Met One BAM 1020 Operating Procedure

By

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For the

Air Quality Program

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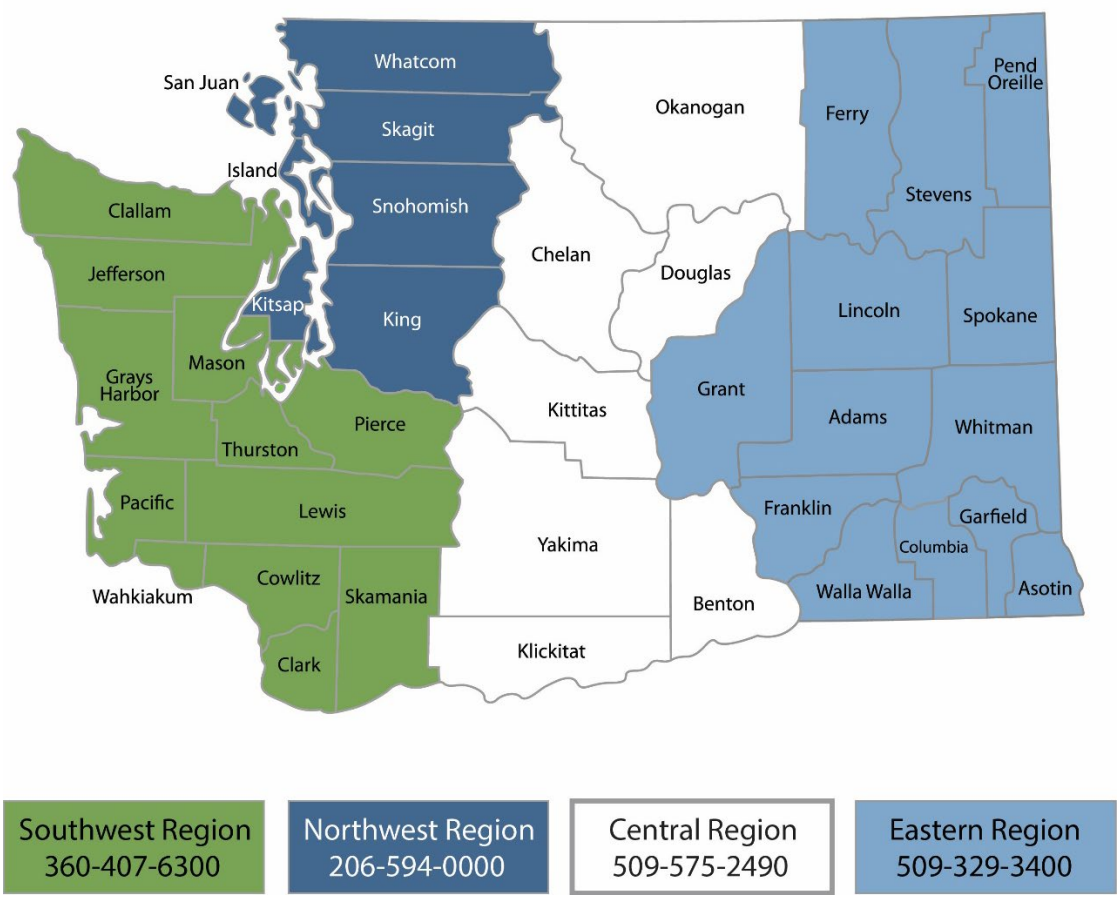

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Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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Air Quality Program
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Revision History

Revision Date	Revision Number	Summary of changes	Revised sections	Revised by
5/29/24	1.0	First tracked version		Christopher Atherly

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Acronyms and Abbreviations

AD	Aerodynamic diameter
AQP	Air Quality Program
AQS	Air Quality System
BAM	Beta Attenuation Monitor
^{14}C	Radioactive isotope of carbon
CFR	Code of Federal Regulations
Comet	Software program for interfacing with BAM units
Ecology	Washington State Department of Ecology
EnvistaARM	Envista Air Resources Manager
EPA	Environmental Protection Agency
FEM	Federal Equivalent Method
FTLT	Filter Tape Leak Test
LSLT	Lower System Leak Test
LPM	Liters per minute
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Radiation Commission
PM	Particulate Matter
$PM_{2.5}$	PM with an aerodynamic diameter 2.5 µm or less
PM_{10}	PM with an aerodynamic diameter 10 µm or less
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
QMP	Quality Management Plan
RH	Relative humidity
SCC	Sharp cut cyclone
SIMS	Site Information Management System
SOP	Standard operating procedure
TSLT	Total System Leak Test
$\mu g/m^3$	Micrograms per cubic meter
VSCC	Very sharp cut cyclone

1. Introduction

This document describes the Washington State Department of Ecology's procedures for sampling ambient air for particulate matter with aerodynamic diameter 2.5 µm or less ($PM_{2.5}$) and aerodynamic diameter 10 µm or less (PM_{10}) using a Met One Instruments Beta Attenuation Monitor 1020 (BAM). It covers the configuration, operation, and maintenance of the BAM. It is intended to be used with the model-specific information and instructions provided by the manufacturer.

When configured for $PM_{2.5}$ monitoring, the BAM provides hourly $PM_{2.5}$ mass concentration measurements in actual conditions. In 2008, EPA designated the BAM as a federal equivalent method (FEM) for measuring $PM_{2.5}$ (73 FR 22362, EQPM-0308-170). To meet the federal requirements for FEM $PM_{2.5}$ measurement, the sampler must be:

- Configured with an approved (BX-802) PM_{10} inlet followed by a BGI, Inc. Very Sharp Cut Cyclone (VSCC) particle size separator;
- Running firmware 3.2.4 or later;
- Equipped with BX-596 ambient temperature and pressure sensor, BX-961 automatic flow controller in actual conditions, and BX-827 or BX-830 Smart Inlet Heater; and
- Operated and maintained in accordance with revision F or later of the BAM 1020 Continuous Particulate Monitor Operation Manual.

When configured for PM_{10} monitoring, the BAM provides hourly PM_{10} mass concentration measurements in standard conditions. In 1998, EPA designated the BAM as an FEM for measuring PM_{10} (63 FR 41253, EQPM-0798-122). To meet the federal requirements for FEM PM_{10} measurements, the sampler must be:

- Equipped with the standard PM_{10} size-selective inlet but no VSCC or SCC; and
- Configured to report concentrations in standard conditions.

This operating procedure describes the configuration for $PM_{2.5}$ monitoring unless otherwise stated.

A photo of the BAM 1020 is shown in Figure 1-1.

Figure 1-1. Photo of BAM 1020 (Met One Instruments, 2012)

2. Principles of Operation

The BAM uses the principle of beta ray attenuation to measure the mass concentration of PM in ambient air. An external pump draws ambient air at 16.7 liters per minute (lpm) first through a PM_{10} inlet and then (for $PM_{2.5}$ monitoring) through a VSCC particle size separator to remove particles greater than 2.5 µm in aerodynamic diameter from the sample stream. The sample stream then passes through a glass fiber filter tape.

A carbon-14 (^{14}C) element above the filter tape constantly emits beta particles, which are detected and counted by a scintillation detector underneath the filter tape. At the beginning of each hour, the BAM counts the beta rays attenuated by a fresh, unsampled spot of filter tape for 8 minutes. The sample stream is then filtered through that spot of tape for 42 minutes. At the end of the sample period, the BAM counts the beta rays attenuated by the sampled spot of tape. The difference in the degree of attenuation between the pre- and post-sampled filter tape is directly proportional to the mass of PM in the sampled air. This mass can be divided by the total volume of air sampled to derive a mass concentration in mg/m^3 or $µg/m^3$.

A schematic diagram of a typical BAM setup is shown in Figure 2-1.

