Test Plan for Performance Evaluations of Ballast Water Filter Systems

Maritime Environmental Resource Center

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1. Background and Objectives of MERC Technology Evaluations

The Maritime Environmental Resource Center (MERC) is a State of Maryland initiative that provides test facilities, information, and decision tools to address key environmental issues facing the international maritime industry. The primary focus is to evaluate the mechanical and biological efficacy, costs, and logistical aspects of ballast water treatment systems and to assess the economic impacts of ballast water regulations and management approaches. A full description of MERC structure, products, and services can be found at www.maritime-enviro.org.

To address the need for effective, safe, and reliable ballast water treatment systems to prevent the introduction of non-native species, MERC has developed as a partnership between the Maryland Port Administration (MPA), Chesapeake Biological Laboratory/ University of Maryland Center for Environmental Science (CBL/UMCES), U.S. Maritime Administration (MARAD), National Oceanic and Atmospheric Administration (NOAA), Smithsonian Environmental Research Center (SERC), and University of Maryland (UM) to provide independent performance testing and to help facilitate the transition of new treatments to operations. Treatment evaluation efforts will also take advantage of expertise and the rigorous technology evaluation format/process developed by the Alliance for Coastal Technologies (ACT, www.act-us.info). ACT is NOAA-funded distributed testbed, headquartered at CBL/UMCES, dedicated to fostering the development and adoption of effective and reliable sensors for studying and monitoring coastal environments.

The following protocols describe how MERC will evaluate the performance characteristics of commercially available ballast water filtration systems through objective and quality assured "pilot-scale" testing (dockside testing at a nominal flow rate of 200m^3/hr). The goal of this specific MERC evaluation is to provide shipping lines, regulators, and flag states with an independent and credible assessment of filter performance under realistic conditions. Therefore, the data and information on performance characteristics will cover legitimate information that users need.

It is important to note that MERC itself does not certify technologies or guarantee that a technology will always, or under circumstances other than those used in testing, operate at the levels verified. MERC does not label or list technologies as acceptable or unacceptable but will present results in a way that can be used to determine regulatory compliance by appropriate agencies of certification societies. Final reports on technology performance will be reviewed by the MERC Advisory Board and provided to filter manufacturers and the MERC funding agencies prior to public release.

2. Introduction to Technology

The filter vendor has provided filter materials for electronics and biopharm applications for over 30 years. Recently the vendor developed a revolutionary new filtration material suitable for high performance water filtration applications. They are now selling this product into electronics polish loop applications. The vendor is a technology/innovation based company which focuses on exploiting the properties of PTFE materials, developing products which add high value in challenging applications. The purpose of this test plan is to determine the effectiveness of the removal of particulates and bacteria from ballast water through the use of a variety of filter cartridge arrangements. The life of the filter cartridges, as defined by the total volume filtered before reaching 30 psid differential pressure, will also be investigated

3. Protocols for Pilot-Scale Evaluations of Ballast Water Filter Systems

Basic Experimental Design:

MERC will evaluate the efficacy of ballast filtration systems onboard the MARAD vessel *M/V Cape Washington* while docked in Baltimore Harbor, Maryland (right). The ballast system of the *Cape Washington* has been modified to allow for delivery of ballast water at variable flow rates up to 700 m^3/hr and pressures up to 36 psi. A nominal flow rate of ≈10 gph (0.4 m3) shall be delivered to the vendor filtration system at a pressure specified by the manufacturer. A detailed drawing of the modified ship ballast system can be found on page 9.

It is important to note that protocols will be the same for all filter trials However, tests of different filters will NOT be conducted simultaneously, and MERC will NOT compare the performance of the systems evaluated. Thus, a final report specific to this filter system will be written upon completion of the evaluation.

MERC will allow the vendor to conduct one leak test to assure proper operations, then six (6) unique trials will be conducted (Appendix 1): 1. An initial test trail will evaluate the efficiency of the polish filter system (Filter #1, 0.1 micron rating, 20" length) without pre-filtering. 2. The second trial will evaluate the efficiency of the polish filter system (Filter #5, 0.1 micron rating, 20" length) without pre-filtering. 3. The third trial will evaluate the efficiency of a prefilter (20micron prefilter #2, 20" length)and the polish filter system (Filter #1, 0.1 micron rating, 20" length). 4. The fourth trial will evaluate the efficiency of a prefilter (20micron prefilter #2, 20" length)and the polish filter system (Filter #5, 0.1 micron rating, 20" length)). 5. A fifth trial will evaluate the efficiency of three prefilters (20micron prefilter #2, 20" length, 10micron prefilter #3, 20" length, and

5micron prefilter #4, 20" length) and the polish filter system (Filter #1, 0.1 micron rating, 20" length). 6. The final trial will evaluate the efficiency of three prefilters (20micron prefilter #2, 20" length, 10micron prefilter #3, 20" length, and 5micron prefilter #4, 20" length) and the polish filter system (Filter #5, 0.1 micron rating, 20" length). (see also table 3.1 below).

Table 3.1 Test plan for membrane filters

Test Number	Filter Type
1	Filter # 1, 0.1 micron, 20" length
2	Filter # 5, 0.1 micron, 20" length
3	20 micron prefilter #2, 20" length
	Filter # 1, 0.1 micron, 20" length
4	20 micron prefilter #2, 20" length
	Filter # 5, 0.1 micron, 20" length
5	20 micron prefilter #2, 20" length
	10 micron prefilter #3, 20" length
	5 micron prefilter #4, 20" length
	Filter # 1, 0.1 micron, 20" length
6	20 micron prefilter #2, 20" length
	10 micron prefilter #3, 20" length
	5 micron prefilter #4, 20" length
	Filter # 5, 0.1 micron, 20" length

The inability to successfully complete (without interruption) an individual test trial, will be considered a "failure". If a failure is determined to be a result of problems associated with the MERC test system or process (e.g., problem with ship's ballast system), the test trial will be discarded and repeated. If the failure is determined to be a result of the filter system (e.g., a mechanical failure resulting in an interruption of filtration during a test run), the results will be noted and included in the final report.

