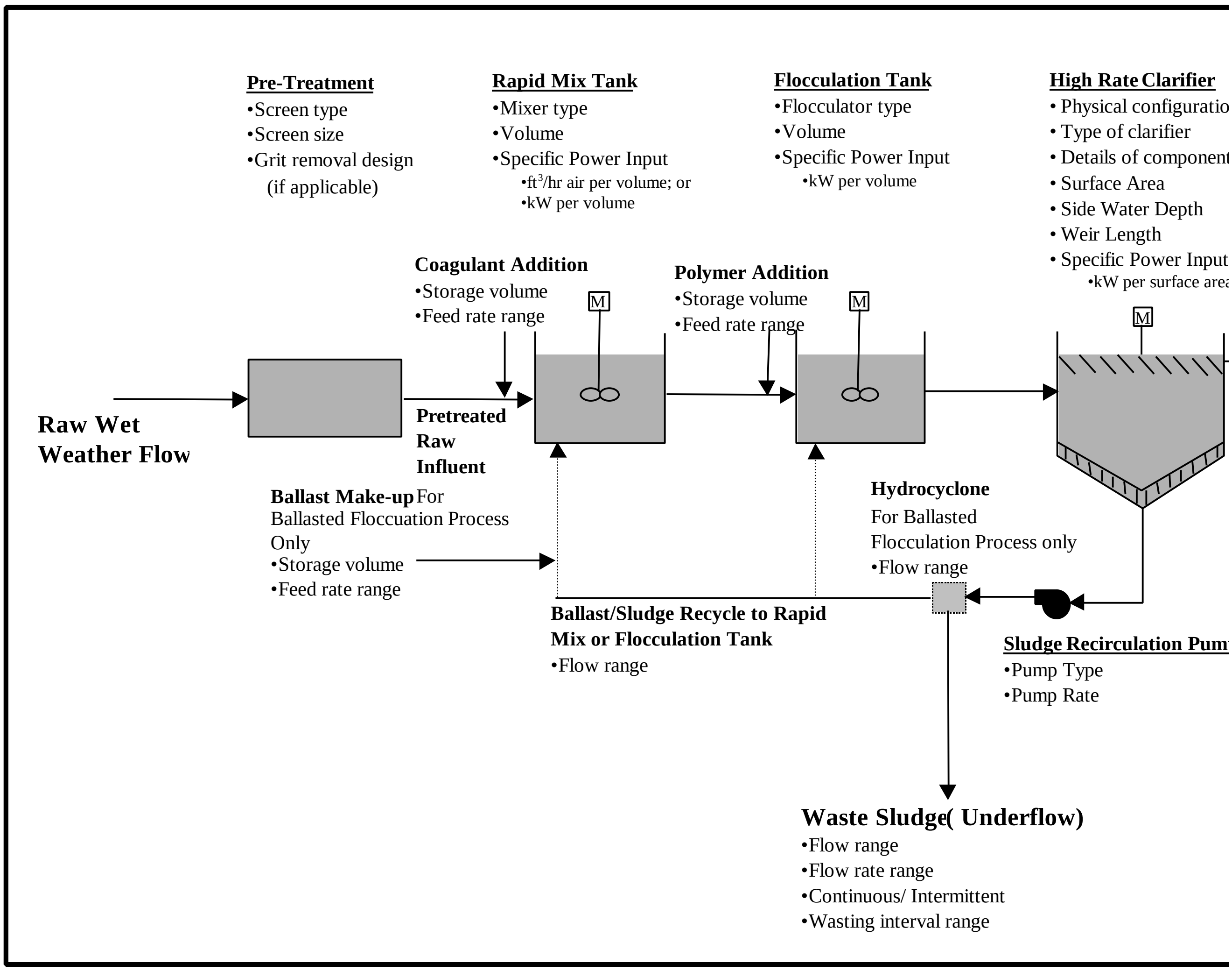


Figure 2.1 Schematic of a Typical Chemically-Enhanced High-Rate Separation I

2.6.1 Operational Characterization

Conducting jar tests is often a cost-effective means of developing data on coagulant types and dosages for a given water quality that gives effective coagulation and particulate removal efficiency. The FTO shall conduct jar tests and other operational characterization tests as appropriate to determine the polymer and coagulant types, chemical dosages, ballast dosages (if appropriate) and other conditions that provide the most effective level of treatment. The Manufacturer shall also perform jar tests in order to compare results. The jar test and related protocol shall be developed to most closely resemble the full-scale equipment operations. For example, retention times, mixing intensity (i.e., velocity gradients) and ballast/sludge recycle addition shall be selected to parallel those anticipated in the Manufacturer's process.

Jar testing shall include the following water quality parameters:

- Core Parameters: TSS, turbidity, total BOD_5, total COD, total P ;
- Supplemental Parameters: as determined during initial characterization from discussions with regulatory authorities or by the FTO in conjunction with the Manufacturer and Owner (see Section 2.5); and,
- Treatability Parameters: pH, alkalinity, temperature, soluble BOD_5, soluble COD, dissolved solids, total soluble phosphorus, ortho phosphorus, particle size distribution, UV transmittance, VSS, and Settleable Solids fraction.

For the case where simulated flow is being used for the verification testing, jar testing shall be completed on both a simulated flow sample and an actual storm influent flow sample.

Jar testing shall be carried out at a minimum on one or more actual storm influent flow samples averaged for the storm event. Additional tests may also be performed on portions of storm events having significantly different characteristics such as "first flush" or dilute influents. Again, composite samples taken for the appropriate portion of a storm(s) should be used for testing purposes.

Conditions for each test shall be identical (i.e., coagulant dosages, mixing intensity, retention time, etc.) to allow for a direct comparison of the results from each test. The results from each set of jar tests shall be compared to assess any difference in coagulation chemistry and performance indicators between the actual wet weather flow and the simulated flow. If the results differ significantly, attempts need to be considered to modify the simulated wet weather flow chemistry to match those of the actual wet weather flow experienced at the site. In any event, it shall be necessary to document the comparative evaluation of actual versus simulated influent jar tests in the site specific Test Plan. These data will provide another important element justifying use of the simulated flows.