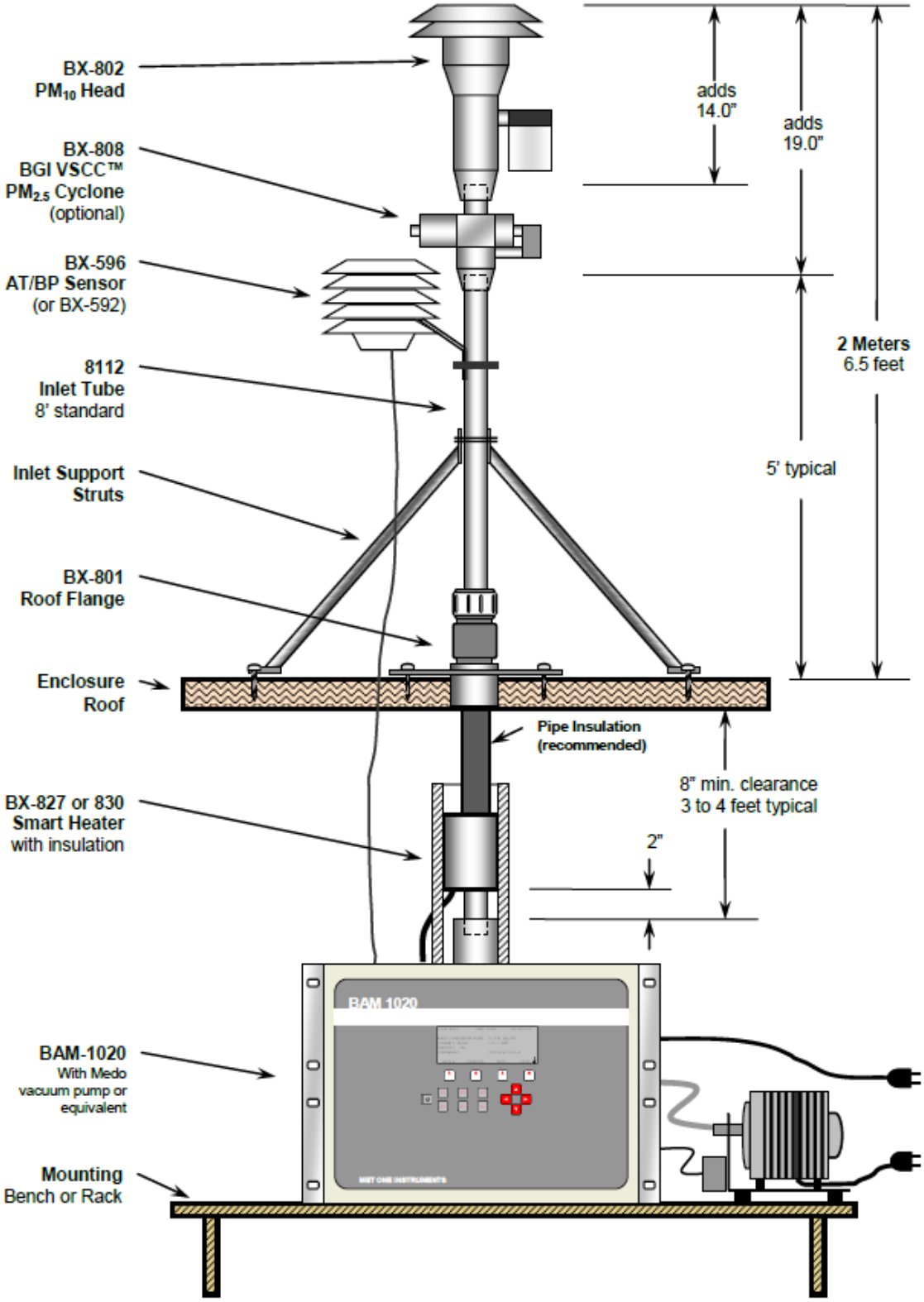

Figure 2-1. Schematic diagram of BAM 1020 (Met One Instruments, 2012)

3. Equipment and Supplies

The diagnostic tools, parts, and supplies necessary to operate and maintain the BAM 1020 are summarized in Table 3-1 below.

Table 3-1. Summary of BAM 1020 standard hardware, tools, routine parts, and supplies

Category	Equipment	Purchase Schedule
Tools and Equipment	Approved, certified, NIST-traceable flow standard	Once
	Flow audit adapter	Once
	Tygon® tubing	Once
	NIST-traceable thermometer	Once
	NIST-traceable handheld barometer	Once
	Digital multi-meter	Once
	Rubber shim (part 7440 in BX-308 tool kit)	Once
	Various hand tools (screwdriver, hexagonal wrench, etc.)	Once
Consumables	Filter tape (Sibata; Met One 460130)	Every 60 days
	Chamois swabs	As needed
	Cotton-tip applicators	As needed
	Rubbing alcohol	As needed
	Lint-free lab wipes	As needed

4. Installation Procedure

4.1. Siting

Proper siting is essential to ensure that data collected are representative at the appropriate scale for the monitoring project. The majority of PM monitoring in the Washington State Ambient Air Monitoring Network (Washington Network) is conducted at the neighborhood scale. Siting criteria for neighborhood-scale PM monitoring sites are described extensively in 40 CFR Part 58, Appendices D and E; the primary considerations are summarized in Table 4-1 below. Operators of sites at other monitoring scales should consult Appendices D and E for siting requirements.

Table 4-1. Summary of PM siting criteria (adapted from Vaughn, 2009)

Parameter	Category	Siting Requirement
Inlet height	General	2-15 m above ground
	On rooftop	2 m above roof
	Collocated samplers	Within 1 vertical m of each other
	Inlet tube length	≤ 16 ft (4.9 m)
Inlet radius clearance	General	≥ 1 m radius clearance
	Collocated samplers	1-4 m between inlets
	Near small obstructions (fences, walls, etc.)	≥ 2 m
	Near large obstructions (buildings, sound walls, billboards, etc.)	Distance ≥ 2x height of obstruction
	Near overhanging trees	≥ 10 m from dripline; ≥ 20 m from dripline is recommended
	Arc of air flow	Unrestricted 270° arc that includes prevailing direction of high concentrations
Nearby Air sources	General	As far away as possible from vents
Distance from roadways	< 3,000 vehicles per day	≥ 5 m from nearest traffic lane
	Elevated roadway (> 25 m high)	≥ 25 m away
	Unpaved roads	As far away as possible

Refer to Ecology's Air Monitoring Site Selection and Installation Procedure (16-02-021) for further information on site selection.

The BAM can be installed in a walk-in shelter, mobile trailer, or environmentally controlled mini enclosure. Enclosures should be selected to minimize environmental interference, including:

- **Temperature:** The BAM is sensitive to rapid fluctuations in temperature. Shelters must be equipped with both a heater and an air conditioner to ensure that shelter temperature does not vary by more than ± 2°C per hour. The shelter temperature set point can be anywhere from 0°C to 50°C. The recommended set point range is 20-30°C.
- **Vibration**: Excess vibration can interfere with the BAM's operation and introduce excessive measurement noise. Wherever possible, the BAM should occupy its own shelter or its own bench to minimize interference from vibration of other instruments. The BAM pump is also a source of vibration, and it should be placed as far as possible from the BAM itself, ideally in a separate outdoor enclosure as shown in Figure **4-1**. Although the photo shows a different style of pump, this enclosure is also compatible with the BAM 1020 Medo pump.

Figure 4-1. Photo of outdoor pump enclosure (photo courtesy of PSCAA)

By default, the BAM ships with an 8-foot inlet that can only be shortened by the manufacturer. Prior to ordering a new instrument, the operator should work with the Calibration and Repair Laboratory to determine the appropriate inlet length for the BAM enclosure and specify that length when purchasing a new BAM.

4.2. Installation

It is recommended that operators follow the detailed instructions found in the BAM 1020 Operation Manual when installing a new instrument. In addition to the manufacturer's

instructions, operators should take the following special precautions when installing the BAM 1020:

- Align the downtube in a straight, vertical line above the inlet of the BAM. If the alignment is not perpendicular, transverse stress on the inlet connections can cause leaks.
- Secure the downtube to the roof with a waterproof roof flange so that the PM10 head and VSCC can be removed without disturbing the instrument.
- Secure the downtube with a tripod or at least two support braces to prevent flexing of the downtube in the wind.
- Tighten the two set screws in the inlet receiver into the downtube hard enough to pierce the anodizing on the downtube. Then loosen the set screws and re-tighten them so they are snug. This process creates a ground connection to prevent the buildup of static electricity on the inlet tube.
- To check the ground after assembly, clear the anodizing from an exposed spot near the bottom of the down tube. Use a digital multimeter to measure the resistance between this spot and the ground connection labeled “CHASSIS” on the back of the BAM to ensure that it measures < 2Ω.
- Connect the BAM-1020 to the data acquisition system using the “Report Port” located on the back of the BAM.

After installing the instrument, conduct the following steps to begin operation:

Table 4-2. Summary of post-installation steps

Step	Section
Verify settings	4.2.1
Install the filter tape	4.2.2
Perform the self-test	4.2.3
Calibrate the ambient temperature, ambient pressure, and flows	4.2.4
Perform a leak check	4.2.5
Perform a 72-hour zero test ($PM_{2.5}$ only)	4.2.6

4.2.1. Verify settings

Verify the following settings in the SETUP menu. The default password for accessing these menus is F1 F2 F3 F4. Note that the CONC TYPE and STD TEMP options differ if monitoring for PM_{10} vs $PM_{2.5}$.

Table 4-3. BAM 1020 configuration parameters

Menu	Sub-Menu	Setting
SETUP > CLOCK	--	BAM 2 minutes ahead of data logger

Menu	Sub-Menu	Setting
SETUP > SAMPLE	BAM SAMPLE	042 MIN
	RANGE	1.000 mg
	OFFSET	-0.015 mg
	CONC UNITS	µg/m^3
	COUNT TIME	8 MIN
SETUP > CALIBRATE	SPAN CHECK	24HR
	FLOW RATE	0016.7
	CONC TYPE	ACTUAL ($PM_{2.5}$) STD (PM_{10})
	FLOW TYPE	ACTUAL
	STD TEMP (PM_{10} Only)	25 C
	HEATER CONTROL	AUTO
SETUP > HEATER	RH Control	YES
	RH Setpoint	35%
	Datalog RH	YES (Chan 4)
	Delta-T Control	NO

4.2.2. Install filter tape

1. Remove the plastic reel covers.
2. Install an empty rubber or cardboard core on the take-up (left) reel.
3. Ensure the pinch rollers are lifted and secured with the latch.
4. Handle the filter tape only by its edges to avoid contaminating the sampling surface. Load the new roll of filter tape on the supply (right) reel and guide the tape into the transport assembly as shown in the drawing on the door of the BAM.
5. Use adhesive tape to fasten the loose end of filter tape to the empty core on the take-up reel.
6. Rotate the reels by hand until the filter tape is taut.
7. Install the plastic reel covers. Tighten them just until the metal plates behind the reels begin to turn.
8. Align the filter tape with the score marks on the edges of the rollers.
9. Unlatch the pinch rollers to lower them onto the tape.
10. Select **TENSION** > **TAPE** to set the tension on the tape.

4.2.3. Self-test

The BAM's built-in self-test function automatically tests the tape and flow systems to ensure that the BAM is ready to enter sampling mode. The self-test should be run initially and after any interruption to sampling, such as a quality control check, filter tape change, or performance evaluation.

1. Select **TAPE** > **SELF TEST**.
2. Read the "Status" line when the self-test is complete. If it displays SELF TEST PASSED, select **EXIT** to return to the home screen (Figure 4-2).
3. If the status displays ERROR OCCURRED, look for an error in the individual test parameters. Resolve the error and repeat the self-test until it passes, then select **EXIT** to return to the home screen (Figure 4-2).