These evaluations will be based upon a simple comparison between organisms and suspended particles found in pre filtered (35 micron) challenge water (just upstream of the filter system) and organisms and suspended particles just downstream of the vendor filter system. Results will be presented as total concentrations (live plus dead) of zooplankton and phytoplankton, and concentrations of total heterotrophic bacteria and three specific indicator pathogens, *E. coli*, intestinal *Enterococci*, and toxigenic *Vibrio cholerae*. , all measured both before and after the filter system. Total suspended solids (TSS), and particle size distributions (PSD) will be measured before and after each filter. See Figure 1 and pages 11 and 12 for more details on the filter evaluation system design.

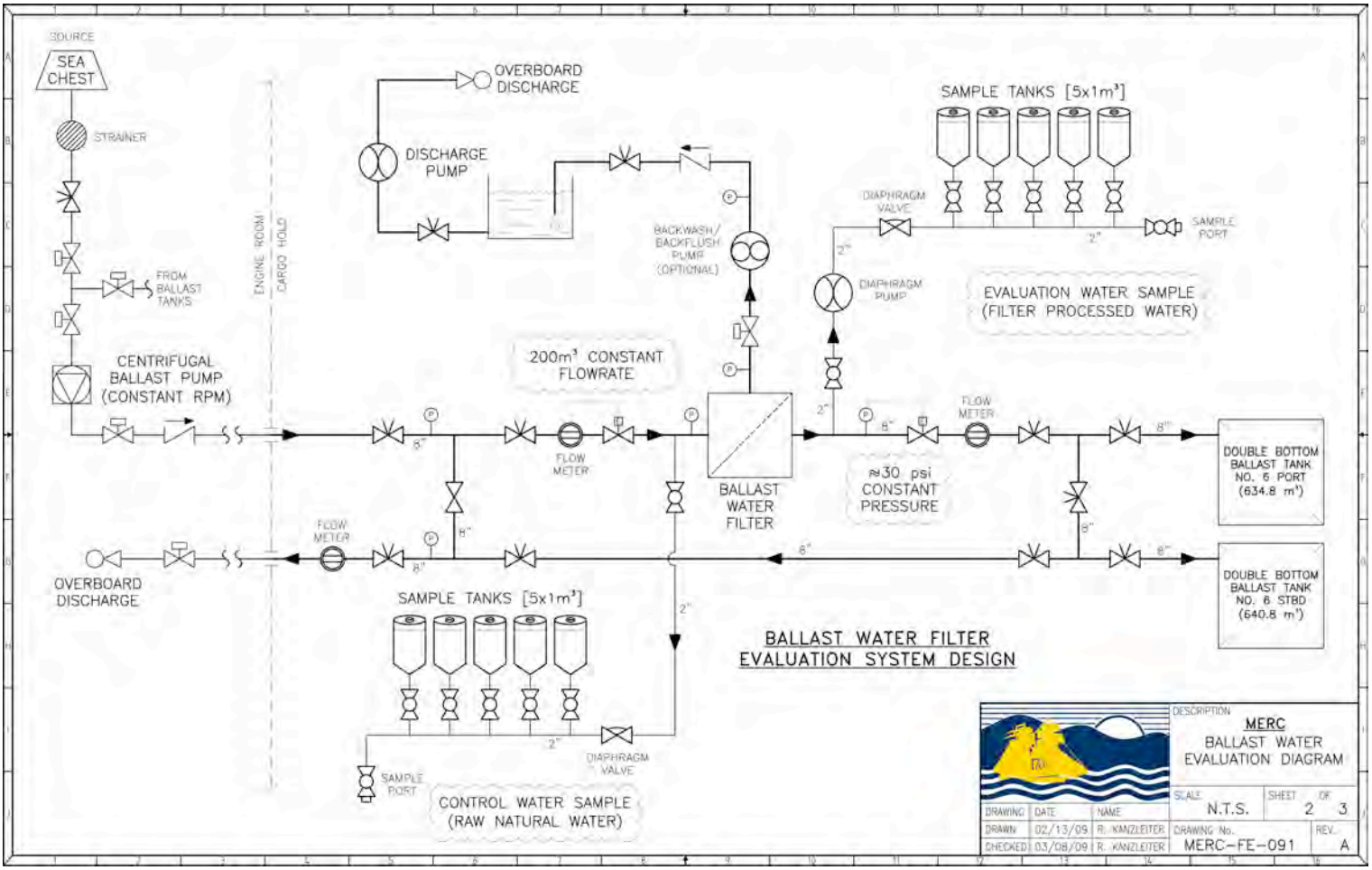


Figure 1. MERC Ballast Water Filter Evaluation System Design

Sampling Design:

The filter system will be operated for five to six hours continuously during each test trial (Appendix 1). The duration of each test trial is dependent upon a specific filtered amount of 3000 gallons (11.4 m3). During the initial 30 minutes, the middle 30 minutes and last 30 minutes, the following samples will be collected. To quantify organisms and particles in the ambient water, water will be collected from the sample port located just upstream of the test filter system (but downstream of the MERC prefilter system) during each of the 3 time points. The filter effluent shall be sampled during the same three 30-minute time periods. Water samples will be collected for zooplankton (upstream only), phytoplankton, and bacteria. In addition, TSS and PSD samples will be collected before and after each separate vendor filter within their filter system. Sample volumes plus details of the physical and biological analyses for each sample are described below.

Basic Water Quality:

A hand-held multi-parameter instrument will be used to measure temperature, salinity, and dissolved oxygen of the water at each sample point (described above) as it is collected. This is considered ancillary data and helps to characterize the ambient conditions during testing.

Total Suspended Solids (TSS):

At each time point, water will be collected by MERC before the test platform and after the initial prefilter (#2 if used) while water will be collected by the vendor after each additional filter used, an appropriate amount filtered, then analyzed for TSS. Sample analyses will be conducted by the vendor.

Particle Size Distributions

At each time point, water will be collected before each filter and after the final filter, kept cold and dark, then shipped overnight to a certified laboratory for next-day analysis of particle size distribution. The size distribution of particles (range 0 – 2 mm) will be analyzed using the laser light scattering method (ASTM D4464).

