TI 176C Flow Rate Audits and Adjustment

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1.0 PURPOSE AND APPLICABILITY

This standard operating procedure (SOP) describes the procedures for performing initial and final flow rate audits at IMPROVE protocol aerosol sampling sites. The procedures listed in this technical note refer to procedures followed by Air Quality Group personnel; the simplified forms used by site operators are displayed and described in SOP 201.

2.0 RESPONSIBILITIES

The field technician shall:

- Prepare the equipment necessary to perform a flow rate audit at a site.
- Calculate the desired audit device readings.
- Perform the initial and final flow rate audits.
- Keep accurate records of the initial and final audits, and any modifications made to the sampler.

3.0 REQUIRED EQUIPMENT AND MATERIALS

The equipment required to perform a flow rate audit includes the following:

- audit device (orifice meter)
- audit cassettes, at least one for each module being audited
- D module funnel
- variable flow restriction device
- copy of the most recent final flow rate audit at the site
- Form 1 Initial Flow Rate Audit Form
- Form 2 Final Flow Rate Audit Form
- calculator capable of doing logs and linear regressions.

4.0 METHODS

IMPROVE aerosol samplers are generally audited twice per year to verify the flow rate and the calibration equations used for the system gauges. One audit, the biannual audit, is done by the site operator roughly six months after the last site maintenance visit. The second audit is done by a field technician at the site during annual site maintenance. This second audit, the field audit, is actually two audits, an initial audit prior to maintenance to determine the state of the sampler, and a final audit following maintenance to be used to derive calibration equations for the system gauges. The procedures for the biannual audit are covered in SOP 201 Section 4.3.3.

Occasionally, a site will develop apparently anomalous flow rates, requiring that an audit be sent to the site. The procedures followed in this situation are similar to those followed during site set up or annual maintenance, except that they are performed by the site operator rather than by field technicians.

The procedure for an audit at an IMPROVE site requires, first, that the materials required for the audit be prepared. A sample log sheet for the initial audit is attached as Form 1. Required flow rates, expected gauge readings, and log sheet for the final audit procedure are prepared as described in TI 176-4.1, producing a form similar to the one in Form 4. The audit form sent to site operators for biannual flow rate audits is described in SOP 210 section 4.3.3, though it is translated to the standard form in Form 1 when returned to the Air Quality Group. The audit form used by site operators for anomalous flow readings is shown in SOP 201 Section 4.3.2, though this form is translated to the standard form in Form 4 by the Air Quality Group for processing. The audit device is prepared as described in SOP 176 section 4.1.2.

As the biannual audit and anomalous flow rate audit procedures are merely variations on the standard audit procedures, and are well described in other sections, they will not be covered in depth here. Instead, the following procedures will be covered.

4.1 Initial flow rate audit

4.2 Final flow rate audit

FORM 1 Initial Flow Rate Audit Form

Site Name:______________________________ Audited by:_______________________________

Sampler Serial #_________________________ Date of Field Audit: _______/_______/________

Audit Device Number:____________________ Audit Constants: a_0=_________ b_0=_________

Temperature: _________°C flow rates are relative to sea level and 20°C

Flow(magnehelic) = $10^a(M)^b$ Flow(vacuum gauge) = c + d*(G)

A Module	closed vacuum = _________			a=________ b=________	c=________ d=________	
Audit Mag reading	System Mag reading	System Vac reading	Audit Mag Flow @ Sea	System Mag Flow @ Sea	System Vac Flow @ Sea	% Error 1-Audit/Mag
nominal						%
						%
						%
						%

B Module	closed vacuum = _________			a=________ b=________	c=________ d=________	
Audit Mag reading	System Mag reading	System Vac reading	Audit Mag Flow @ Sea	System Mag Flow @ Sea	System Vac Flow @ Sea	% Error 1-Audit/Mag
nominal						%
						%
						%
						%

C Module	closed vacuum = _________			a=________ b=________	c=________ d=________	
Audit Mag reading	System Mag reading	System Vac reading	Audit Mag Flow @ Sea	System Mag Flow @ Sea	System Vac Flow @ Sea	% Error 1-Audit/Mag
nominal						%
						%
						%
						%

D Module	closed vacuum = _________			a=________ b=________	c=________ d=________	
Audit Mag reading	System Mag reading	System Vac reading	Audit Mag Flow @ Sea	System Mag Flow @ Sea	System Vac Flow @ Sea	% Error 1-Audit/Mag
nominal						%
						%
						%
						%