2.7 Development of the Experimental Design

2.7.1 Purpose and Scope of Experimental Design

The purpose of the experimental design is to define the test conditions, performance measures, measurement requirements and data quality indicators for verification testing. The development of the experimental design uses as input:

- Knowledge of equipment operation
- Site characteristics
- Influent characteristics
- Operational testing data (jar tests)
- Verification testing objectives.

The preparation of the experimental design is the initial planning stage of verification testing. It is followed by a second more detailed planning stage in which the specific test procedures are established . These procedures form the detailed blueprint, laying out "how to" implement the experimental design. Mandatory and suggested elements of the test procedures are described in Section 3 of this Generic Protocol.The elements that shall be considered in the experimental design are as follows:

- Verification testing objectives;
- Test equipment influent characteristics;
- Test equipment operating conditions;
- Test equipment performance measures;
- Other measured data; and,
- Data quality indicators.

Verification testing objectives have been previously discussed in Section 2.2 and further discussion will not be added here. Guidance regarding the remaining aspects of the experimental design is presented in the following sub-sections.

2.7.2 Test Equipment Influent Characteristics

The Generic Protocol addresses the use of influents derived from actual storm flows and simulated flows. The use of actual storm flows covering a representative range of influent quality and quantity conditions is strongly preferred for verification testing.

The following protocol sub-sections outline considerations for experimental design using actual storm influents and simulated influents.

2.7.2.1 Actual Storm Influents

The experimental design presented in the Test Plan shall indicate the minimum requirements for the nature (i.e., duration and range of flow and quality variation) and number of storm events to be used for testing.

An actual storm influent is the result of rainfall and/or snowmelt phenomena. Influent quality variations are generally observed through the course of a storm event. For purposes of verification testing, the duration of a storm event is defined as the period starting at the onset of rainfall and/or snowmelt induced flow increase until influent flows return to typical dry weather rates.

Correlation of influent flow data with rainfall or temperature measurements can help define the duration of storm events and is recommended though not mandatory.

2.7.2.2 Nature of Storm Events

Ideally, testing should reflect the full range of rainfall induced influent quantity and quality conditions the test equipment will need to treat.

The equipment shall be tested for one or more storm events that encompass flows exceeding 67% of the equipment design capacity (Qd) for any continuous period of a storm event, with a minimum duration of 3 times the hydraulic residence time (HRT), calculated using Qd and the total volume of the test equipment as supplied by the manufacturer.

A storm event is defined as a period of continuous or intermittent rainfall. It is differentiated from the previous and the following storm event by a minimum period with no precipitation. This inter-event period varies by climatic region and should be defined by the FTO.

The results of testing with sustained high flows (Q peak) ≥0.67 Qd for 3 times HRT shall be discretely reported as evidence indicative of performance under peak flow conditions.

Testing using storms producing influent flows <0.67 Qd (peak or otherwise) with total storm durations greater than 3 times test unit HRT calculated using Qd shall be acceptable. Results from testing with influent flows <0.67 Qd and the required duration shall be reported separately.

Storm events of duration less than 3 times the test unit HRT calculated at Qd, shall not be used for verification testing purposes.

2.7.2.3 Number of Storm Events

The FTO shall determine the number of storm events sufficient to provide confidence in test results. In order to assist the FTO, the following guidance is provided to establish a scientific basis for selection of the number of events.

In general, the error associated with an estimate of mean equipment treatment performance (effluent concentration or percent removal) diminishes as the sample size increases. At the same time, the requirement to monitor a large number of storm events can be expensive and require quite protracted test periods. A balance must therefore be developed between the number of events and the acceptable error.

For a given confidence interval of (1-α), and assuming that the underlying population is normally distributed, the error, *E*, corresponding to the estimate of the population mean is defined as Equation 2.1 below.

$$E = t_{a/2}\left(\frac{s}{\sqrt{n}}\right) \qquad \text{(Equation 2.1)}$$

Where:

E	Is the error estimate (same units as parameter of interest)
$t_{\alpha/2}$	Is a random variable having the Student's t-distribution with n-degrees of freedom
s	Standard deviation of sample set of size n

Values of expected error in the estimate of population mean, *E*, for a range of sample sizes, *n*, and a confidence interval of 95% (two-tailed), are listed in Table 2.1. Since *E* is dependent on *s*, the values listed are expressed as units of *s*. Obviously, as *s* decreases the relative magnitude of *E* decreases.

Table 2.2 Estimated Error E as a Function of Sample Standard Deviations at 95% Confidence Limits

Sample Size *n*	**Estimate Error *E***
2	8.98 (*s*)
3	2.48 (*s*)
4	1.39 (*s*)
5	1.24 (*s*)
10	0.72 (*s*)
15	0.55 (*s*)
20	0.47 (*s*)
60	0.25 (*s*)
120	0.18 (*s*)

For sample sizes of less than about 7, the expected error in the estimate of the sample mean (effluent concentration or removal efficiency) is greater than the sample standard deviation. Although the absolute magnitude of the error will depend on the standard deviation of the sample set, an error approximately 1 (*s*) should be generally acceptable for characterization of treatment facilities. Accordingly, the FTO shall target between 5 and 7 events for testing.

2.7.2.4 Simulated Influents

If it is intended to employ simulated flows for verification testing, the FTO shall characterise the quality of the simulated flows. Sampling for simulated flow quality characterization shall be carried out at a representative location. In some cases, the simulated flow may be comprised of two or more flow components . See also Influent Characterization Section 2.4.

Under these circumstances, a sample(s) may be made up at the proposed flow component blend ratio (e.g. ratio of primary effluent to final effluent) of the individual flow components. The individual flow component samples themselves shall be collected at representative locations.

Industry standard procedures shall be employed for sample collection, preservation and storage and subsequent analysis. Details of sampling methods, storage and preservation techniques, analytical methods and field and laboratory QA/QC procedures, shall be documented in the site specific Test Plan.

Average actual flow quality shall then be compared with average simulated flow quality. Ideally, the average characteristics of both influent types shall match as closely as possible for all parameters of interest (core, supplemental, and treatabillity).