Phytoplankton

At each time point, 250 ml of unfiltered water upstream and downstream of the test platform will also be collected (in an amber Nalgene bottle) to determine concentrations of phytoplankton. These subsamples will be fixed with standard Lugol's solution and analyzed by using a Zeiss IM inverted microscope with (1 ml to 500 μl depending on cell density) direct counts under a Sedgewick rafter slide.

Zooplankton

At each time point, 500 ml of unfiltered water upstream of the test platform will also be collected (in an amber Nalgene bottle) to determine concentrations of zooplankton. Total concentration of organisms will be determined using standard techniques of fixation and analysis. Zooplankton samples will be fixed with buffered, 10% formalin in 125ml Nalgene bottles and transported to SERC for quantification. Total counts and general taxonomic classification will be conducted under a dissecting microscope at approximately 25X. In the case of samples containing high numbers of zooplankton such as the unfiltered or 'control', this assay may involve subsampling and scaling to report concentrations in the form of numbers per cubic-meter. Where numbers are very low, as may be if filtering is very effective, every organism in the sample will be individually counted. Larval forms of invertebrates will be identified to higher taxonomic levels such as order (e.g., Decapoda) suborder (e.g., Balanomorpha) or class (e.g., Bivalvia). Adults will be identified to species in most cases.

Bacteria

One liter of raw water will be collected in clean, labeled 1-liter bottles upstream and downstream of the test platform. Each bottle will be sample-rinsed 3 times, the sample collected, then the bottles placed in a cooler to keep dark and cool for immediate transport back to the lab to be tested for total heterotrophic bacteria, *Escherichia coli*, *Enterococci*, and *Vibrio cholerae*. To determine total bacterial densities, 1ml of water sample will be diluted and spread in triplicate onto Marine Agar (MA) and incubated at 25ºC or room temperature for 5 days. Colony forming units will be counted at day 3 and 5, and recorded as colony forming units (CFU) per 100 mL of

sample water. *E. coli* density will be assayed by membrane filtration and incubation on modified thermo tolerant *E. coli* agar (mTEC) (Becton Dickson, Sparks, MD). Enterococci densities will be estimated using the IDEXX Enterolert kits (IDEXX Laboratories, Inc., Westbrook, ME). Toxigenic *V. cholerae* densities will be determined by a DNA colony blot hybridization method that detects *ctxA* gene. Total bacterial cells will be fixed after filtering 100 mL of sample water through a 0.22 μm nucleopore polycarbonate membrane, with formalin to preserve cells. Viable *V. cholerae* O1 cells will be enumerated using a direct-fluorescent antibody kit (DFA) (New Horizons Diagnostics).

Sample and Data Management:

We will use the established SERC ballast water sample labeling and databases format and structure for this evaluation. Sample-labels and record keeping check-lists will be generated using SERC protocols, and data will be stored both in existing SERC databases (servers) and in a MERC repository for analytical data.

Data Analysis

Although multiple samples and measures from each tank will be taken, to avoid pseudo-replication, the unit of replication for statistical analyses is each trial (n = 3+). We assume that all measures for a single trial provide one estimate of filter system efficacy. Thus, efficacy for any parameter is estimated as changes found before and after filtration (percent reduction). This approach controls for variation due to temporal changes in environmental conditions.

4. Evaluation Schedule (dates listed are based on current plan and may vary)

- MERC Test Plan for Filter System Evaluations completed and Evaluation Agreement signed by TBD.
- Filter System(s) will be delivered to the Cape Washington in Baltimore by TBD.
- Filter Systems will be installed and operational by TBD.
- First evaluations of the Filter Systems initiated TBD.
- MERC will complete sample analysis and compile data from the evaluation by TBD.
- MERC will distribute a draft report on the performance of individual Filter System for review by the MERC Advisory Board and individual manufactures by t1t1 TBD.
- MERC will submit a final report to MPA, MARAD, NOAA and manufacturer by TBD

5. Data Recording, Processing, and Storage

This section describes methods employed during data recording, processing, and storage to minimize errors and assure high quality analyses.

Documentation and Records:

A variety of data will be acquired and recorded electronically and manually by MERC partners (CBL/UMCES, SERC, and UM) during this evaluation. Operational information and results will generally be documented in field/laboratory record books and on the data

sheet/chain-of-custody forms (see below). Copies of these raw data will be transferred to the MERC office, which will store it permanently along with the rest of the study data.

Data Review:

All data are to be recorded directly in the field/laboratory record book as soon as they are available. Records are to be written in water-proof ink and written legibly. Any corrections will be initialed by the person performing the correction, will be crossed out with a line (not blackened or white-out), and will be dated according to the date that the correction was made. These data will include electronic data, entries in field/laboratory record books, operating data from the MERC test facility, and equipment calibration records. Records will be spot-checked within two weeks of the measurement to ensure that the data are recorded correctly. The checker shall not be the individual who originally entered the data. Data entries shall be checked in general for obvious errors and a minimum of 10 percent of all records shall be checked in detail. Errors detected in this manner shall be corrected immediately. The person performing the review will add his/her initials and the date to a hard copy of the record being reviewed. The MERC staff member will place this hard copy in the files for this evaluation. In addition, data generated by each MERC staff will be provided to the MERC Program Coordinator and reviewed before they are used to calculate, evaluate, or report results.