4.1 Initial Flow Rate Audit

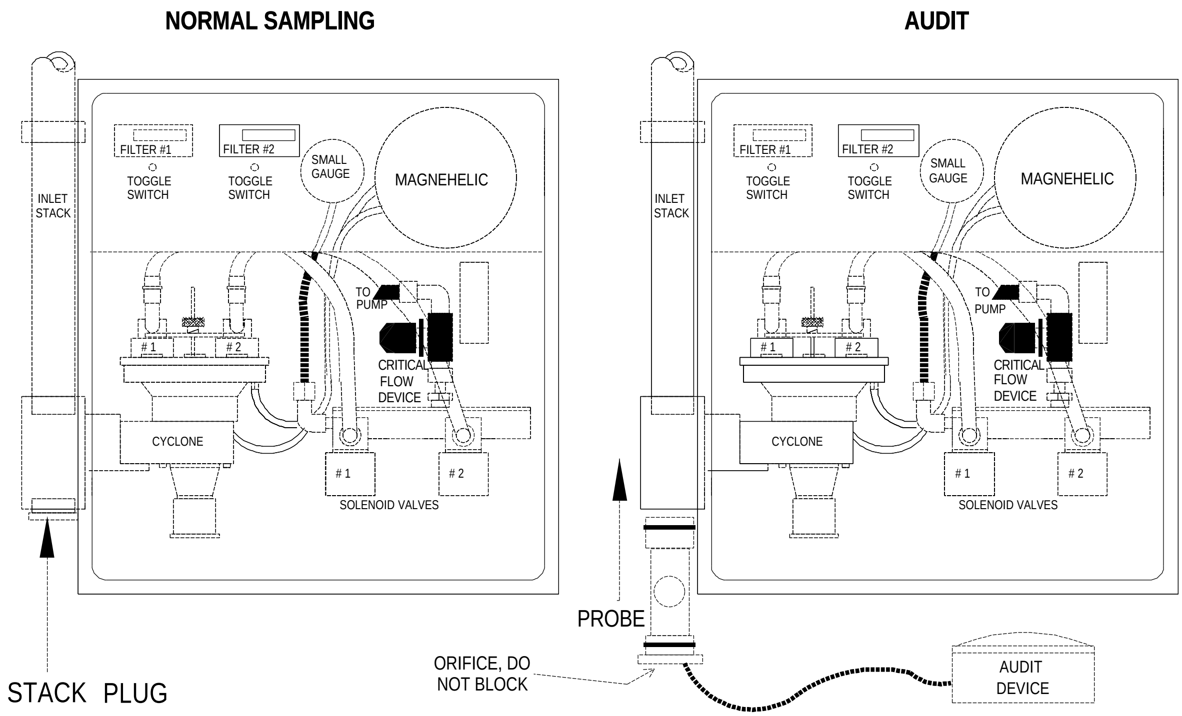
Initial flow rate audit procedures for modules A, B, and C are as follows:

1. Fill out the top section of the form shown in Form 1, Initial Flow Rate Audit Form.
   - Print the site name and the name of the field technician(s) auditing the sampler
   - Record the sampler serial number; it should be printed on a metal University of California identification tag stuck inside the controller module. It is generally mounted on the door or the left side of the module. Note that samplers not purchased by the IMPROVE program do not have identification tags.
   - Record the current date
   - Record the audit device number, and the audit constants a_0 and b_0 from the audit device calibration equation. These values are printed on the calibration sticker on the audit device.
   - Record the current temperature at the site, in °C.
   - For each sampling module; A, B, C, and D; record the calibration constants currently being used for the system gauges. These values are calculated at the bottom of each module section on the Final Flow Rate Audit form. Use the most recent final audit form to get these numbers.
2. Install an audit cassette on the cyclone of each module being audited. Connect it to solenoid #1 (the solenoid farthest to the left). The audit cassette must have the same substrate and pressure drop as the standard cassette for that module. Verify that all cyclone ports either have filters mounted on them, or are covered by port caps to prevent leaks.
3. Review Figure 1, A, B, C Module Audit Diagram
4. Turn on the pumps:
   - for a Module A Controller, flip the pump override switch on the face plate from “auto” to “manual” (off to on) to turn the pumps on.
   - for a Controller Module, turn the dial on the 25 minute timer past 5 minutes to turn the pumps on. Note, the pumps will turn off when the timer reaches zero.
5. Record the vacuum gauge reading (closed vacuum) with no solenoids open on the Initial Flow Rate Audit Form for each module. Tap the vacuum gauge to be sure the needle is not sticking.
6. Remove the knurled plug at the base of the inlet stack on module A as indicated in Figure 1.
7. Insert the probe of the audit device into the base of the module A inlet stack. Push the probe in as far as it will go so that both O-rings are inside the inlet. Be careful not to restrict the orifice of the audit device probe in any way.
8. Place the audit device gauge on a <u>LEVEL SURFACE, FACE UP</u> (see Figure 1)**.**
9. Flip the toggle switch for filter 1 and record the value displayed on the audit device on the Initial Flow Rate Audit Form as the Module A nominal audit Mag.(magnehelic) reading.
10. Remove the audit device probe from the bottom of the inlet stack.
11. Flip the filter 1 toggle switch and record the system magnehelic reading and the system vacuum gauge reading in the same row as the audit Mag reading in initial audit form. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
12. Calculate the audit magnehelic flow rate, the system magnehelic flow rate, and the system vacuum gauge flow rate using the equations at the top of the audit form. Be sure to use the audit constants for calculating the audit magnehelic flow, and the calibration constants from