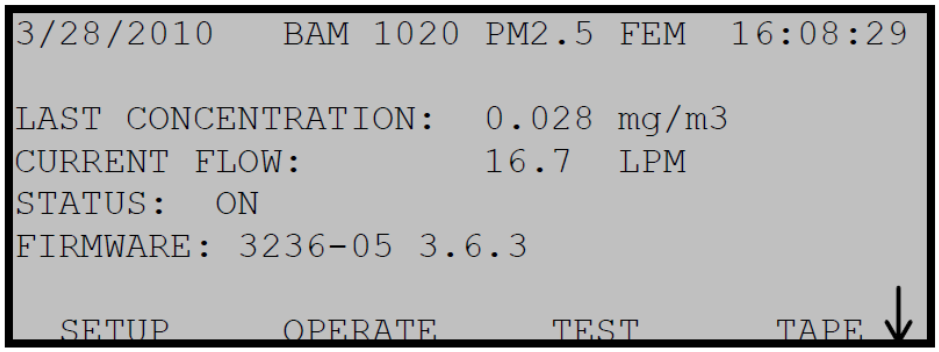

Figure 4-2. BAM 1020 home screen

Note: A quick way to ensure the BAM is left on the home screen is to ensure that there is not an EXIT button at the bottom of the screen. The home screen is the only screen without an EXIT option.

4.2.4. Calibrate ambient temperature, pressure, and flows

The ambient temperature, ambient pressure, and flows must be calibrated upon installation and relocation of the BAM 1020.

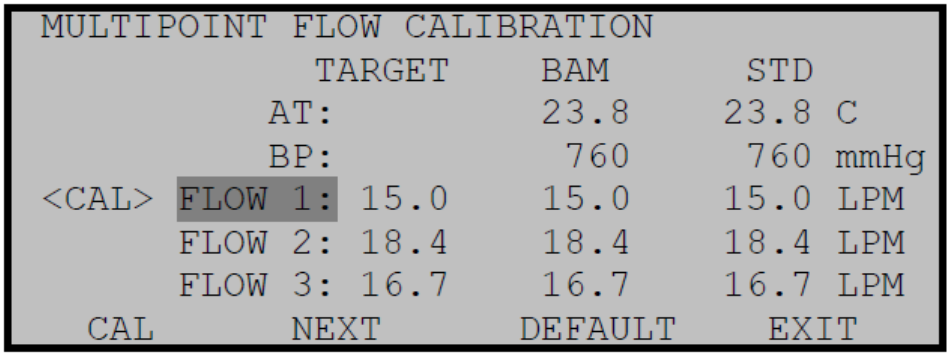

Figure 4-3. Multipoint flow calibration screen

The MULTIPOINT FLOW CALIBRATION screen allows the user to view and calibrate temperature, pressure, and flow rate. For each parameter, the BAM column shows the

instrument's indicated value. The STD column is identical to the BAM column by default and can be programmed with actual values from transfer standards to calibrate the BAM.

1. Select **TEST** > **FLOW** to enter the MULTIPOINT FLOW CALIBRATION screen. The default password is F1 F2 F3 F4.
2. Measure the actual ambient temperature inside the radiation shield using a certified, NIST-traceable thermometer. Use the soft arrow keys to program it into the STD column of the ambient temperature (AT) line.
3. Select **NEXT** to navigate to the barometric pressure (BP) line. Measure the actual BP at the BAM inlet using a certified BP standard and program it into the STD column of the BP line.
4. Remove the PM_{10} head and install the flow audit adapter. Ensure that the valve is in the open position (parallel to the inlet). Connect tubing between the flow audit adapter and an approved, certified flow transfer standard.
5. Select **NEXT** to navigate to the three flow points. At each point, allow the flow to stabilize and read the actual volumetric flow from the flow transfer standard and program it into the STD column.
6. Select **CAL** to store the results and recalibrate the BAM.
7. Select **EXIT** to return to the home screen (Figure 4-2).

4.2.5. Leak check

1. Select **TEST** > **TAPE**. Press FWD to advance the tape to a clean, unsampled spot.
2. Ensure that the flow audit adapter is installed above the VSCC in place of the PM_{10} head. Turn the flow audit adapter valve to the closed position (perpendicular to the inlet).
3. Select **TEST** > **PUMP** and turn the pump on.
4. Allow the pump to stabilize for 20-30 seconds.
5. Read the flow rate on the BAM display and record it in the As-Found Leak Check section of the BAM QC form. The flow rate must be ≤ 1.5 lpm for the leak check to pass.
6. Turn off the pump and slowly open the flow audit adapter valve.

4.2.6. 72-hour zero test

To meet EPA requirements for federal equivalency, all $PM_{2.5}$ BAM units must undergo a 72-hour zero background test when first deployed and annually thereafter. Each BAM has a programmable background value (BKGD) to compensate for site-specific characteristics such as grounding, radon, or radio-frequency interference.

Note: The 72-hour test for a BAM measuring PM_{10} is optional. If electing to skip the 72-hour zero test, simply set the BKGD value to 0 in the SETUP > CALIBRATE menu.

The 72-hour zero test should only be performed when the BAM is installed in its permanent location and fully configured for sampling. Before performing the 72-hour zero test, contact the Calibration and Repair Laboratory.

Avoid performing the 72-hour zero test during periods of wildfire smoke, if possible. If the test must be conducted during a high smoke event, it should be repeated once PM concentrations return to normal. If the background adjustment from the repeated test differs by more than ±0.002 mg/m^3 from the initial test, adjust past values to align with the new offset value.

The following is a brief set of instructions for performing the 72-hour zero test. For additional information, operators should refer to the detailed instructions that accompany the BX-302 Zero Filter Kit included with all BAM units.

1. Before performing the 72-hour zero test, retrieve the current settings file using Comet (see section 6.1). Copy and paste the settings file into the electronic logbook.
2. Select **SETUP** > **CALIBRATE** and use the **NEXT** button to navigate to the BKGD setting. Record the current BKGD setting in the electronic logbook.
3. Use the soft arrow keys to set the BKGD value to 0.0000. Save and select **EXIT** to return to the home screen (Figure 4-2).
4. Remove the PM_{10} head.
5. Install the BX-302 0.2 µm filter kit above the VSCC.
6. In Envidas Ultimate, right-click the BAM channel and set the analyzer flag to Zero.
7. Allow the BAM to warm up with the BX-302 kit installed for 24 hours before starting the 72-hour zero test.
8. Allow the BAM to sample for at least 72 continuous hours, not including the 24-hour warm-up period. If any error flags are shown or if shelter temperatures change by more than ±2°C per hour, the results are invalid, and the test must be restarted.
9. Calculate the mean hourly concentration recorded during the 72-hour zero test in mg/m^3 and subtract this number from 0. This value should normally be within ±0.002 mg/m^3 of prior BKGD values on the same instrument.
10. In the SETUP > CALIBRATE menu, program the resulting value (the negative of the mean 72-hour concentration in mg/m^3) into the BKGD field.
11. Ensure that the standard deviation of the recorded concentrations is less than 2.4 $\mu g/m^3$. If the standard deviation exceeds 2.4 $\mu g/m^3$, contact the Calibration and Repair Laboratory for assistance.
12. Remove the BX-302 filter, reinstall the PM_{10} head, and remove the flags from the BAM channel to enter normal sampling mode.
13. Record the new BKGD value and calculated standard deviation in the electronic logbook.

Contact the Quality Assurance unit for assistance with analyzing and interpreting 72-hour zero test data.

5. Quality Control and Maintenance Procedure

To ensure proper operation of the BAM 1020 and meet the requirements of 40 CFR, Part 58, Appendix A, routine quality control (QC) maintenance must be conducted at regular intervals. The QC and maintenance procedure must be performed every 30 days except for the filter tape change, which takes place every 60 days.

Additional maintenance steps must be performed every 6 months and every 12 months. The 12-month maintenance is performed by the Calibration and Repair Laboratory unless other arrangements are made.

5.1. Monthly quality control and maintenance

Operators are required to perform a QC check and monthly maintenance every 30 days. The monthly QC/maintenance procedure consists of:

Table 5-1. Summary of monthly quality control and maintenance steps

Procedure	Frequency	Section
As-found leak check	Every 30 days	5.4
Filter tape inspection	Every 30 days	5.5
Nozzle and vane cleaning	Every 30 days	5.6
Filter tape change	Every 60 days	5.7
Clean the PM_{10} inlet	Every 30 days	5.8
Clean the VSCC	Every 30 days or as needed	5.9
As-left leak check	Every 30 days	5.10
Ambient temperature and pressure verification	Every 30 days	5.11
Three-point flow verification	Every 30 days	5.12
Temperature/pressure flow calibration	As needed	5.13
Clock verification	Every 30 days	5.14
Self-test	Every 30 days	5.15

All operators of $PM_{2.5}$ and PM_{10} BAMs in the Washington Network are required to record the results of monthly QC checks on the appropriate Washington State Department of Ecology FEM PM BAM Quality Control Check Results form (see Appendix A).

5.2. Preparation

Using Envidas Ultimate Reporter, create a logbook entry noting the time you began the QC check, the instruments you intend to service, and the names of people onsite.

Note: It is not necessary to take the BAM 1020 channels off scan when performing a quality control check. The BAM will flag any data collected while in "maintenance" mode and Envidas Ultimate will automatically invalidate this data. To verify the BAM is in "maintenance" mode, exit to the main screen and verify that STATUS indicates MAINTENANCE.

5.3. Six-month maintenance

5.3.1. Clean or replace pump muffler

The BAM's standard Medo pump has a gray plastic muffler, which may clog with dust and debris over time. Clean or replace this muffler every 6 months or if the pump is unable to draw 16.7 lpm.

The Calibration and Repair Laboratory recommends replacing the muffler with a 30-inch length of Tygon tubing, which will not clog and may improve pump performance.