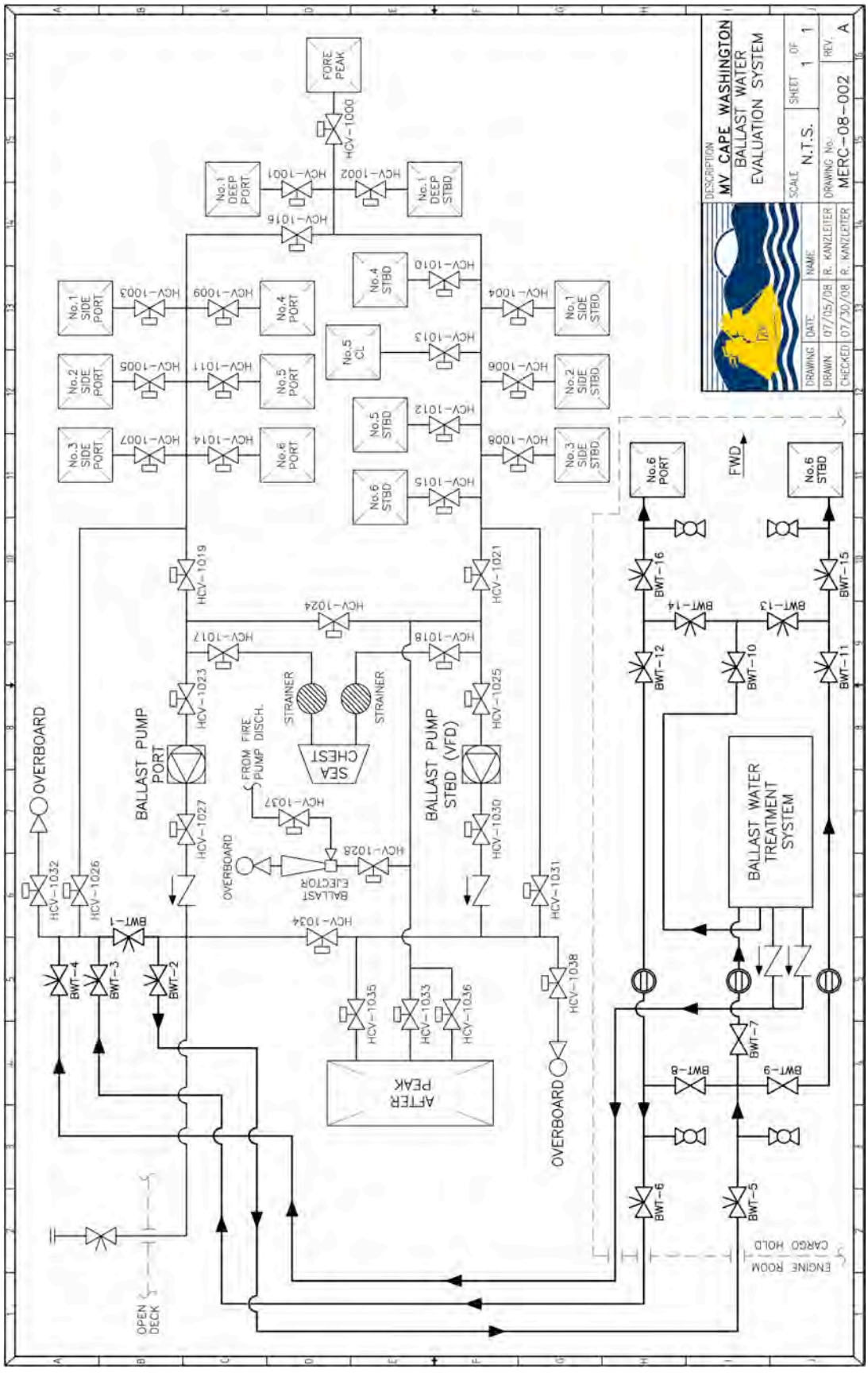
6. Quality Assurance/Quality Control

Treatment and filtration performance evaluations are implemented according to the Test/QA plans and technical documents (e.g., Standard Operating Procedures) prepared during planning of the evaluation. Prescribed procedures and a sequence for the work are defined during the planning stages, and work performed shall follow those procedures and sequence. Technical procedures shall include methods to assure proper handling and care of test instruments. All implementation activities are documented and are traceable to the Test/QA plan and SOPs and to test personnel.