the most recent final audit at the site for calculating the system magnehelic flow and the system vacuum gauge flow.

13. Calculate the percent error, using the equation in the last column of the form.
    - If the error is less than 5%, skip to step # 22, no further audit data are required for this module.
    - If the error is greater or equal to 5%, continue to step 14.
14. Install a flow restricting device between the filter and the solenoid.
15. Replace the audit device probe in the bottom of the inlet stack. Push the probe in as far as it will go so that both O-rings are inside the inlet. Be careful not to restrict the orifice of the calibration probe.
16. Flip the filter 1 toggle switch and adjust the flow restricting device installed in step 14 to reduce the audit device reading by 10% from the previous reading. Record the new audit device reading below the previous audit reading.
17. Remove the calibration probe from the bottom of the inlet stack.
18. Flip the filter #1 toggle switch and record the system magnehelic reading and the system vacuum gauge reading in the same row as the audit reading from step 16. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
19. Repeat steps 15 through 18 twice more, first reducing the nominal audit reading by 20%, and then reducing it by 30%. Once completed, there should be audit Mag readings, system Mag readings, and system vacuum gauge readings for nominal, 10% below nominal, 20% below nominal, and 30% below nominal on the initial audit form for the module being audited.
20. Calculate the percent error, using the equation in the last column of the form.
21. Perform a quality control check on the collected data. The steps are as follows:
    a. Linearly regress Log_{10}(audit Mag flow rate) against Log_{10}(system Mag reading)
    b. Calculate r^2.
    c. If r^2 is ≤ 0.990, the audit is bad. Verify that no arithmetic errors were made. If no errors are apparent, the field technician must repeat the audit procedure, starting with step 7 of this section.
    d. If r^2 is > 0.990, the audit is good, and the field technician may continue with the audit procedure.
22. Repeat steps 6 through 21 for Module B and for Module C.