The FTO may need to experiment with other simulated influent sources and/or changes in the blend of simulated influent components, to obtain as close a match as possible. At a minimum, a match shall be made for as many core performance parameters as possible. Additional guidance regarding matching simulated to actual influents is presented in the Section 2.6 (see jar testing).

Testing using simulated flows may be conducted at a constant flow or with time varying flows. If time varying flows are selected, the range and pattern of variation shall relate to the influent characteristics.

In some instances, a design storm (i.e. synthetic hydrograph) is used in conjunction with a hydrologic/hydraulic model to develop a design hydrograph. In turn, the design hydrograph may be used as input for the sizing of wet weather treatment facilities including chemically enhanced high rate separation. Where a design storm approach is contemplated, the simulated influent hydrograph shall mimic the design hydrograph as closely as possible.

In any case, the simulated flow pattern shall be documented and presented in the Verification Report and Verification Statement.

The number of simulated test runs shall follow the same guidance previously presented for actual storm events. (See above).

2.7.3 Test Equipment Operating Conditions

The experimental design shall specify the operating condition or range of operating conditions to be considered in verification testing. Conditions that will need to be specified include:

- Influent flow(s) which in turn determines unit process hydraulic retention times (HRT) and surface overflows (SORs) (see also Section 2.7.2 Test Equipment Influent Characteristics);
- Underflow wasting cycle and/or flow(s);
- Mixer/flocculator power input range;
- Coagulant types and feed rates;
- Coagulant aid types and feed rates;
- Chemicals used for pH adjustment and feed rates;
- Ballast type, characteristics and feed rates;
- Sludge recycle rates or ballast carrier recycle rates;
- Start-up with treatment units full or empty; and,
- Diversion of effluent during start-up phase.
- Shut-down procedures.

Equipment shall be tested through a full operating cycle (start-up, dynamic operation, and shutdown) for each test run unless it is proposed to divert effluent under start-up conditions.

2.7.4 Test Equipment Performance Measures

The performance of test equipment shall be measured using performance indicators assessing both treatment capabilities and operating requirements.

2.7.4.1 Treatment Performance

The following shall be used to measure treatment efficiency:

1. Flow-weighted average effluent concentration of the quality parameter of interest ($Ceff_{p,t}$) .
2. Effluent concentration ($Ceff_{p,t}$) variation plotted as a function of time.

3. Removal efficiency calculated using flow weighted average influent and effluent concentrations for the quality parameter of interest ($R_{p,t}$.).

The recommended flow-weighting calculation scheme is based upon the incremental flow volume in the time interval prior to the sub-sample being taken.

Both the concentration and removal efficiency treatment performance indicators shall be calculated for a number of testing durations. The durations are presented in Table 2.2.

Table 2.32 Duration for Calculation of Treatment Performance

Actual Storm Influent (for storms > 3 x HRT)	Simulated Influent
• First 30 minutes after producing first effluent	• First 30 minutes after producing first effluent
• Total storm	• First 60 minutes after producing first effluent
	• First 180 minutes after producing first effluent or 3 x HRT whichever is greater

In certain instances the manufacturer may indicate that it is not contemplated to discharge treated effluent from the test equipment during the start-up phase. Rather, effluent from start-up operation would be returned to a WWTP, sewer or stored. Under these circumstances, start of testing shall occur at a time designated by the FTO. Testing and reporting shall otherwise be the same including the time variation of effluent concentration and average concentration and removal efficiency for 30 minutes, 60 minutes and 180 minutes for simulated effluents and 30 minutes and total storm for actual storm influents. The Verification Document and Verification Statement shall clearly indicate that the start up phase was not evaluated and that concentration and removal efficiency should be interpreted in that light.

The treatment performance indicators are calculated as follows:

$$Ceff_{p,t} = \frac{\sum_{i=1}^{n} C_{i,p}\,\Delta V_i}{\sum_{i=1}^{n} \Delta V_i} \qquad \text{(Equation 2.2)}$$

Where:

$C_{i,p}$ (mg/L) is the instantaneous concentration of quality parameter ***p*** at the end of the i^{th} sampling interval;

$C_{eff\ p,t}$ (mg/L) is the flow weighted average effluent concentration of parameter P for the duration of testing ***t***;

ΔV_i (gal)	is the flow volume treated in the i[th] interval; and,
n	is the number of sampling intervals spaced at Δt minutes apart.

$$R_{p,t} = \left(\frac{C_{in\,p,t} - C_{eff\,p,t}}{C_{in\,p,t}} \right) x100\% \qquad \text{(Equation 2.3)}$$

Where:

$C_{in\ p,t}$ (mg/L)	is the flow weighted average influent concentration of parameter P for the duration of testing ***t***;
$C_{eff\ p,t}$ (mg/L)	is the flow weighted average effluent concentration of parameter P for the duration of testing ***t***;
$R_{p,t}$ (%)	is the removal efficiency for the performance indicator quality parameter ***p*** for the duration of testing ***t***; and;
t (min)	is the duration of testing which can be for an entire operating cycle of the test equipment or for some lesser period representing one or more phases of an operating cycle (e.g. Start-up Phase). Where $t = n\Delta t$.

The verification testing monitoring program shall allow for determination of removal efficiencies from the influent source to the treated effluent (i.e., raw influent source prior to pre-treatment) and the removal efficiency of the process following pre-treatment (i.e. influent of test equipment).

The core quality parameters that shall be used for evaluating test equipment treatment performance are as follows:

- Total suspended solids – (TSS);
- Total 5-day Biological Oxygen Demand – (BOD_5);
- Total chemical oxygen demand – (COD)
- Total phosphorus (TP)
- Turbidity

Supplemental quality parameters can be included in the Verification Report and Statement at the request of the Manufacturer or others, provided appropriate sampling and analytical protocols have been followed. (See Section 2.5)

All treatment performance measures shall be calculated for each test run and presented separately. Treatment performance shall be presented separately for actual storm and simulated influents. Average treatment performance of all test runs for actual and simulated influent shall also be presented.

2.7.4.2 Test Equipment Operations and Maintenance Performance Indicators

Both quantitative and qualitative performance indicators shall be evaluated to assess test equipment operations and maintenance performance.