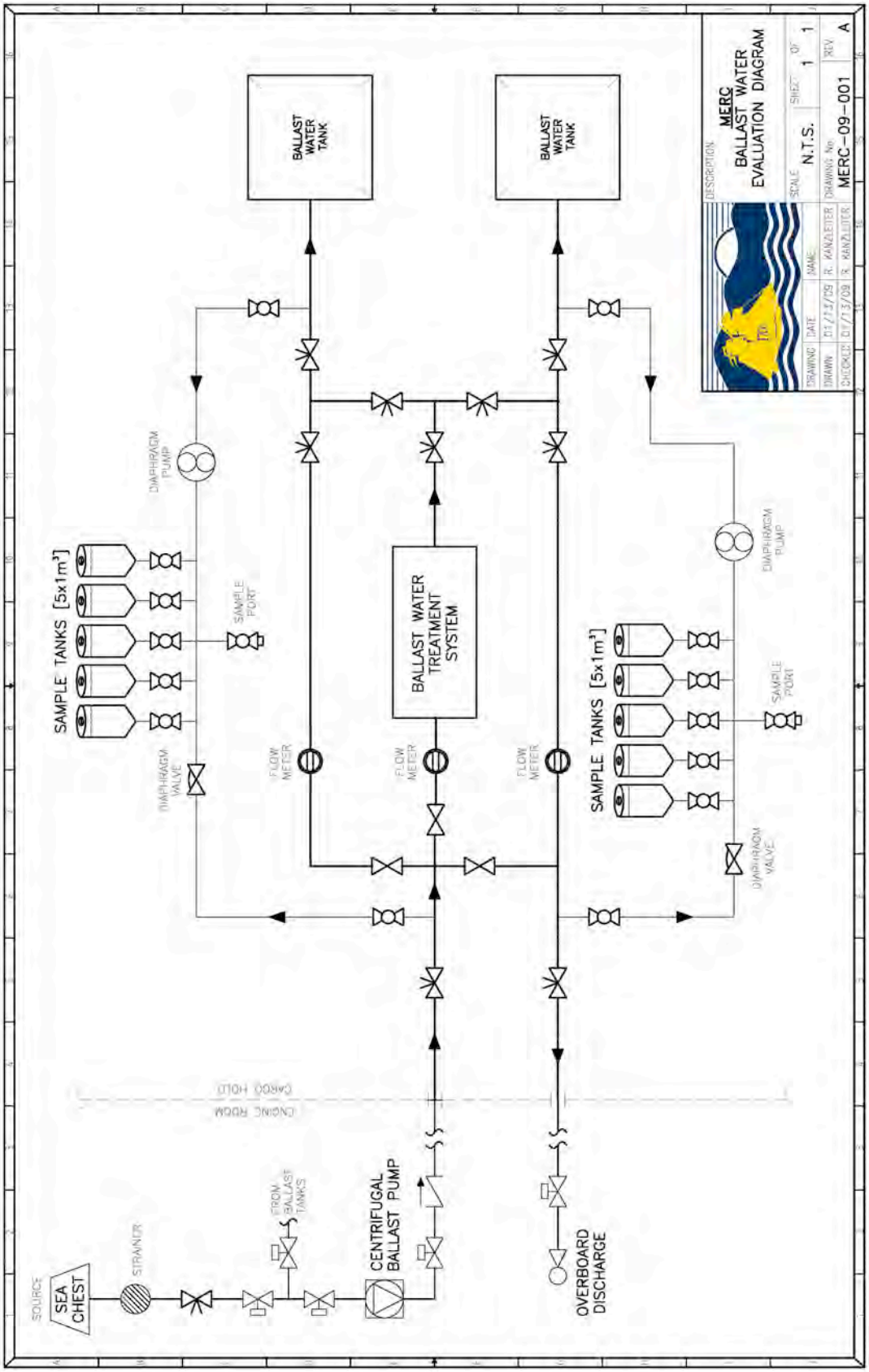
7. Roles and Responsibilities

The evaluation is coordinated and supervised by the MERC Principal Investigator, Program Coordinator and MERC personnel. Staffs participate in this test by installing, maintaining, and operating the respective technologies throughout the test; operating the reference equipment, collecting the water samples, downloading the data from the instrument package, and informing the MERC Program Coordinator staff of any problems encountered. Manufacturer representatives shall install, calibrate, maintain, and operate the filter system. QA oversight is provided by the MERC Program Coordinator. In addition to aiding the development of these protocols, the MERC Advisory Board will be consulted during the evaluation in the event problems occur, will assist in the analyses of results, and will review the final Filter Performance Report prior to release. Specific responsibilities are detailed below.

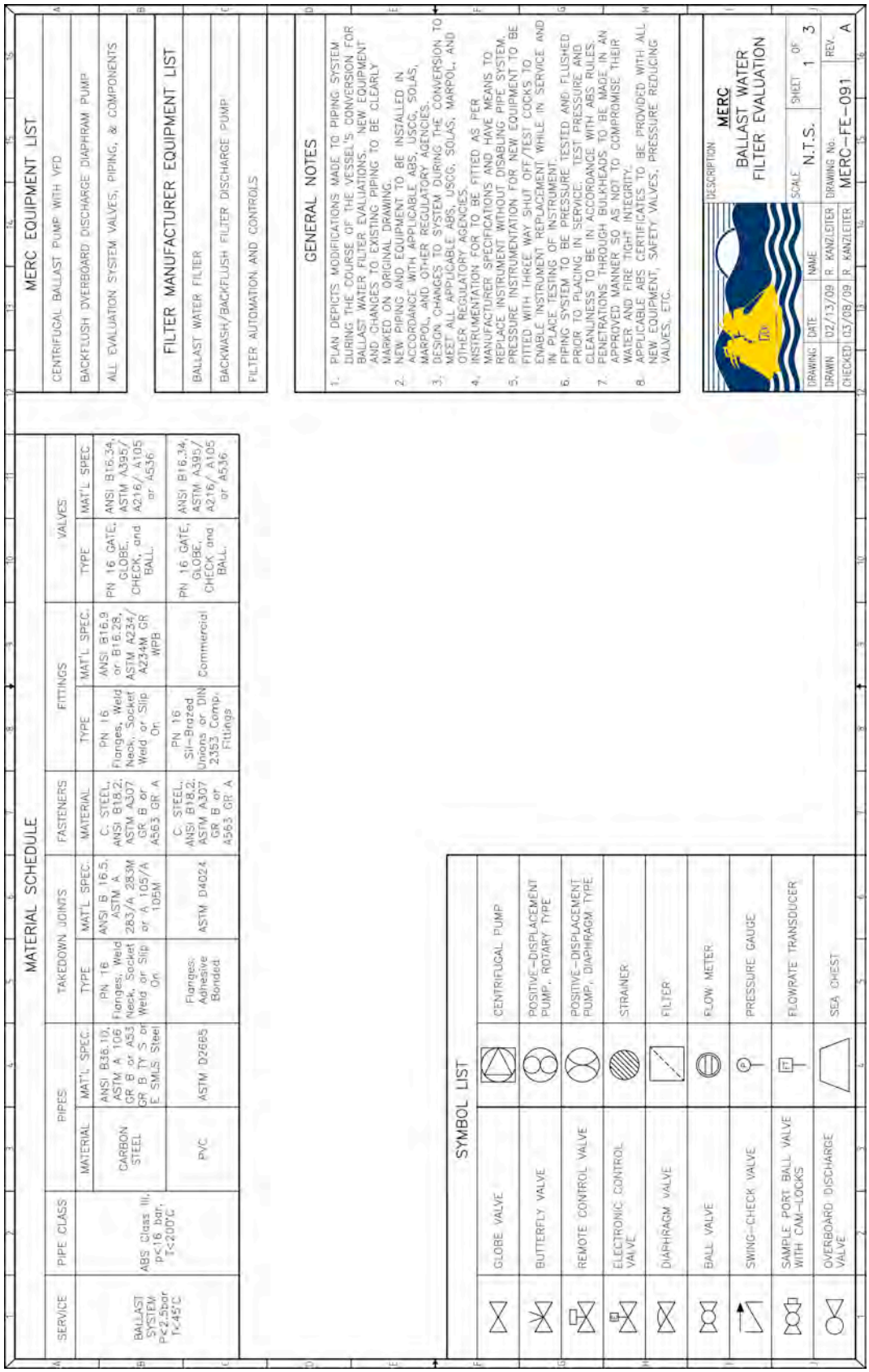
8. Modified *Cape Washington* ballast system to allow for treatment system testing by MERC.