5.3.2. Test filter temperature sensor

1. **TEST** > **FILTER-T**. This will raise the nozzle and turn on the pump.
2. Allow the pump to warm up for 5 minutes and the reference thermometer to equilibrate to room temperature. If the Smart Heater has recently been running, allow additional time for the inlet to cool to room temperature.
3. Compare the filter temperature displayed to the ambient room temperature on the reference thermometer. The acceptance limit is ±1°C.
4. If necessary, calibrate the sensor by entering the ambient temperature from the reference thermometer in the **REFERENCE** field, then select **CALIBRATE**.
5. **EXIT** to the TEST menu.

5.3.3. Test smart heater

1. **TEST** > **HEATER**.
2. If the heater is on, select **OFF** and allow it to equilibrate to room temperature.
3. Select **ON** and verify that the heater warms to the touch after several minutes.
4. **EXIT** to the home screen. The heater will automatically turn off.

Record the maintenance steps completed in the electronic logbook.

5.4. As-found leak check

The most common cause of invalid data from the BAM is a leak where the nozzle contacts the filter tape. Particularly in wet and humid conditions, filter tape debris can build up on the nozzle over time and cause a leak at the contact point. Frequent leak checks are useful for detecting small leaks as they develop and preventing data loss. At sites where leak check failures are common, it is recommended that operators increase the frequency of the leak check and nozzle and vane cleaning to once every 14 days as described in Section 5.4.12.

1. **TEST** > **TAPE** to put the BAM in maintenance mode and suspend sampling. Press **FWD** to advance the tape to a clean, unsampled spot.

2. Remove the PM_{10} head and replace it with the flow audit adapter. Do not remove the VSCC. Turn the flow audit adapter valve to the closed position (perpendicular to the inlet).
3. Select **TEST** > **PUMP** and turn the pump on.
4. Allow the pump to stabilize for 20-30 seconds.
5. Read the flow rate on the BAM display and record it in the As-Found Leak Check section of the BAM QC form. The flow rate must be ≤ 1.5 lpm for the leak check to pass.
6. Turn off the pump and slowly open the flow audit adapter valve.
7. Press EXIT to return to the home screen (Figure 4-2).

If the result of the leak check is greater than 1.5 lpm, an advanced leak check is required. Conduct an advanced leak check by following the steps below. Full details regarding the advanced leak check procedure are available in the Met One document "BAM-1020-9804 Leak Check Rev A.pdf".

1. Ensure that the flow audit adapter is installed above the VSCC and in the open position.
2. Connect tubing between the flow audit adapter and an approved, certified flow transfer standard.
3. Navigate to the **TEST** > **PUMP** menu. Press **NOZZLE** to raise the nozzle if needed, remove the filter tape from beneath the nozzle, and insert the Nozzle Seal Tool with the hole positioned beneath the nozzle.
4. Press **NOZZLE** to lower the nozzle.
5. Verify the LEAK status is set to LEAK OFF.
6. Press **PUMP** to start the pump.
7. Allow at least 2-3 minutes for the flow to stabilize. After the flow rate stabilizes, note the flow rate as measured by the certified flow transfer standard. This is the "Without Tape" value.
8. Stop the pump and raise the nozzle. Remove the Nozzle Seal Tool and place a piece of filter tape (approximately 3 inches long) directly below the nozzle.
9. Press **PUMP** to start the pump and lower the nozzle.
10. When the flow rate stabilizes, note the value on the certified flow transfer standard. This is the "With Tape" value.
11. Stop the pump, raise the nozzle, and remove the piece of filter tape.
12. Subtract the "With Tape" value from the "Without Tape" value. The advanced leak check passes if the difference is 0.3 lpm or less.
13. If the difference is greater than 0.3 lpm, an out of tolerance leak exists at the nozzle/tape interface. Thoroughly clean the nozzle and conduct the advanced leak check again. If the advance leak check is still greater than 0.3 lpm, contact the Calibration and Repair Laboratory.

5.5. Filter tape inspection

Examine the spent filter tape for holes. Holes in the filter tape usually indicate a spot of hard debris on the nozzle punching into the tape. Such debris may require additional cleaning.

Figure 5-1 shows spent filter tape from a BAM with a clean nozzle and vane on the left, and from a leaking nozzle and vane on the right. The leaking BAM likely has a buildup of debris on the nozzle causing the pinholes visible in the photo.

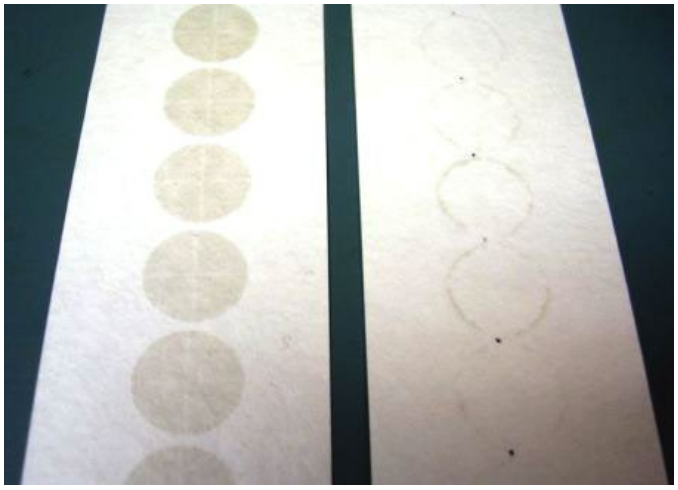

Figure 5-1. Spent filter tape from clean (left) and leaking (right) nozzle (Met One, 2012)

5.6. Nozzle and vane cleaning

Note: Although the BAM 1020 Operation Manual recommends cotton-tip applicators for nozzle and vane cleaning, these have been found to leave lint debris in the nozzle and vane, causing subsequent leaks. Operators should instead use lint-free chamois swabs designed for cleaning electronic equipment. If necessary, the Calibration and Repair Laboratory can provide these.

1. Raise the pinch rollers and latch them in the open position.
2. Select **TEST** > **PUMP** and select **MOVE NOZZLE** to raise the nozzle.
3. If the filter tape is due for replacement:
    - Remove the knobs on the take-up and supply reels and remove the roll of tape from both sides.

If the filter tape is not due for replacement:

- Remove the knob on the take-up (left) reel and turn tape clockwise to relieve the tape tension.
- Slide the tape out from around the rollers and allow it to hang loosely in front of the BAM.

4. Inspect the vane with a flashlight and clean any debris with a chamois swab dipped in rubbing alcohol.
5. Select **TEST** > **PUMP** and select **MOVE NOZZLE** to lower the nozzle.
6. Use a finger to raise the nozzle and insert an alcohol-dipped chamois swab. Release the nozzle and allow it to press down on the swab.
7. Rotate the nozzle several times with the swab in place.
8. If there is visible debris on the swab, repeat with a fresh swab until the swab comes out clean.

9. Inspect the capstan shaft and pinch rollers. Clean with a cotton swab or water and a lint-free wipe if there is any visible debris. Rubbing alcohol is not recommended for cleaning the pinch rollers as it can cause the rubber to dry out.
10. If the filter tape is due for replacement:
11. Proceed to step 1 of the filter tape change steps described in section 5.1.5.
12. If the filter tape is due for replacement, select MOVE NOZZLE to lift the nozzle, then proceed to step 4 of the filter tape change steps described in section 5.1.5.

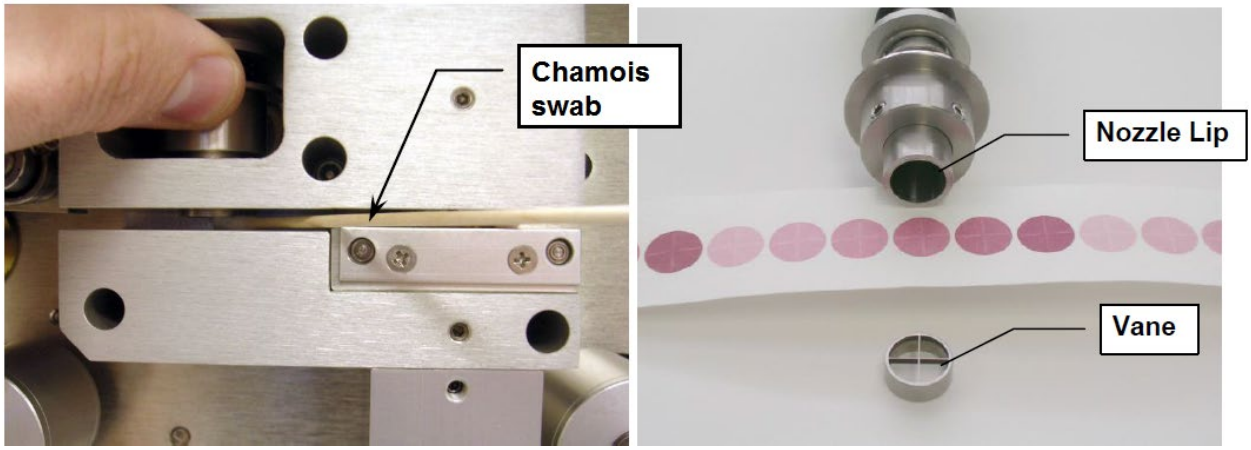

Figure 5-2. Close-up view of nozzle and vane cleaning (Met One Instruments, 2012)

5.7. Filter tape change (every 60 days)

1. Remove the used filter tape from the rubber or cardboard core on the take-up (left) reel and discard it. Reinstall the empty rubber or cardboard core on the take-up reel.
2. Handle the filter tape only by its edges to avoid contaminating the sampling surface. Load the new roll of filter tape on the supply (right) reel and guide the tape into the transport assembly as shown in the drawing on the inside of the door of the BAM.
3. Use adhesive tape to fasten the loose end of filter tape to the empty core on the take-up reel.
4. Rotate the reels by hand until the filter tape is taut.
5. Install the plastic reel covers. Tighten them just until the metal plates behind the reels begin to turn.
6. Align the filter tape with the score marks on the edges of the rollers.
7. Unlatch the pinch rollers to lower them onto the tape.
8. If the leak check adapter is installed on the downtube, ensure that it is open. Select TENSION > TAPE to set the tension on the tape.