Qualitative O&M performance indicators shall be prepared by the FTO, in conjunction with the Manufacturer and Owner and shall include:

- Observations regarding ease of operation during all phases of operation;
- Log of any operating problems recorded during testing;
- Quality of the O&M manual; and,
- Observations regarding labour requirements during all phases of operation.

Quantitative O&M performance indicators shall include:

- Duration in hours of typical start-up and shut-down/clean-out operations;
- Electrical consumption for all unit processes measured as kWh per MG treated;
- Coagulant consumption measured as lb. per MG treated;
- Polymer consumption measured as lb. per MG treated;
- Ballast agent consumption measured as lb. per MG treated;
- Consumables (electricity, coagulant, polymer and ballast agent) cost measured as $ per MG treated. Unit costs used for this calculation as well as an appropriate cost index value (e.g. ENR index) shall also be presented as supporting information;
- Waste sludge mass production measured as lb./MG treated;
- Waste sludge volume production measured as gal/MG treated;
- Waste sludge flow characteristics:
  - continuous or intermittent flow;
  - average sludge flow during a test run measured as gpm;
  - peak sludge flow during a test run measured as gpm.

All the O&M performance indicators shall be measured on a test by test basis. Indicator data shall be presented for each test as well as averages calculated for all testing.

2.7.5 Other Measured Data

To assist the reader in determining how performance data contained in a Verification Report may be applicable to the conditions at another site, the additional information needs to be collected to allow for interpretation of the Verification Statement from site to site. These include both influent and effluent quality characteristics and operational conditions.

2.7.5.1 Influent and Effluent Characteristics

Influent characteristics may vary significantly from site to site and event to event. As a result, there is a need to monitor treatability parameters in addition to the core parameters to fully document the characteristics of the influent wastewater and the resulting effluent characteristics. The following is the complete list of core parameters and treatability parameters:

- TSS*;
- VSS;
- PSD (Particle Size Distribution);
- BOD_5 (soluble and total*);
- COD (soluble and total*);
- Phosphorus (total soluble, total*, ortho);
- pH;
- dissolved solids;
- Settleable solids
- Temperature;
- Alkalinity;
- Turbidity*;
- UV Transmittance.

Notes: *Core performance parameters

If the FTO has chosen to evaluate equipment performance using supplemental parameters, they shall also be included in the overall list.

2.7.5.2 Underflow or Waste Sludge Characteristics

Similarly, for underflow or waste sludge streams, the comprehensive list of parameters is as follows:

- TSS*; and,
- VSS.

* - Core parameters

2.7.5.3 Operational parameters

All operating conditions need to be measured for each verification run for interpretation of results. The following is a list of the operating conditions which need to be measured for each run:

- All flows to the process;
- Waste sludge flows and variations;
- Coagulant, polymer and ballast dosages;
- Electrical power consumption; and,
- Operating conditions of all relevant sludge handling equipment (i.e. pumps, hydrocyclone, etc.).

2.7.6 Data Quality Indicators

Data quality indicators (DQIs) qualitative and quantitative descriptors are used in interpreting the degree of acceptability or utility of data. Principal DQIs include:

- Precision;
- Bias;
- Accuracy;
- Representativeness;
- Comparability; and,
- Completeness.

The acronym PARCC if often employed to stand for the principal DQIs.

The FTO shall determine acceptable values or qualitative descriptors for all PARCC indicators in advance of verification testing as part of the experimental design. The assessment of data quality will require specific field and laboratory procedures to determine the data quality indicators. All details of DQI selection and values shall be documented in the Test Plan. Reference shall be made to EPA Guidance for Quality Assurance Project Plans – Appendix D (EPA QA/G5, 1998) and Guidance for the Data Quality Objectives Process (EPA QA/G-4, 1994) for details.

2.8 Quality Assurance/Quality Control

The FTO shall be required to include discussion on quality assurance prior to the start of verification testing as part of the Test Plan. The quality assurance and quality control (QA/QC) discussion shall specify procedures that shall be used to ensure data quality and integrity. The FTO shall adhere closely to the procedures specified to ensure that data generated by verification testing can serve as a basis for performance verification.

The discussion can be subdivided into the following main areas:

- Project management;
- Measurement/ data acquisition;
- Assessment/ oversight; and,
- Data validation and usability.

The following sections provide an overview of the requirements of each area. Specific information on the requirements is contained within the EPA Guidance for Quality Assurance Plans (EPA QA/G-5).

2.8.1 Project Management

The QA discussion shall include documentation on the management of the project, the project history and objectives, and the responsibilities of each of the participants. The purpose of this element is to ensure that the project approach and goals are clearly stated and understood by all participants. This area shall include a list of individuals involved in the project, their roles and responsibilities, a concise definition of the purpose of the study, a project schedule including a task organization chart, documentation of the data quality objectives, special training and certification requirements, and a complete list of required documentation for the study.

2.8.2 Measurement/ Data Acquisition

The QA discussion shall include specific information on all aspects of the experiment design including a detailed description of each component. Specific requirements in the area of measurement and data acquisition are as follows:

- A schedule of project sampling, analysis, and peer review activities;
- Documentation of any assumptions made in the design of the experiment and all procedures for locating and selecting environmental samples;
- Validation of any non-standard sampling or measurement techniques and equipment to assess the potential impact on the representativeness of the data generated;
- Description of the requirements for sampling handling and custody in the field, laboratory and in transport. The description shall include examples of sample labels, custody forms, and sample custody logs;
- Documentation of analytical methods, equipment and the specific performance for each method. Reference may be made to Standard Methods (APHA 1999) or USEPA Methods (EPA 6001/A-79-020);

- Identification of required measurement quality control checks for both the field and the laboratory. Information presented shall include the frequency of each type of QC check and references for the procedures used to calculate each of the QC statistics;
- Identification of all equipment calibration requirements including standards for calibration, and calibration methods; and,
- Identification of any types of data needed for project implementation obtained from non-measurement sources including definition of acceptance criteria and discussion on the limitations on the use of any such data.