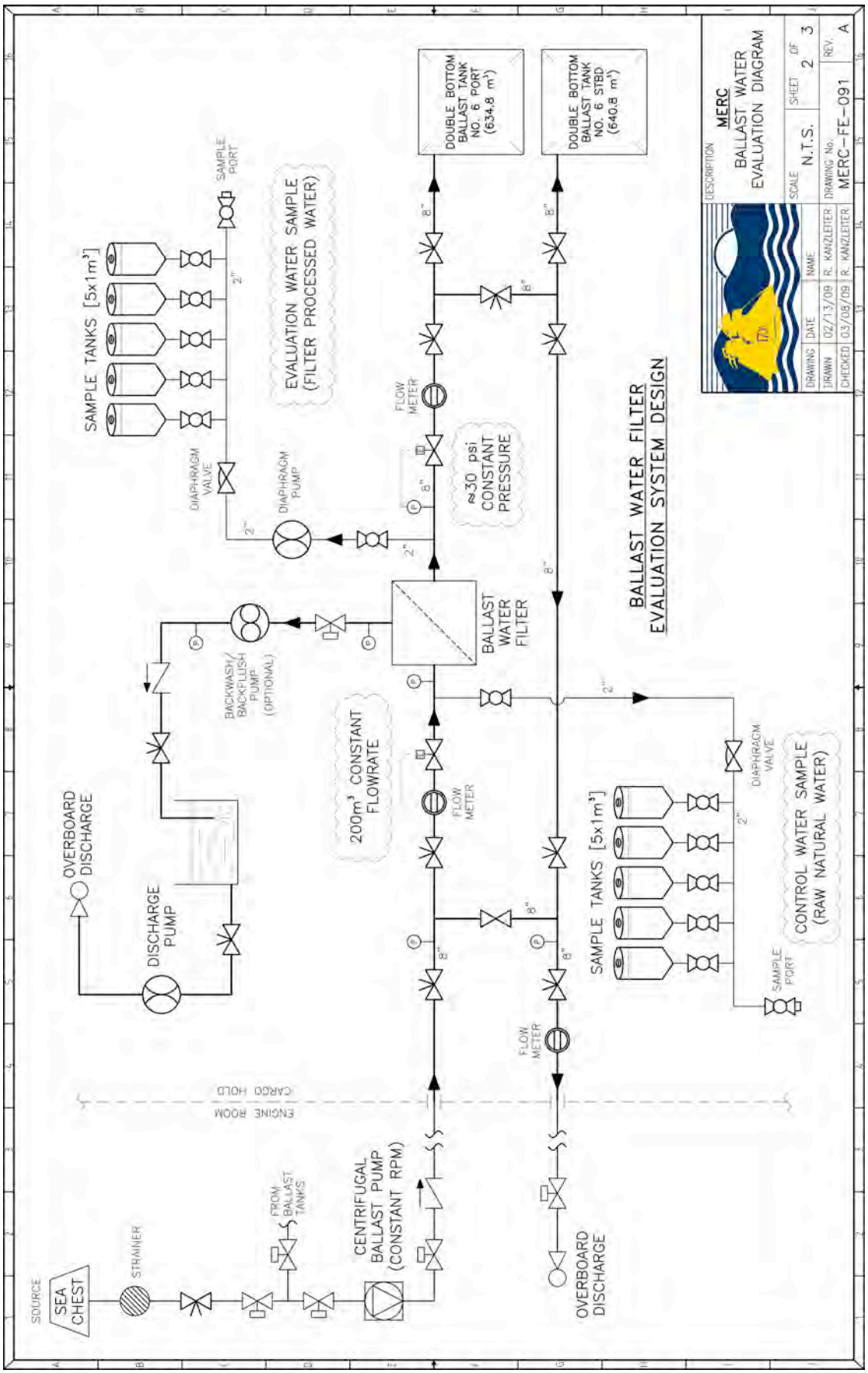


9. MERC *Cape Washington* ballast water treatment system test setup and sampling design.

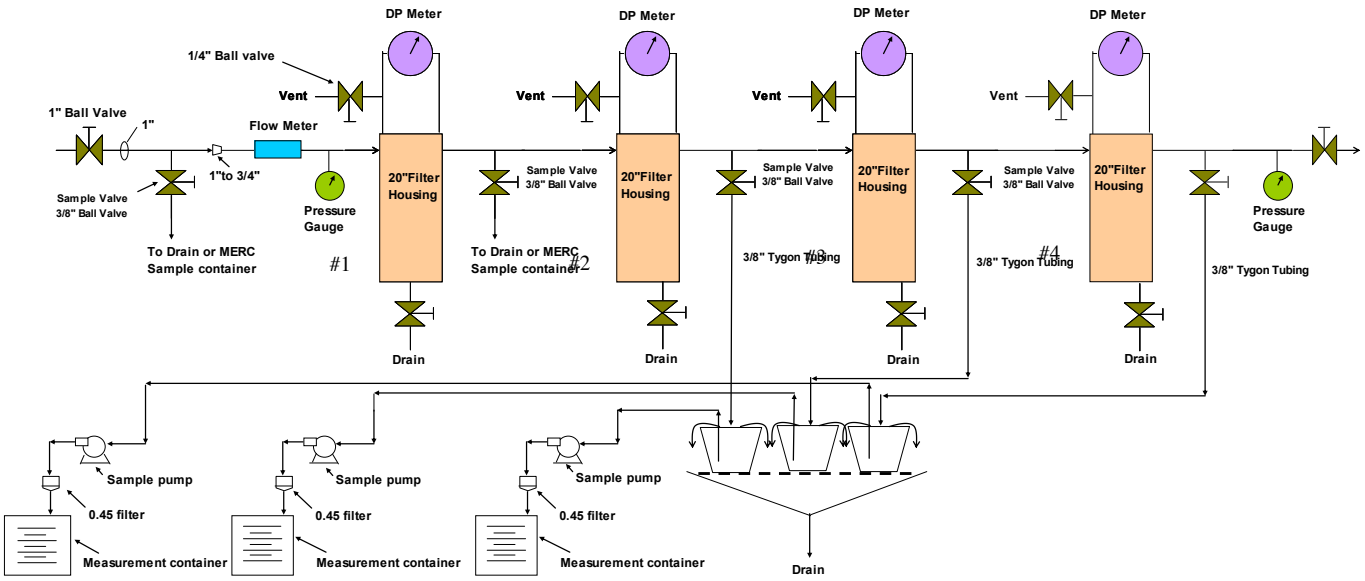


10. MERC *Cape Washington* ballast water filter system test setup and sampling design.




BALLAST WATER FILTER
EVALUATION SYSTEM DESIGN
MERC
BALLAST WATER
EVALUATION DIAGRAM
SCALE N.T.S.
SHEET 2 OF 3
DRAWING No. MERC-FE-091
REV. A
DRAWN R. KANZLEITER 02/13/09
CHECKED R. KANZLEITER 03/08/09
SOURCE
SEA CHEST
STRAINER
FROM BALLAST TANKS
CENTRIFUGAL BALLAST PUMP (CONSTANT RPM)
OVERBOARD DISCHARGE
ENGINE ROOM
CARGO HOLD
FLOW METER
200m³ CONSTANT FLOWRATE
BACKWASH/ BACKFLUSH PUMP (OPTIONAL)
BALLAST WATER FILTER
≈30 psi CONSTANT PRESSURE
DOUBLE BOTTOM BALLAST TANK NO. 6 PORT (634.8 m³)
DOUBLE BOTTOM BALLAST TANK NO. 6 STBD (640.8 m³)
DIAPHRAGM VALVE
DIAPHRAGM PUMP
SAMPLE PORT
SAMPLE TANKS [5x1m³]
EVALUATION WATER SAMPLE (FILTER PROCESSED WATER)
CONTROL WATER SAMPLE (RAW NATURAL WATER)
DISCHARGE PUMP
OVERBOARD DISCHARGE

Appendix 1: Vendor Proposed Test Format



Proposed Tests

A list of the six planned tests is provided below:

General Test Parameters

10 gpm constant filtered water flow
Test length – 5 hrs or until the pressure drop across the 0.1 um filter reaches 30 psid
Total test volume – 3000 gallons or total volume filtered before reaching 30 psid pressure drop (0.1um filter)

Test #1 – Filter #1, 20", 0.1um

Test #2 – Filter #5, 20", 0.1 um

Test #3 – Filter #2, 20", 20um ⟶ Filter #1, 20", 0.1 um

Test #4 – Filter #2, 20", 20um ⟶ Filter #5, 20", 0.1 um

Test #5 – Filter #2, 20", 20um ⟶ Filter #3, 20", 10 um ⟶ Filter #4, 20", 5um ⟶ Filter #1, 20", 0.1 um

Test #6 - Filter #2, 20", 20um ⟶ Filter #3, 20", 10 um ⟶ Filter #4, 20", 5um ⟶ Filter #5, 20", 0.1 um

Calinration Run – January 5th

A dry run of the anticipated testing will be performed on January 5th. During the dry run, we plan to do the following:

1. Complete the installation of the test skid, sample piping, and low-level TSS set-up.
   a. Change out three DP meters from the current 0-15 psid gauges to 0-30 psid gauges
   b. Connect tubing from the final three sample ports to the overflow buckets
   c. Connect tubing from the overflow buckets to the TSS sample filter pumps, 0.45um filter, and measurement jugs.

d. If possible, verify MERC-provided incoming and outgoing connections
e. Any other installation requirements

2. If available, run potable water through the test skid to:
   a. Check for leaks and repair