Note: It is strongly recommended that operators change the filter tape during every other QC check in the sequence described here. However, in the event that it is necessary to change the filter tape outside of a normal QC check, the filter tape change should always be followed by an as-left leak check (section 5.4.6) and self-test (section 5.4.11).

5.8. Clean PM_{10} inlet

1. Remove the condensation jar.
2. Unscrew the collector assembly from the acceleration assembly as shown Figure 5-3.
3. Remove the four screws on the underside of the top plate of the acceleration assembly and separate the top plates from the insect screen and assembly body.
4. Clean using brushes, a lint-free cloth, and/or compressed air. It is possible to clean the parts with water if they are thoroughly dry before reassembly.
5. Using a brush, lint-free cloth, and/or cotton swabs, clean the collector plate and the walls around the three vent tubes. Run a wet cloth through the three vent tubes.
6. Wipe out the bottom of the collector assembly where the O-rings are located.
7. Grease the O-rings with silicone grease (never use other types of grease) and inspect for damage. Replace if necessary.
8. Wipe out the condensation jar and lid. Grease the seal inside the lid.

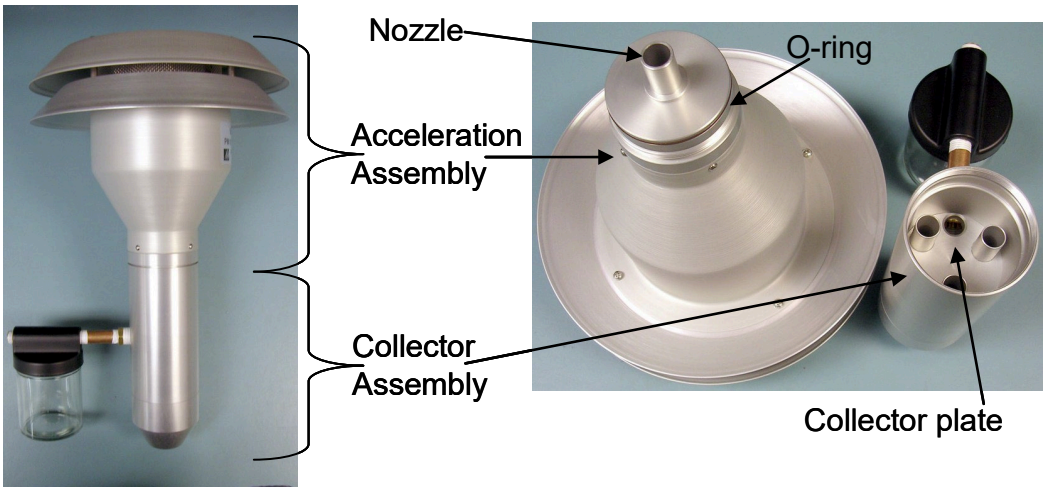

Figure 5-3. Diagram of PM_{10} head inlet components (Vaughn, 2009)

5.9. Clean VSCC

1. Remove the top cap and the emptying cup as shown in Figure 5-4.
2. Use a damp, lint-free wipe to remove visible dirt and debris, paying special attention to the emptying cup and the cone inside the top cap.
3. Inspect the O-rings for damage and adequate lubrication. Replace O-rings and/or apply silicone grease if necessary.
4. Reinstall the VSCC on the inlet.

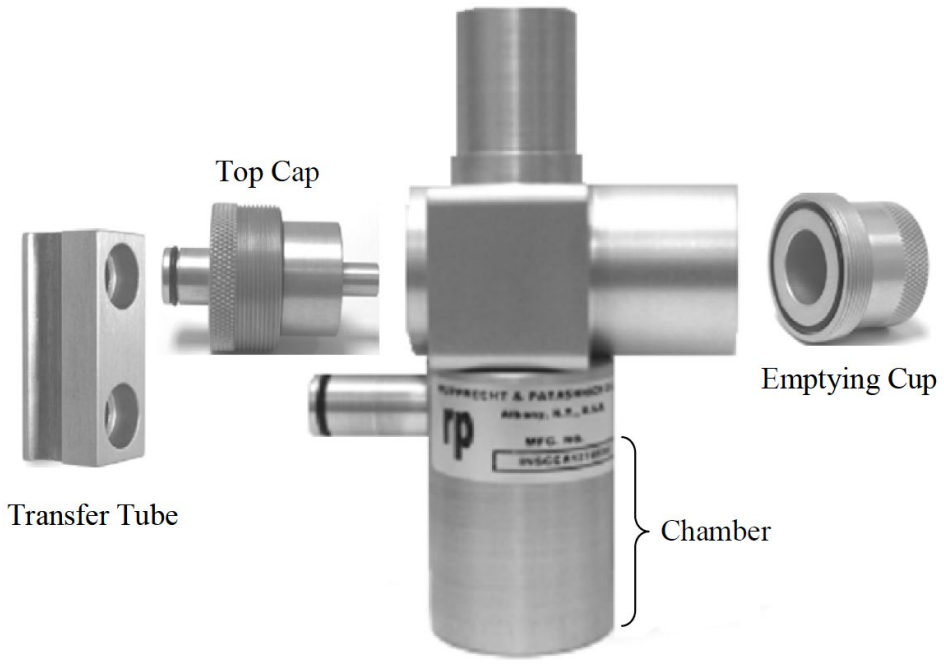

Figure 5-4. Exploded view of VSCC components (Vaughn, 2009)

5.10. As-left leak check

The leak check must be repeated after the nozzle and vane cleaning (and filter tape change, if applicable) to ensure that any debris at the vane/nozzle was successfully removed and that no new leaks were introduced.

1. Repeat the leak check procedure in section 5.1.2.
2. Record the results in the As-Left Leak Check section of the BAM QC form.

If a leak greater than 1.5 lpm persists, repeat the nozzle and vane cleaning procedure in Section 5.6. If the leak persists after thorough nozzle and vane cleaning, repeat the leak check with a rubber shim (part 7440 from BX-308 tool kit) under the nozzle. If the leak check passes with the rubber shim, the leak is in the probe line. Check the flow audit adapter, VSCC, and BAM inlet for signs of leaks. If the leak check fails with the rubber shim, the leak is internal to the BAM body. Contact the Calibration and Repair Laboratory for troubleshooting assistance.

5.11. Ambient temperature and pressure verification

The MULTIPOINT FLOW CALIBRATION screen allows the user to view and calibrate the ambient conditions and flows. For each parameter, the BAM column shows the instrument's indicated value. The STD column is identical to the BAM column by default, although operators can input actual values from their transfer standards to recalibrate the BAM when needed.

Note: Operators should complete a full initial QC before making any changes to the STD column. If recalibration is needed, record the results of the initial QC, and label the QC form "as

found." Calibrate the necessary parameters following the steps in section 5.4.9. Then repeat the QC check and record the results in a separate QC form labeled "as left."

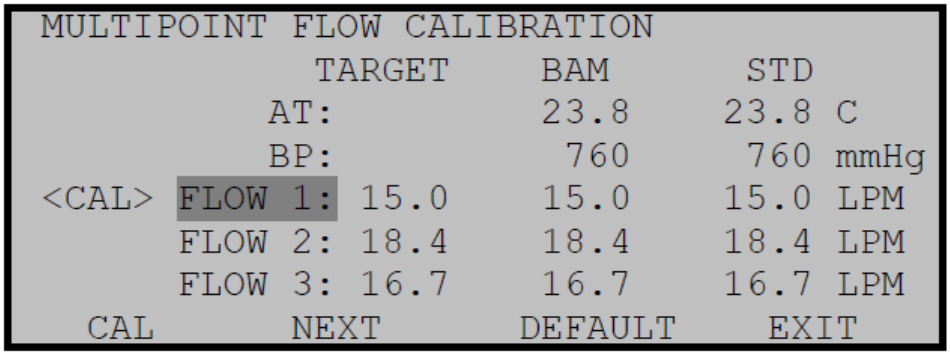

Figure 5-5. Multipoint flow calibration screen

1. Select **TEST** > **FLOW** to enter the calibration menu for ambient conditions and flows. The default password is F1 F2 F3 F4.
2. Select **NEXT** to navigate through the MULTIPOINT FLOW CALIBRATION screen. The arrow keys are used to adjust the values in the "STD" column and should only be pressed when recalibration is necessary.
3. Record the indicated ambient temperature (AT) from the BAM column on the QC form.
4. Measure the actual ambient temperature inside the radiation shield using a certified, NIST-traceable thermometer and record it on the QC form.
5. Select **NEXT** to navigate to the barometric pressure (BP) line and record the indicated BP on the QC form.
6. Measure the actual BP at the BAM inlet using a certified BP standard and record it on the QC form.

5.12. Three-point flow verification

Although the BAM operates at a flow rate of 16.7 lpm, the QC check tests the BAM at three flows between 15.0 and 18.4 lpm. Testing three flows ensures not only that the operating and design flows are accurate but also that the slope of the BAM's mass flow sensor is properly calibrated.

1. Ensure that the flow audit adapter is installed above the VSCC and in the open position.
2. Connect tubing between the flow audit adapter and an approved, certified flow transfer standard.
3. Following the ambient temperature and pressure check, select **NEXT** to navigate to the "Flow 1" line (15.0 lpm) on the MULTIPOINT FLOW CALIBRATION screen. This will start the pump at 15 lpm.
4. Record the BAM's indicated flow and the transfer standard's actual flow on the QC form.
5. Select **NEXT** to navigate to flows 2 (18.4 lpm) and 3 (16.7 lpm) and record the indicated and actual flows.
6. Select **EXIT** to return to the home screen (Figure 4-2).