2.8.3 Data Validation and Usability

Data validation and usability shall ensure that individual data collected conform to specific criteria developed to ensure data reconciliation with the project's objectives. QA activities shall form the bulk of data validation and usability. The QA discussion shall include specific information on data review, validation, and verification requirements including the criteria used to review and validate data, validation and verification methods, and reconciliation with data quality objectives.

Specific tables and comparisons used for data validation shall include:

- Comparison of analytical results or field measurements against data precision goals;
- Comparison of analytical results against data accuracy goals;
- Comparison of analytical results from simulated influent data with actual influent;
- Tabulated results of field blanks, trip blanks and laboratory blanks for each core, supplemental or treatability parameter;
- Tabulation of analytical methods and detection limits and working ranges of field instrumentation;
- Presentation of tables indicating data completeness (i.e. number of samples, analyses completed and QA samples versus experimental design); and
- Calibration check data for field instrumentation including flow meters.

2.9 Health Safety and Environmental Plan

The Test Plan shall include details on safety procedures to be followed during the fieldwork. Safety conditions addressed shall include the following:

- Storage, handling and disposal of hazardous chemicals;
- Conformance with applicable electrical and plumbing codes at the test site;

- Ventilation equipment for trailers or buildings housing equipment if gases are present which may pose a safety hazard;
- Any other specific safety or environmental issues associated with a specific piece of equipment; and,
- Any permitting requirements for directly discharged effluents.

2.10 Development of the Test Plan

The FTO shall prepare a Test Plan specific to each location where testing is proposed. The Test Plan shall be prepared in conjunction with the facility Owner and equipment Manufacturer, and shall be reviewed by NSF prior to implementation. The specific contents of the Test Plan can vary from site to site; however, at a minimum, the Test Plan must address the following:

Test Plan Table of Contents

1.0 Purpose of Verification Testing

2.0 Equipment Verification Testing Responsibilities

3.0 Site Characteristics

4.0 Influent Characteristics

5.0 Equipment Description

6.0 Operational Characterization

7.0 Experimental Design

8.0 Field Operations Procedures

9.0 Quality Assurance Project Plan

10.0 Data Management, Analysis and Reporting

11.0 Health, Safety and Environmental Plan

12.0 References

Appendices

1. Standard Operating Procedures (Field and Analytical)
2. Historical Site Characterization Data
3. Influent Characterization Data
4. Operational Characterization Data

3. VERIFICATION TESTING

Verification testing procedures have been divided into two discrete phases:

1. Initial Testing
2. Verification Testing

3.1 Initial Testing

During initial testing, a Manufacturer may want to evaluate equipment operation and determine chemical coagulant types, ballast dosages and other conditions that result in effective treatment of the influent.

After jar testing has identified effective treatment conditions, initial testing should be conducted at the test site to optimize the operating parameters of the Manufacturer's equipment. Several runs may be needed to further refine appropriate chemical types and dosages and operating conditions. This may include adjustment of chemical feed rates, underflows, and influent flow and loadings rates. Other factors may also need to be adjusted to optimize the performance of the equipment. At the end of these tests, an effective operating scheme shall be defined.

It may not be practical to carry out optimization testing using only actual storm events. Consequently, initial testing may employ simulated influent. If it is intended to employ actual storm events for verification testing, it is recommended that at least one actual storm event of duration greater than 3 x HRT be included in the initial testing program.

The initial testing period shall occur prior to the start of verification testing. Initial testing can be concluded once repeatable results are achieved with the optimized equipment settings and chemical feed rates.

The initial period should also be employed to debug field testing, monitoring and sampling equipment and procedures.

Because these runs are being conducted to define operating conditions for verification testing, a strictly defined schedule for sampling and analysis may not need to be followed. However, adhering to the schedule for sampling and analysis to be followed during the verification program would be wise to allow the operator to gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the optimization testing, the NSF may conduct an initial on-site inspection of field operations and sampling activities. The sampling and analysis schedule for verification testing shall be followed during the on-site inspection.

3.2 Verification Testing

The objective of verification testing is to operate the treatment equipment provided by the Manufacturer and assess its ability to meet the effluent concentration goals and removal efficiencies when treating wet weather flow.

Chemically-enhanced high-rate separation equipment shall be operated for verification testing purposes on actual wet weather influent including CSO, SSO and excess wet weather flow at a wastewater treatment plant or a suitable simulated influent. The operation approach and coagulant types and dosages shall be selected based on the results of site and influent characterization, jar testing and initial testing.

3.2.1 Nature of Influent

Verification testing shall be based upon one of the following:

- Testing over a number of actual storm events; or;
- Testing over a number of simulated influent runs; or,
- Testing over a number of actual storm events and simulated influent runs.

The nature of influent(s) and the number of actual storms or simulated events used in verification testing shall be the decision of the FTO. In any event, the details of the proposed number and nature of testing events shall be documented in the Test Plan. In the case where simulated effluent is contemplated, the Test Plan supported by data from influent characterization and jar testing, shall specify the composition and the method of blending the simulated influent. When both actual storm events and simulated influent events are proposed, verification test results shall be presented separately for each.

3.2.2 Operating Cycle

Each test shall be comprised of a complete operating cycle consisting of the following:

- Start-up Phase;
- Normal Dynamic Operation Phase; and,
- Shutdown Phase.

The start-up phase shall consist of bringing the process into normal dynamic operation from rest. This phase consists of the filling of the reactors and an initial period where the process is acclimating.

In certain instances the manufacturer may indicate that it is not contemplated to discharge treated effluent from the test equipment during the start-up phase. Rather, effluent from start-up operation would be returned to a WWTP, sewer or stored. Under these circumstances, start of testing shall occur at a time designated by the FTO. Testing and reporting shall otherwise be the same including the time variation of effluent concentration and average concentration and removal efficiency for 30 minutes, 60 minutes and 180 minutes or 3 times HRT (whichever is greater) for simulated effluents and 30 minutes and total storm for actual storm influents. The Verification Document and Verification Statement shall clearly indicate that the start up phase was not evaluated and that concentration and removal efficiency should be interpreted in that light.