   b. Verify gauges/instruments work properly
   c. Check operation of the low-level TSS test set-up.
3. Record any necessary changes to the test procedure
4. Make a list of any additional piping, connections, or other equipment required

Summary Test Procedure

TEST #1

1. Put on safety glasses and any other required safety gear.
2. Complete any piping or other equipment changes determined during the dry run.
3. Verify that the ballast water is ready to be pumped to the test skid and that all connections have been made to the skid and from the skid to drain.
4. Fill and test the system for leaks prior to installing the test filter
   a. Open the ¾" valve on the exit of the test skid
   b. Verify that the drain valves on the bottom of the housings are closed
   c. Verify that the sample valves are closed
   d. Open the vent valves on all of the housings. Verify that all the vent line tubing will drain to a bucket or drain.
   e. Start pump to send ballast water to the test skid.
   f. Slowly open the 1" incoming ball valve to the skid. Adjust flow to about 1-2 gpm and slowly fill the system until water is observed flowing from all the vent lines. You will likely need to throttle the ¾" outlet ball valve to fully fill the system.
   g. Once the system is filled, open the incoming valve and throttle the outlet valve until the system pressure reads about 30 psi. Check for any major leaks. Some small leaks may be acceptable if they do not cause a safety hazard.
   h. Shut the system down and repair any leaks. Repeat leak test procedure, if required.
5. Install Filter #1 (20" 0.1um) in the last housing in the series.
   a. Open the vent valve on the last housing (#4)
   b. Open the drain valve on the housing to drain the water.
   c. Unscrew and remove the bowl
   d. Wet the o-rings on the filter with water
   e. Insert the filter into the filter housing by pushing and twisting the filter slightly until it seats in the housing.
   f. Replace the bowl and close the drain valve.
   g. Open the ¾" exit valve on the filter skid
   h. Start the feed pump to the filter skid and open the 1" incoming valve slightly and adjust the flow to fill the system at about 1 -2 gpm.
   i. When water is consistantly flowing from the vent on the filter housing, close the vent.
   j. Adjust the outtlet valve to pressurize the filter skid to about 30 psi and maintain this for about 2 minutes. This will ensure that the filter is fully wet.
   k. Vent all the housings to be sure there is no air in the system.