5.13. Temperature, pressure, and flow calibration (as needed)

Note: Operators should complete a full initial QC before making any changes to the STD column. The acceptance limits for ambient temperature are ±2°C and for ambient pressure are ±10 mm Hg. Flows must be within 4% of the reference standard and 5% of the design flow (16.7 lpm). If recalibration is needed, record the results of the initial QC and label the QC form "as found." Calibrate the necessary parameters following the steps below. Then repeat the QC check and record the results in a separate QC form labeled "as left."

1. Select **TEST** > **FLOW** to return to the MULTIPOINT FLOW CALIBRATION screen.
2. Use the **NEXT** key to navigate through the parameters. Adjust the STD values using the soft arrow keys to match the actual readings from the transfer standard(s).
3. When all necessary parameters have been updated in the STD column, select CAL to store the results and recalibrate the BAM.
4. Select EXIT to return to the home screen (Figure 4-2).

5.14. Clock verification

1. Verify that the BAM clock is 2 minutes ahead of the data logger clock (e.g., BAM says 13:02 and data logger says 13:00).
2. Record the data logger time and as-found BAM time in the Clock Verification section of the BAM QC form.
3. If the BAM is not 2 minutes ahead of the data logger, adjust the BAM clock in the SETUP > CLOCK menu and record the results on the QC form as the as-left BAM time.

5.15. Self-test

The BAM's built-in self-test function automatically tests the tape and flow systems. The self-test should be run after every QC check and any other interruption to sampling, such as a filter tape change or performance evaluation.

1. If the leak check adapter is installed, ensure that the valve is open.
2. **TAPE** > **SELF TEST**.
3. Read the "Status" line when the self-test is complete. If it displays SELF TEST PASSED, select **EXIT** to return to the home screen.
4. If the status displays ERROR OCCURRED, look for an error in the individual test parameters on the BAM screen. Resolve the error and repeat the self-test until it passes, then select **EXIT** to return to the home screen.
5. Remove the leak check adapter.

Note: Always return to the home screen following any sampling interruption, including QC checks and maintenance. Entering the TEST or TAPE menus automatically puts the BAM into MAINTENANCE mode. The home screen will display STATUS: MAINTENANCE when these menus have been accessed in the previous hour. The BAM will automatically return to sampling (ON) mode at the top of the next hour if the home screen is displayed.

It is not necessary or recommended to enter the OPERATE menu at all. Even if the OPERATE menu is used to turn operation off, the BAM will still automatically return to ON mode and begin sampling at the top of the hour.

Before leaving the site, always verify that the flow audit adapter is removed, the VSCC and PM_{10} head are installed, the BAM displays the home screen, and the results of all QC checks and maintenance are recorded in the electronic logbook.

5.16. 14-day nozzle and vane cleaning (optional)

Nozzle and vane cleaning is recommended in dusty or humid environments or at sites with a history of leak check failures every 14 days. Cleaning reduces the likelihood of leak check failures and minimizes data loss when they do occur.

The following is a quick guide to the 14-day nozzle and vane cleaning. Detailed instructions can be found in the linked sections in Table 5-2. 14-day nozzle and vane cleaning steps and in Table 5-2.

Table 5-2. 14-day nozzle and vane cleaning steps

Step	Section/Notes
As-found leak check	5.4
Filter tape inspection	5.5
Nozzle and vane cleaning	5.6
As-left leak check	5.10
Self-test	5.15
Logbook entry	Log as-found and as-left leak check values. No QC form necessary.

5.17. Twelve-month maintenance

The 12-month maintenance is performed by the Calibration and Repair Laboratory unless other arrangements are made. The Calibration and Repair Laboratory retains records of 12-month maintenance completed. This maintenance consists of:

1. Clean or replace the internal debris filter.
2. Check the membrane span foil.
3. Test the filter RH sensor.
4. Test the beta detector count rate and dark count.
5. Clean the inlet tube.
6. Test/replace lithium battery on circuit board.
7. Rebuild the vacuum pump.
8. Replace the nozzle O-ring.
9. Replace the pump tubing.
10. Repeat the 72-hour zero test.

The Calibration and Repair Laboratory will work with operators to arrange the annual 72-hour zero test at the operating site and update the BKGD value as necessary.

6. Data Collection and Storage

6.1. Communication software setup

Comet is Met One's software to download data, settings, and diagnostic information from the BAM over a serial connection. The serial cable should be connected from the COM port of the data logger to the "Report Port" on the back of the instrument. Comet version 1.2.12 should be installed on all data loggers with BAMs. When installing the software, the BAM1020.dll plugin should be updated according to the directions in Comet_V1.2.12\Comet_Plugin\Read Me.txt.

When opening Comet for the first time, select Create to set up a new station. Provide the station short name, select BAM 1020 from the drop-down, select the COM port assigned to the BAM, and ensure that the baud rate is 9600.

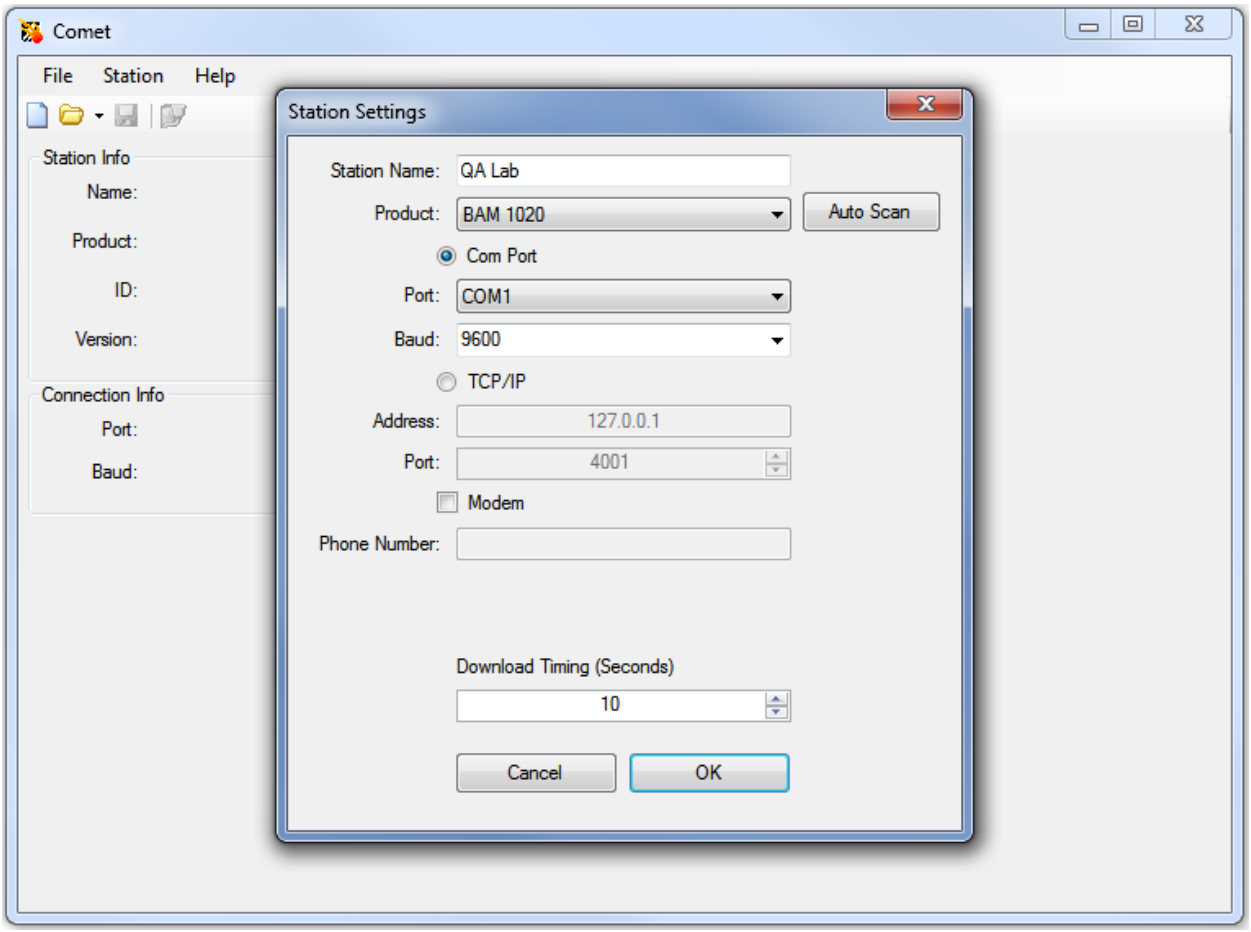

Figure 6-1. Comet setup screen

Users can then select Retrieve Current to retrieve the BAM's data, settings, diagnostic information, alarm history, and factory (internal diagnostic) data. Upon setting up Comet, immediately download a settings file to capture the BAM's configuration parameters. If settings are inadvertently or incorrectly changed in the future, the downloaded settings file serves as a record of historical settings.