Normal dynamic operation refers to the period when all internal reactor processes are operating at their normal conditions including internal recycle streams, coagulant dosages, etc. During this period, the influent flows and/or quality characteristics will be varying according to the wet weather conditions being encountered or according to the simulated influent flow patterns up to the maximum flow handling capacity of the equipment. The duration of this phase or the simulated test conditions shall be dependent on the wet weather event experienced or predetermined under simulated operation

Following the normal dynamic operation phase, there will be no more influent to the process and treated effluent is no longer produced. At this point, the process shall be shutdown and prepared for the next wet weather event or simulated influent test.

Consideration should be given in the operating cycle to cleaning between real storm events or simulated test runs. The cleaning activities shall parallel those recommended by the manufacturer for full scale application.

3.2.3 Measured Parameters and Measured Process Streams

Verification testing shall include the following measured parameters:

- Core treatment performance parameters;
- Any supplemental performance parameters selected by the FTO;
- All measurements supporting determination of Operations and Maintenance performance parameters; and,
- Treatability parameters.

Measured process streams during verification testing shall include:

- Raw influent prior to pre-treatment;
- Influent to test equipment;
- Effluent from test equipment; and,
- Sludge or underflow from test equipment.

3.2.4 Sampling and Monitoring Strategy

Sampling of all streams shall be carried out at a representative location using industry standard procedures. Automatic samplers may be employed for sampling but it will be incumbent upon the FTO to demonstrate that the use of automatic sampling equipment does not bias test results.

The estimation of $C_{eff\ p,t}$ and $R_{p.t}$ for each core parameter for various durations, requires that sequential sub-samples be collected. The FTO shall collect sub-samples at pre-determined time intervals (Δt) during the entire duration of verification testing. The raw influent, test equipment influent and effluent sub-samples and the determination of the time variation of $C_{eff\ p,t}$ shall then be appropriately preserved and taken for analysis.

It is recognized that for actual storm events, it is difficult, if not impossible, to predict the exact duration of a particular event. At the same time, when automatic sampling equipment is employed, the total duration of sampling must be pre-determined. The FTO shall review rainfall and influent flow (e.g. CSO, SSO, WWTP excess flow) historical data and determine the appropriate frequency and number of sub-samples based upon this information. Sub-sampling shall be more frequent during the start-up phase (i.e. first 30 minutes) of testing. Table 3.1 presents the sampling frequency for actual storm events.

Table 3.1 Influent/Effluent Sampling Frequency for Actual Storm Events

Process Stream	Operations Phase	Duration of Sampling for Phase (minutes)	Sample Interval (minutes)	No. of Sub-Samples [1]
Raw Influent	• Start-up • Dynamic Operation	30 Storm duration	5 Variable	6 Up to 18
Test Equipment Influent	• Start-up • Dynamic Operation	30 Storm duration	5 Variable	6 Up to 18
Test Equipment Effluent	• Start-up • Dynamic Operation	30 Storm duration	5 Variable	6 Up to 18

Notes: 1) The number of sub-samples assumes a standard tray of 24 bottles.

For simulated influent conditions, the sampling frequency is presented in Table 3.2. In this case, an additional sample covering the period from start-up to 30 minutes into dynamic operation has been suggested (initial dynamic sample).

Table 3.2 Influent/Effluent Sampling Frequency for Simulated Storm Conditions

Process Stream	Operations Phase	Duration of Sampling for Phase (minutes)	Elapsed Time Since Start of Testing (minutes)	Sample Interval (minutes)	No. of Sub-Samples
Raw Influent	• Start-up • Initial Dynamic • Dynamic	30 30 120	30 60 180	5 5 20	6 6 6
Test Equipment Influent	• Start-up • Initial Dynamic • Dynamic	30 30 120	30 60 180	5 5 20	6 6 6
Test Equipment Effluent	• Start-up • Initial Dynamic • Dynamic	30 30 120	30 60 180	5 5 20	6 6 6

The sampling frequency for waste sludge/underflow is presented in Table 3.3 for actual storms and simulated influent conditions.

Table 3.3 Sampling Frequency for Waste Sludge/Underflow

Influent Type	Operations Phase	Sample Interval (minutes)	Number of Samples
Actual Storm	• Start-up • Dynamic Operation	• 15 or at first blowdown • 30 or at blowdowns	Up to 2 Storm duration dependant
Simulated Influent	• Start-up • Initial Dynamic • Dynamic Operation	• 15 or at first blowdown • 30 or at blowdown • 30 or at blowdown	Up to 2 Up to 1 Up to 4

The recommended monitoring strategy for other measured parameters is presented in Table 3.4. The FTO may adopt alternative monitoring approaches but shall be required to document the details of these approaches and to provide assurance that alternative approaches will produce appropriate data quality.

Table 3.4 Monitoring Strategy for Verification Testing – All Phases

Parameter	Frequency of Monitoring	Comments
• Flow	• Continuous	• Influent, effluent, underflow
• Waste Sludge Volume	• At blowdown/continuous	
• Chemical Feed	• Prior to start and every 30 minutes thereafter	• Applicable to coagulant, polymer and ballast agent
• Electrical Power	• Twice during verification test	• Measured for flash mixer, flocculator and recirculation pump
• On-Site Testing	• Continuous or at same sample frequency as shown in Table 3.1, 3.2 and 3.3	• Typically pH, temperature • May also include turbidity and other parameters

Again, if it is determined to divert flows from the test unit during the initial period of operation, start-up shall be deemed to be the first 30 minutes of operation during which effluent discharge occurred.

4. DATA ASSESSMENT AND REPORTING

4.1 Data Assessment

Verification testing will generate a significant amount of data. All raw data shall be included along with all analysis results in the Verification Report. Raw data shall be included in hard copy form and in electronic format. Data in electronic format shall be included in generally commercially available programs for word processing, spreadsheet or database processing, or commercial software developed especially for data collection and processing on a specific hardware instrument or piece of equipment.

The Verification Report shall be a comprehensive document containing all raw and analyzed data, all QA/QC data sheets, a description of all types of data collected, a detailed description of the testing procedure and methods, results and QA/QC results. The Test Plan(s) shall also be included as part of the Verification Report.

All raw test data shall be included in the verification test study records. Raw test data includes all paper records including field notebooks, bench sheets, field data sheets, custody sheets, and instrument printouts.