6. Open the outlet valve fully and adjust the inlet flow to 10.0 gpm using the inlet valve.
    a. Record the time, flowrate, pressure drop across the housing, temperature, inlet pressure and outlet pressure.
    b. Continue to take measurements every 30 minutes and record the data
7. Open the sample valve after the #4 housing slightly and adjust the flow to the overflow bucket to about 1800- 2000 ml/min.
8. Start the low-level TSS measurement system
    a. Verify that the suction line is securely in the overflow bucket
    b. Start the sample pump and flow water through the empty 0.45um filter disk holder to remove excess air. Shut off the pump and discard any water collected.
    c. Select a 0.45um filter for testing and record the number.
    d. Insert the filter disk into the holder and screw the top back on, but DO NOT fully tighten.
    e. Remove any trapped air in the holder by VERY briefly turning on the sample pump until water flows from the top and/or around the threads. Caution: Water will likely spray a little, so be prepared!
    f. Close the filter holder tightly and make sure the outlet is securely in the measurement jug
    g. Turn on the pump and adjust the pressure to 30 psig
    h. Record the time
    i. Keep track of the volume in the measurement jug. If the level reaches 15 liters, use another measurement jug to continue measurement and empty the used jug. Continue to keep track of the total volume filtered until the test is complete.
    j. When the test is complete
        i. Shut off the sample pump
        ii. Shut the sample valve to the overflow bucket
        iii. Record the total volume collected in the measurement jugs
        iv. Carefully remove the filter disk and place it in the small (2”x2”) square filter disk container (has “Millipore” written on it). Mark the container with the test number and the filter disk number.
        v. The filter disk will be dried and measured by vendor.
9. MERC personnel will be responsible for collecting samples for TSS, bacteria, DOC, TOC, etc.
10. Continue to run the test until the pressure drop across the filter reaches 30 psid, or the total volume filtered reaches 3000 gallons (5 hours at 10 gpm)
11. When the test is complete
    a. Record the time and pressure drop across the housing, along with the rest of the measurements outlined in step 5.
    b. Shut off the feed pump
    c. Close the 1” inlet valve
    d. Remove the test filter
        i. Open the vent valve
        ii. Open the drain valve to drain the housing
        iii. Open the housing and remove the filter
        iv. Allow the filter to drain for a few minutes, then place in a plastic bag. Label the bag with the date and test number. The filter will be dried and weighed by vendor.
12. If no tests are to be performed immediately after this test, vent and drain the filter housings and dump all the overflow and measurement collection containers.

TEST #2

1. Repeat Test #1, except install Filter #5 (20" 0.1um) in step 5.
2. Note that Steps 2 and 4 may be skipped if no additional work was required after Test #1

TEST #3

1. Repeat Test #1, but also include the following
   a. Install Filter #2 (20" 20um) in the first housing (#1) as a prefilter
   b. MERC personnel will be responsible for collecting TSS, bacteria, DOC, etc. after the prefilter (Filter #2). We will not do a low level TSS test on this stream.
   c. If the prefilter (Filter #2) plugs quickly and reaches 30 psid before the final filter (Filter #1)
      i. Record all measurements per step 6
      ii. Shut down and replace the prefilter (Filter #2)
      iii. Shut down the sample pump for the TSS measurement of the final filter (Filter #1) while the prefilter is changed, but DO NOT change the 0.45 filter disk.
      iv. Restart the system
      v. Restart the sample pump for the TSS test.
      vi. Record all measurements per step 6.

TEST #4

1. Repeat Test #3, except install Filter #5 (20" 0.1) in the final filter housing (#4)

TEST #5

1. Repeat Test #1, but also include the following
   a. Install Filter #2 (20" 20um) in the first housing (#1) as a prefilter
   b. MERC personnel will be responsible for collecting TSS, bacteria, DOC, etc. after the prefilter (Filter #2). We will not do a low level TSS test on this stream.
   c. Install Filter #3 (20" 10 um) in the second housing (#2) as another prefilter
   d. Install Filter #4 (20" 5 um) in the third housing (#3) as another pre-filter
   e. Adjust the incoming flow to 11 gpm. This will account for the TSS sample water that will be removed from the system after the second and third prefilters and keep the final filter flow at 10 gpm.643
   f. The second and third pre-filters (#3 and #4) will use the low-level TSS test set-up identical to the final filter (Filter #1)
      i. Start the low-level TSS measurement system
3. Verify that the suction line is securely in the overflow bucket
4. Start the sample pump and flow water through the empty 0.45um filter disk holder to remove excess air. Shut off the pump and discard any water collected.
5. Select a 0.45um filter for testing and record the number.
6. Insert the filter disk into the holder and screw the top back on, but DO NOT fully tighten.

7. Remove any trapped air in the holder by VERY briefly turning on the sample pump until water flows from the top and/or around the threads. Caution: Water will likely spray a little, so be prepared!
8. Close the filter holder tightly and make sure the outlet is securely in the measurement jug
9. Turn on the pump and adjust the pressure to 30 psig
10. Record the time
11. Keep track of the volume in the measurement jug. If the level reaches 15 liters, use another measurement jug to continue measurement and empty the used jug. Continue to keep track of the total volume filtered until the test is complete.
12. When the test is complete
    a. Shut off the sample pump
    b. Shut the sample valve to the overflow bucket
    c. Record the total volume collected in the measurement jugs
    d. Carefully remove the filter disk for each test and place it in the small (2"x2") square filter disk container (has "Millipore" written on it). Mark the container with the test number and the filter disk number.
    e. The filter disk will be dried and measured by vendor.
    g. If any of the prefilters (Filter #2, #3, #4) plug quickly and reach 30 psid before the final filter (Filter #1)
        ii. Record all measurements per step 6
        iii. Stop the low-level TSS sample pumps
        iv. Shut down and replace the plugged prefilter (Filter #2,#3, or #4)
        v. DO NOT change the 0.45 filter disk on the final filter (Filter #1).
        vi. If it is the first pre-filter (Filter #2) that plugs, DO NOT change the 0.45um disk on the 2nd and 3rd prefilters
        vii. If it is either the 2nd or 3rd prefilter (that are using the low-level TSS test) that plug, then
    f. Record the total volume collected in the measurement jug for the filter that plugged
    g. Carefully remove the filter disk from the filter that plugged and place it in the small (2"x2") square filter disk container (has "Millipore" written on it). Mark the container with the test number and the filter disk number.
    h. The filter disk will be dried and measured by vendor.
        viii. Restart the system
        ix. Restart the sample pumps for the low-level TSS tests.
        x. Record all measurements per step 6.
        xi. Continue with the rest of the test.

TEST #6

1. Repeat Test#5, except install Filter #5 (20" 0.1) in the final filter housing (#4)