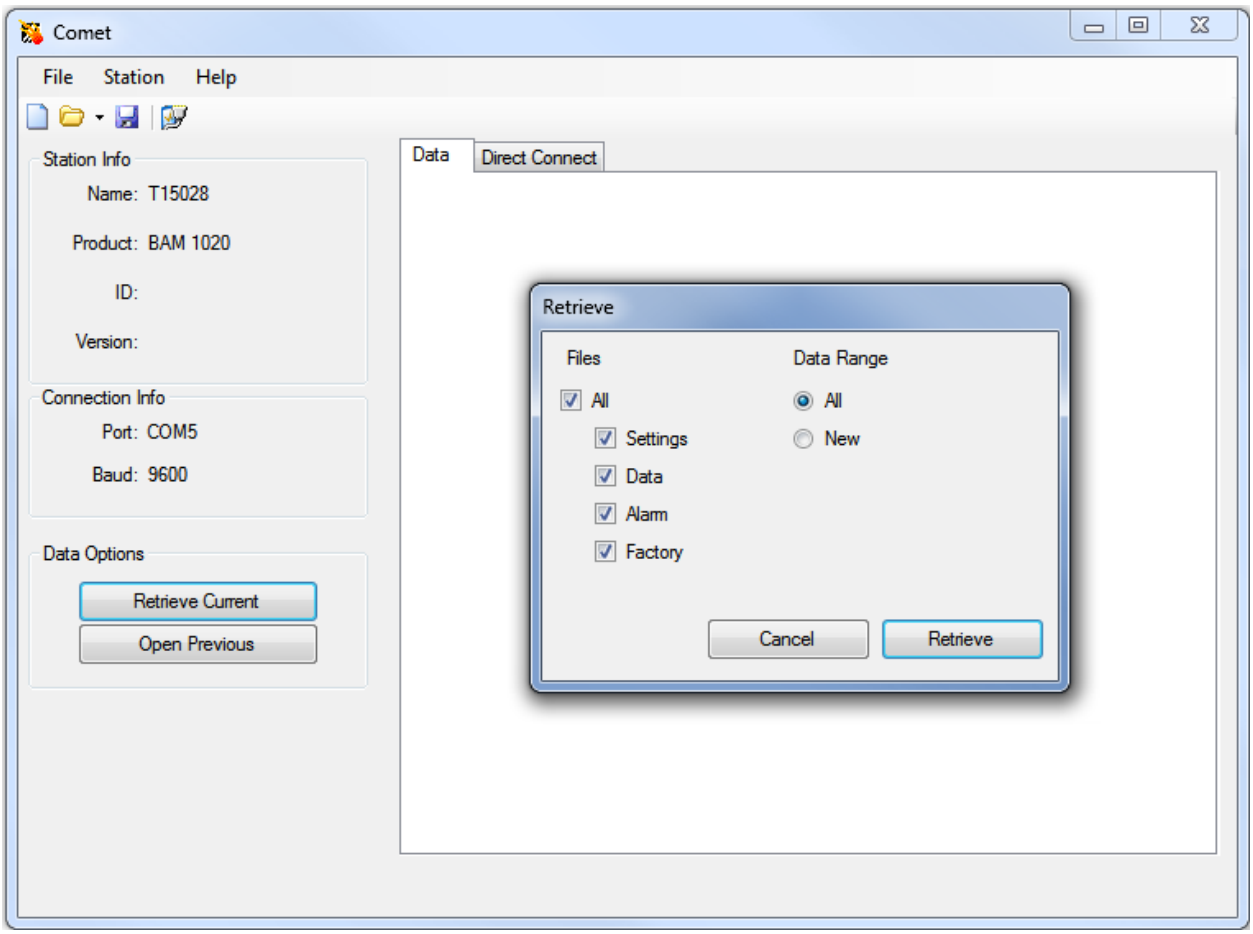

Figure 6-2. Comet user interface

6.2. Envidas channel configuration

6.2.1. Set average type to “Last Sample”

The BAM computes hourly average PM concentration at 58 minutes (:58) past each hour. To collect the correct hourly average concentration, Envidas must be configured to collect data in “Last Sample” mode. In the BAM channel configuration in Envidas Ultimate Setup, select **Last Sample** under the **Average** drop-down menu as shown in Figure 6-3.

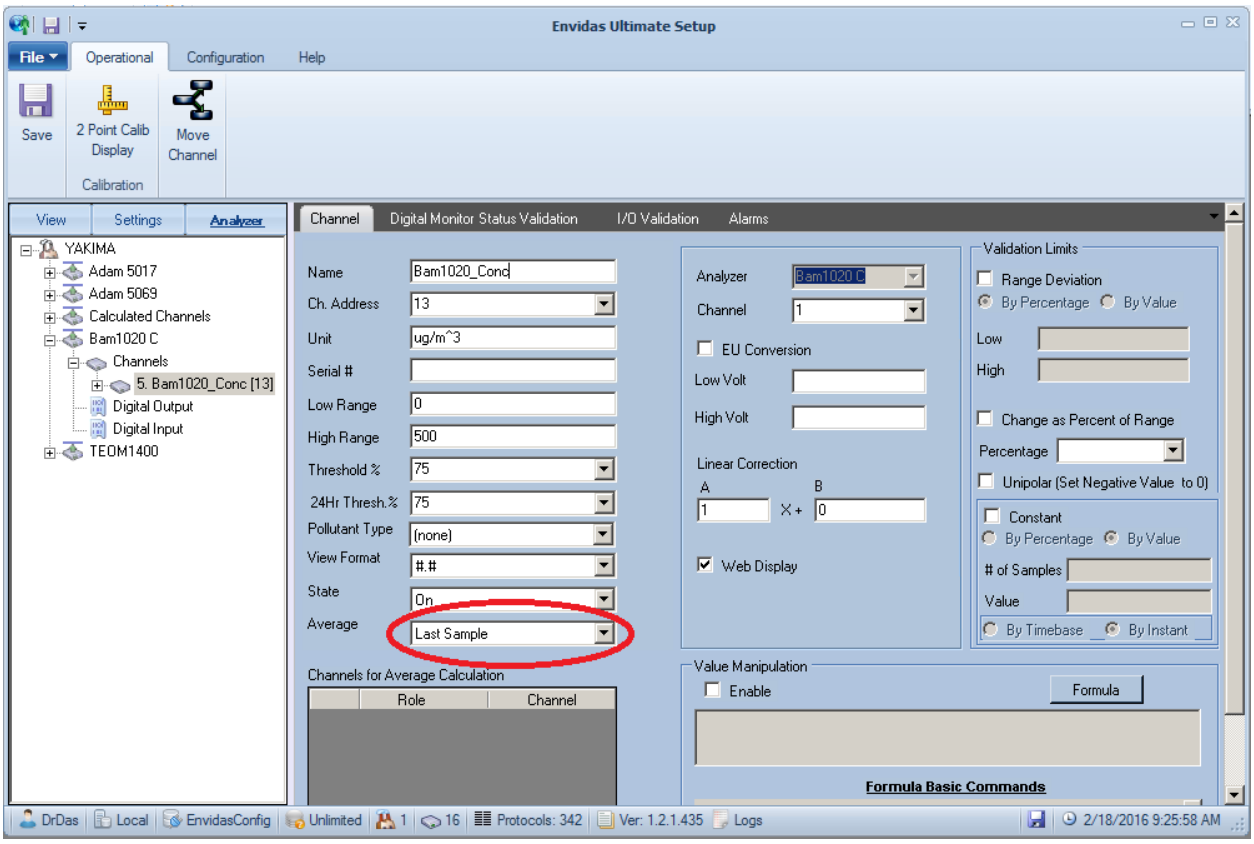

Figure 6-3. Screenshot of BAM 1020 channel configuration in Envidas Ultimate

6.2.2. Enable Sync Clock setting

The BAM clock must be set 2 minutes ahead of the data logger clock for its hourly concentrations to be associated with the correct timestamp in Envidas. Envidas Ultimate should be configured to automatically reset the BAM time 2 minutes ahead once per day. This setting can be updated in **Settings** > **Communication** > **Leased** > **Port #** > **BAM 1020** > **Device**. Ensure that the **Sync Clock** box is checked, enter **-2** under **Minute Offset**, and enter **1440** under **Check Every _ Minutes**. The correct configuration of this screen is shown in Figure 6-4.

The BAM clock must be verified upon installation and at each monthly station visit to ensure that it is 2 minutes ahead of the data logger, as described in section 5.4.10.

6.2.3. Set up automatic invalidation of errors

The BAM will record a full-scale value (985 µg/m^3) whenever it detects an error that interferes with valid, accurate data collection. Envidas should be configured to automatically flag concentrations of 985 µg/m^3 as invalid. In the **Device** screen, check the **Set Value to Invalid** box and enter **985** as shown in Figure.