Data assessment steps shall include:

- Data verification/ Validation confirming that requirements of QC acceptance have been met. (e.g. comparison of DQIs)
- Data reduction, summarizing and/ or averaging data
- Synthesis of results into tables and charts.

4.2 Performance Results

4.2.1 Treatment Performance

All simulated results will be reported separately from actual storm results. Individual test results as well as averages by influent type will be presented.

For the analytical data obtained during the verification testing, 95% confidence intervals shall be calculated by the FTO for core parameter effluent concentrations and percent removals. As the name implies, a confidence interval describes the range in which any population measurement may exist with a specified percent confidence. The following equation can be employed for confidence interval calculation for normally distributed parameters:

$$95\%\ Confidence\ Interval = X \pm t_{n-1,0.975}\ (S/\sqrt{n})$$ (Equation 4.1)

where:

X is the sample mean;

S is the sample standard deviation;

n is the number of independent measurements in the data set; and,

t is the Student's distribution value with n-1 degrees of freedom.

Calculation of confidence intervals shall not be required for equipment operating results such as flows, chemical dosages, hydraulic retention times, SORs, etc.

Please note that Section 4.2.1 is based on the assumption that the results obtained from analysis of samples will be normally distributed. This may not be the case; it may be obvious that a graph of the data would be skewed. In such instances, it may be more appropriate to apply the relevant statistics to the log transforms of the basic data and then apply the relevant inverse transforms as appropriate. In other words, a log normal distribution may need to be determined to obtain a nearly normal distribution.

Simulated Results

Results shall be presented in the Verification Report and Verification Statement for each test run using simulated influent for the following:

- Flow weighted average effluent concentrations and data range for:
  - First 30 minutes after start-up;
  - First 60 minutes after start-up; and,
  - Full test (180 minutes) or 3 times HRT, whichever is longer.
- Time variation of effluent concentration for the full test run;
- Removal efficiency from raw influent to final effluent:
  - First 30 minutes after start-up;
  - First 60 minutes after start-up; and,
  - Full test (180 minutes) or 3 times HRT, whichever is longer.
- Removal efficiency from equipment influent (following pre-treatment) to final effluent:
  - First 30 minutes after start-up;

- First 60 minutes after start-up; and,
- Full test (180 minutes) or 3 times HRT, whichever is longer.

Results of testing from all simulated influent tests shall be arranged and presented as follows:

- Average effluent concentrations and 95% confidence intervals;
  - First 30 minutes after start-up
  - First 60 minutes after start-up
  - Full test (180 minutes) or 3 times HRT, whichever is longer
- Time variation of effluent concentrations plotted for all test runs;
- Removal efficiency from raw influent and equipment influent and 95% confidence intervals for:
  - First 30 minutes after start-up
  - First 60 minutes after start-up
  - Full test (180 minutes) or 3 times HRT, whichever is longer.

The flow-weighting scheme for simulated as well as actual storm influents is presented in Table 4.1.

Table 4.1 Influent/Effluent Flow Weighting Scheme

Influent Type	Operations Phase	Time Since Start (minutes)	Calculation Scheme
Actual Storm Influent	• Start-up	30	• Calculate the flow weighted average with the 6 sub-samples using flow volumes during sampling intervals (ΔV_i) for flow-weighing
	• Dynamic	Storm duration less 30 minutes	• Calculate from start-up using appropriate remaining interval volumes (ΔV_I) for flow-weighing
Simulated Influent	• Start-up	30	• Calculate the flow weighted average with the 6 sub-samples using flow volumes during sampling intervals (ΔVi) for flow-weighting
	• Initial Dynamic	60	• Calculate from start-up using appropriate remaining interval volumes (ΔV_I) for flow-weighting for first 60 minutes
	• Dynamic	180 or 3 times HRT, whichever is longer	• Calculate from start-up using the appropriate volume (ΔV_I) for flow-weighting for 180 minutes or 3 times HRT, whichever is longer

Actual Storm Influent

Results will be presented in the Verification Report and Verification Statement for actual storms of duration ≥3 times HRT calculated using Qd. Results shall be stratified into two groups as follows:

- Q_{peak} ≥0.67 Qd for peak flows of duration ≥ 3 x HRT
- Q_{peak} <0.67 Qd for total storm durations of ≥ 3 x HRT

For each individual storm in each size group, the following results shall be presented:

- Flow weighted average effluent concentrations and data range for:
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.
- Time variation of effluent concentrations;
- Removal efficiency from raw influent to final effluent:
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.
- Removal efficiency from pre-treatment effluent to final effluent :
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.

For the average of all storms in each size group, the following results shall be presented:

- Flow weighted average effluent concentrations and 95% confidence intervals:
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.
- Time variation of effluent concentrations;
- Removal efficiency from raw influent to final effluent and 95% confidence intervals:
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.
- Removal efficiency from pre-treatment effluent to final effluent and 95% confidence intervals:
  - First 30 minutes after start-up; and,
  - Full storm or duration of sampling.

The flow-weighting scheme for actual storm influents was also presented in Table 4.1.

4.2.2 O&M Performance

The following data or information shall be presented in the Verification Report and Verification Statement regarding test equipment operations and maintenance performance:

Qualitative O&M performance indications shall include:

- Observations regarding ease of operation during all phases of operation;
- Log of any operating problems recorded during testing;
- Quality of the O&M manual; and,
- Observations regarding labor requirements during all phases of operation.

Quantitative O&M performance indicators shall include:

- Duration in hours of typical start-up and shut-down/clean-out operations;
- Electrical consumption for all unit processes measured as kWh/MG treated;
- Coagulant consumption measured as lb/MG treated;
- Polymer consumption measured as lb/MG treated;
- Ballast agent consumption measured as lb/MG treated;
- Consumables unit cost measured as $/MG treated. Unit costs used for this calculation as well as an appropriate cost index value (e.g. ENR index) shall also be presented as supporting information;
- Waste sludge mass production measured as lb/MG treated;
- Waste sludge volume production measured as gal/MG treated;
- Waste sludge flow characteristics:
  – continuous or intermittent flow;
  – average sludge flow during a test run measured as gpm;
  – peak sludge flow during a test run measured as gpm.

All the O&M performance indicators shall be measured on a test by test basis. Indicator data shall be presented for each test or storm event as well as averages calculated for all testing.

4.2.3 Other Measured and Calculated Data

All other measured data including the following shall also be reported in the Verification Report:

Influent and Effluent Characteristics

All influent and effluent data for core and supplemental treatment performance parameters shall be presented as indicated in Section 4.2.1. In addition, influent and effluent treatability parameters shall be presented including the following:

- VSS;
- Soluble BOD_5;
- Soluble COD;
- Soluble total and ortho phosphorus;
- pH;
- Temperature;
- Alkalinity;
- PSD;
- Dissolved solids; and,
- UV Transmittance.

All influent and effluent treatability data shall be averaged for each test run using the flow weighting scheme presented in Table 4.1. Data presented shall include:

- For simulated influents, the influent and effluent treatability parameter concentration data averaged for each test and for all tests shall be reported. The time variability of treatability parameter concentrations shall also be reported;
- For simulated influents, if discrete samples are analyzed, the influent and effluent treatability parameter data range for each test shall be reported;
- For actual storm events with Q peak ≥ 0.67 Qd and duration ≥ 3 x HRT, the influent and effluent treatability parameter concentration data averaged for each test and for all tests, shall be reported. The time variation of treatability parameter concentrations shall also be reported;
- For actual storm events with Q peak ≥ 0.67 Qd and duration ≥ 3 x HRT, the influent and effluent treatability parameter data range for each test shall be reported;

- For actual storm events with Q peak < 0.67 Qd and duration ≥ 3 x HRT, the influent and effluent treatability parameter concentration data averaged for each test and for all tests, shall be reported. The time variation of treatability parameter concentrations shall also be reported; and,
- For actual storm events with Q peak < 0.67 Qd and duration ≥ 3 x HRT, the influent and effluent treatability parameter data range for each test shall be reported.

Underflow or Waste Sludge Characteristics

Underflow or waste sludge treatability parameters shall include:

- VSS.

Measured Operational Parameters

Measured operational parameters shall include:

- Influent and effluent flows;
- Underflow flows (if appropriate);
- Coagulant, polymer or ballast dosages; and,
- Electrical utilization.

For actual and simulated influent test runs, the FTO shall report the following in addition to the requirements in Section 4.2.2:

- The time variation of influent, effluent and underflow flows;
- Average and peak influent and effluent flow rates;
- Total volume of effluent, influent and underflow/sludge produced;
- Average coagulant, polymer and ballast dosages for the test run; and,
- Electrical utilization in kWh for the test run.

Data shall be reported for each test run and clearly indicated as simulated or actual storm influent and again for actual influents, be differentiated as Q peak ≥ 0.67 Qd or Q peak < 0.67 Qd.

Calculated Operational Parameters

Calculated operational parameters shall include the following in addition to the data requested in Section 4.2.2.

- Degritting tank (if appropriate) HRT calculated for average and peak flows during a test run;
- Rapid mix tank HRT calculated for average and peak flows during a test run;

- Flocculation tank HRT calculated for average and peak flows during a test run; and,
- Clarifier HRT and surface overflow rate (SOR) calculated for average and peak flows during a test run.

Calculated operation parameters shall be evaluated and presented for each simulated or actual storm influent test run and again for actual storm influents be differentiated by the Q peak criterion. Runs shall be clearly labelled as actual or simulated influents.

4.3 Verification Report

The FTO shall prepare a draft Verification Report describing the verification testing that was carried out and the results of that testing. The Verification Report shall undergo a complete review by NSF International and the EPA, as well as a peer review as recommended by the Technology Panel on High Rate Separation. The vendor shall review and be provided the opportunity for input on its content. This report should full describe the technology and the verification of its performance characteristics. At a minimum, shall include the following items:

- Introduction
- Executive Summary
- Description and Identification of product Tested
- Procedures and Methods Used in Testing
- Results and Discussion
- Conclusions and Recommendations
- References
- Appendices, which may include test data.

4.4 Verification Statement

NSF and EPA shall prepare a Verification Statement that briefly summarizes the Verification Report for issuance to the technology vendor. The Verification Statement shall provide a brief description of the testing conducted and a synopsis of the performance results. The Statement is intended to provide verified vendors a tool by which to promote the strengths and benefits of their product.

5. REFERENCES

ANSI/ASQC: *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs (E4)*, 1994.

United States Environmental Protection Agency: *Environmental Technology Verification Program - Quality and Management Plan for the Pilot Period (1995 – 2000)*, EPA/600/R-98/064, 1998. Office of Research and Development, Cincinnati, Ohio.

NSF International, *Quality Management Plan*, ETV Pilot – Wet Weather Flow Technologies, 2000. Ann Arbor, Michigan.

United States Environmental Protection Agency: *Methods for Analysis of Water and Wastes*, EPA/600/4-79-020. Office of Research and Development, Washington, DC.

APHA, AWWA, and WEF: *Standard Methods for the Examination of Water and Wastewater*. Washington, DC. 20th Edition, 1999.

United States Environmental Protection Agency: *EPA Guidance for Quality Assurance Project Plans*, *EPA QA/G-5*, EPA/600/R-98-018, 1998. Office of Research and Development, Washington, DC.

United States Environmental Protection Agency, *Guidance for the Data Quality Objectives Process*, *EPA QA/G-4*, EPA/600/R-96-055, 1996. Office of Research and Development, Washington, DC.

XCG File #3-1077-01

DRAFT VERSION 4.2

GENERIC VERIFICATION PROTOCOL FOR CHEMICALLY-ENHANCED HIGH-RATE SEPARATION

MAY 26, 2000

Submitted to:

NSF INTERNATIONAL
789 DIXBORO ROAD
ANN ARBOR, MICHIGAN 48105

Submitted by:

XCG CONSULTANTS LTD.
1 PORT STREET EAST, SUITE 201
MISSISSAUGA, ONTARIO
L5G 4N1

With Support From:

U.S. ENVIRONMENTAL PROTECTION AGENCY
ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

TABLE OF CONTENTS

FIGURES

TABLES