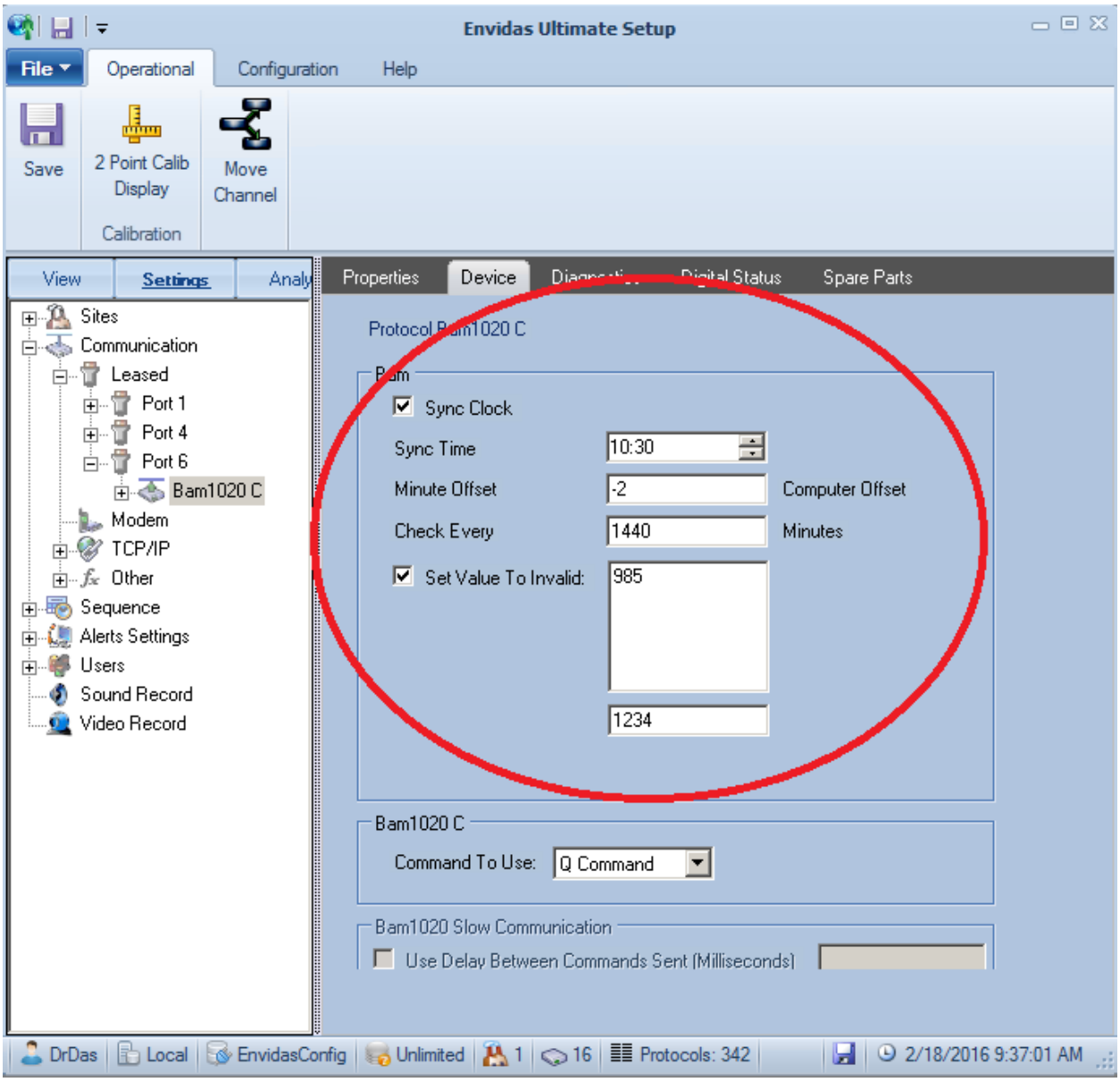

Figure 6-4: Screenshot of BAM 1020 device settings in Envidas Ultimate

6.3. Diagnostic data storage

Envidas is configured to collect a subset of the BAM's diagnostic parameters through the Diagnostic Report menu. Diagnostic polling must be set up directly by the Information Technology (IT) Unit using a PowerShell script and cannot be customized or modified by non-IT staff. The following parameters can be obtained from Envidas Ultimate Reporter or EnvistaARM by selecting the **Diagnostic** icon on the Operational tab:

Table 6-1. Diagnostic parameters available in Envidas

Parameter	Unit	Meaning	Target Value
Qtot	m^3	Total flow volume collected during the previous hour	0.7
RH	%	Relative humidity of sample air downstream of heater	<35 %
AT	°C	Ambient temperature at BAM inlet	Actual ambient temperature
E	--	External/Interface Reset	0
U	--	Telemetry/Interface Fault	0
M	--	Maintenance Alarm	0
I	--	Internal Error/Coarse Link Down	0
L	--	Power Failure/Processor Reset	0
R	--	Reference Error/Membrane Timeout	0
N	--	Nozzle Error/Delta-T Alarm	0
F	--	Flow Error	0
P	--	Pressure Drop/Delta-Pressure Alarm	0
D	--	Deviant Membrane Density/BAM CAL Alarm	0
C	--	Count/Data Error	0
T	--	Tape System/Filter Tape Error	0

The single-letter flags (rows 4-12) have a binary output, with 0 indicating normal operation and 1 indicating that an error of that type has occurred. For further information on alarm descriptions and troubleshooting steps, see Section 7.1 or the BAM 1020 Operation Manual. A flag value of 1 corresponds to a reported concentration of the BAM's full-scale value (985 $\mu g/m^3$), which is automatically flagged "Invalid" by Envidas.

If further troubleshooting is needed, the following additional diagnostic parameters can be obtained from the factory report in Comet: filter temperature (°C), filter pressure (mmHg), barometric pressure (mmHg), reference membrane value, stability, and total mass. Contact the Quality Assurance Unit for assistance obtaining and interpreting these data.

7. Data Validation and Quality Assurance

Operators are responsible for conducting daily review of data to identify issues or error codes, allowing issues to be solved as soon as possible. The Ecology Quality Assurance unit is responsible for final data validation.

Data validity is evaluated using several criteria, including, but not limited to, the results of quality control checks and performance audits and the diagnostic parameters in Table 7-1. It summarizes the tolerance limits for critical and operational criteria. Criteria that trigger invalidation outside of tolerance limits are marked with a ✓. The validity of data outside of the remaining limits is evaluated using a weight-of-evidence approach. The full table of critical and operational criteria can be found in EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II.

Table 7-1. Summary of critical and operational criteria used to determine data validity

Criteria	Frequency	Tolerance limits	Invalid
Flow check	Monthly QC; semi-annual audit	± 4% actual flow; ± 5% design flow	✓
Leak check	Monthly QC; semi-annual audit	≤ 1.5 lpm	✓
Temperature verification	Monthly QC; semi-annual audit	± 2°C	Weight-of-evidence
Pressure verification	Monthly QC; semi-annual audit	± 10 mm Hg	Weight-of-evidence
Clock verification	Monthly QC; semi-annual audit	2-3 minutes ahead	✓
Status	Hourly	Error flag	✓

7.1. Error flags

Error flags are collected as binary codes in the hourly diagnostic report as described in Section 6.3. Table 7-2 below summarizes possible error flags and codes. Operators should consult the BAM 1020 Operation Manual for help interpreting and remedying error flags.

Table 7-2. BAM 1020 error flags

Warning	Decimal	Letter Code	Explanation
External/Interface Reset	2048	E	The BAM was unable to reset its clock following a clock synchronization signal from an external data logger.
Telemetry/Interface Fault	1024	U	The BAM was unable to transmit data to an external data logger.
Maintenance Alarm	512	M	The sample cycle was stopped because the BAM was put in SETUP or TEST mode.
Internal Error/Coarse Link Down	256	I	The BAM encountered an internal error and could not calculate a valid concentration.
Power Failure/ Processor Reset	128	L	AC power was lost.
Reference Error/ Membrane Timeout	64	R	Span reference membrane was not extending or withdrawing properly.
Nozzle Error/Delta-T Alarm	32	N	The nozzle motor was not operating correctly. Alternately, the Delta-T set point was exceeded by more than 1 degree.
Flow Error	16	F	Flows were outside the specification limits. Alternately, ambient temperature or barometric pressure values were outside the sensor's range.
Pressure Drop/ Delta-Pressure Alarm	8	P	The pressure drop across the filter tape has exceeded the acceptable limit, typically due to heavy particulate loading.
Deviant Membrane Density/BAM CAL Alarm	4	D	The reference membrane span check was outside the acceptable ±5% limits.
Count/Data Error	2	C	The beta particle counting system is not operating properly.
Tape System/Filter Tape Error	1	T	The filter tape was exhausted, broken, improperly aligned, or improperly tensioned.

7.2. Negative concentrations

A BAM that is operating under normal, valid conditions typically shows variation of ± 3 µg/m^3 in hourly concentrations. Therefore, the BAM will occasionally report negative concentrations when the true PM concentration is below 3 µg/m^3. These concentrations must not be invalidated or forced to 0, as this would cause upward bias in 24-hour average concentrations.

If the BAM reports negative concentrations for several hours at a time, if 24-hour concentrations are negative, or if hourly concentrations are below -10 µg/m^3, there may be a problem. Operators should examine the spent filter tape for holes and thoroughly clean the nozzle if any holes are found. If excessive negative values persist, operators should verify that the BKGD value is programmed correctly, look for sources of electrical noise, and verify that the inlet tube is grounded. Contact the Calibration and Repair Laboratory for assistance with these troubleshooting steps.

8. References

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"Correction to the Description of Equivalent Method EQPM-0308-170 MetOne Instruments, Inc.'s BAM-1020 Beta Attenuation Mass Monitor." Federal Register 73:81 (25 April 2008) pp. 22,362-22,363.

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"Probe and Monitoring Path Siting Criteria for Ambient Air Quality Monitoring." Code of Federal Regulations Title 40, Pts. 50, 53 and 58, 2013 ed.

U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. "List of Designated Reference and Equivalent Methods." https://www3.epa.gov/ttnamti1/files/ambient/criteria/reference-equivalent-methods-list.pdf

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Vaughn, David L. Standard Operating Procedure for the Continuous Measurement of Particulate Matter: Met One BAM-1020 $PM_{2.5}$ Federal Equivalent Method EQPM-0308-170. Petaluma: Sonoma Technology, 2009 (STI-905505.05-3645-SOP).

Appendix A: BAM 1020 QC Form

Use of the BAM 1020 QC form below is required for all operators in the Washington Network. Contact the Ecology Quality Assurance unit for a spreadsheet copy of this form.

Met One BAM 1020/1022 QC Form

AQS No.		Date	
Location		Auditor	
Sampler Model No.	PM2.5 BAM 1022 20	QC Start Time	PST
Sampler Serial No.		Audit Stop Time	PST
State Tag No.			

Performance Evaluation Results

Reference Standards			
	Serial Number	Model	Cert Date
Flow			
Temperature			
Pressure			

As-Found Leak Check		
Flow (≤1.5 LPM)		LPM
Pass/Fail		

As-Left Leak Check		
Flow (<1.5 LPM)		LPM
Pass/Fail		

Advanced Leak Check		
Flow (<0.3 LPM)		LPM
Pass/Fail		

Clock Verification	
Data logger time	
As-found BAM time	

Temperature Audit		
Actual		°C
Indicated		°C
Difference (±2ºC)		°C

Pressure Audit		
Actual		mmHg
Indicated		mmHg
Difference (±10mmHg)		mmHg

Flow Audit			
	Flow Rate (LPM)		% Diff (±4%)
	Actual	Indicated	
Flow 1			
Flow 2			
Flow 3			
PM10 Only (STD)			
Design Flow Difference (±5%)			

Result:

Comments:

Revised 4/8/24