Figure 1 A, B, and C Module Audit Diagram

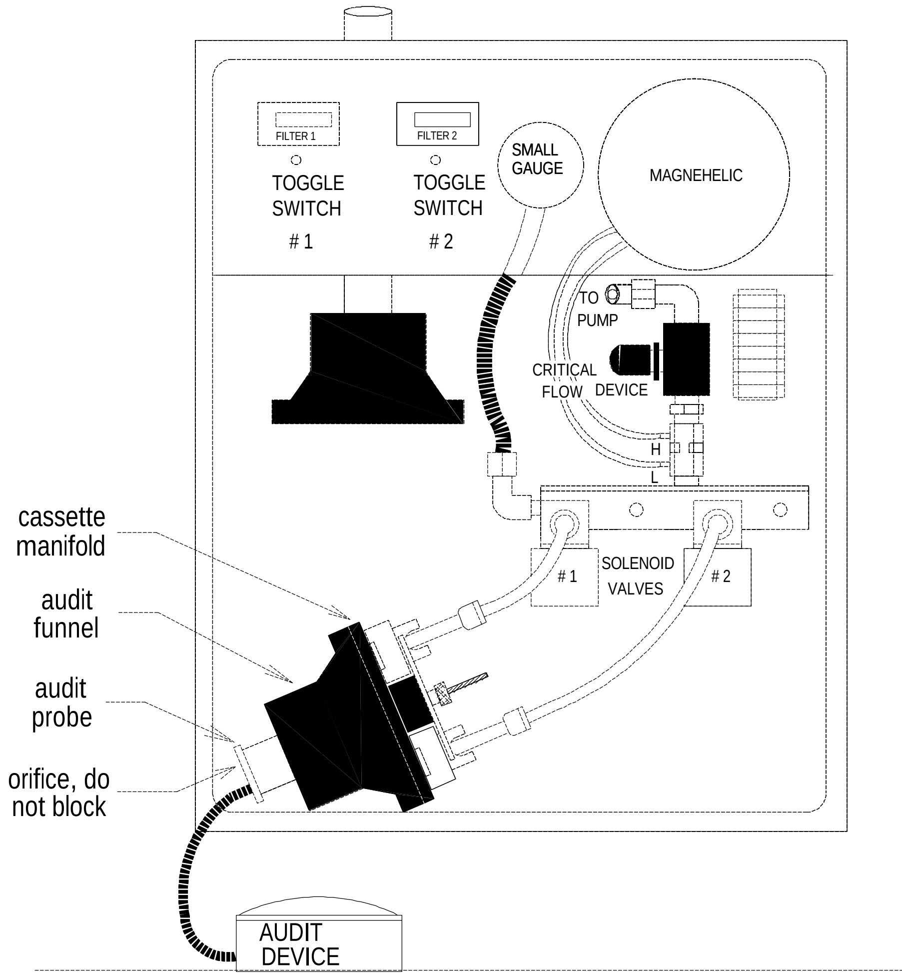


23. Review Figure 2 for D module audit
24. Remove the manifold plate from the funnel in the sampler by pulling down on the cassette hold-down plate until the manifold plate pops off the funnel. If it is too firmly seated for this, you can insert a long screwdriver between the manifold plate and the cassette hold-down plate and use this as a lever to help pop the manifold off the funnel.
25. Attach the manifold plate to the audit funnel by pressing the two parts together until no gap exists between the two pieces.
26. Unscrew the white nylon tip of the audit device probe and set it aside.
27. Insert the calibration probe, with the tip removed, into the top of the D module calibration funnel, pressing firmly and twisting to ensure an o-ring seal. Be careful not to restrict the orifice on the probe in any way.
28. Place the audit device on a level surface, face up. (see Figure 2 Module D Audit Diagram)**.**
29. Verify that the audit cassette is mounted on the cassette manifold and connected to solenoid #1.
30. Flip the toggle switch for filter 1 and record the value displayed on the audit device on the Initial Flow Rate Audit Form as the Module D nominal audit mag.(magnehelic) reading
31. Flip the toggle switch for filter # 1 and read the system vacuum gauge and system magnehelic, recording the results in the same row as the audit mag reading in initial audit form. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators
32. Calculate the audit magnehelic flow rate, the system magnehelic flow rate, and the system vacuum gauge flow rate using the equations at the top of the audit form. Be sure to use the audit constants for calculating the audit magnehelic flow, and the calibration constants from

the most recent final audit at the site for calculating the system magnehelic flow and the system vacuum gauge flow.

33. Calculate the percent error, using the equation in the last column of the form.
    - If the error is less than 5%, skip to step # , no further audit data are required for this module.
    - If the error is greater or equal to 5%, continue to step 34.
34. Install a flow restricting device between the filter and the solenoid.
35. Flip the filter 1 toggle switch and adjust the flow restricting device installed in step 34 to reduce the audit device reading by 10% from the previous reading. Record the new audit device reading below the previous audit reading.
36. Flip the filter #1 toggle switch and record the system magnehelic reading and the system vacuum gauge reading in the same row as the audit reading from step 35. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
37. Repeat steps 35 and 36 twice more, first reducing the nominal audit reading by 20%, then reducing it by 30%. Once completed, there should be audit mag readings, system mag readings, and system vacuum gauge readings for nominal, 10% below nominal, 20% below nominal, and 30% below nominal on the initial audit form for the module being audited.
38. Calculate the percent error, using the equation in the last column of the form.
39. Perform a quality control check on the collected data. The steps are as follows:
    a. Linearly regress Log_{10}(audit mag flow rate) against Log_{10}(system mag reading)
    b. Calculate r^2.
    c. If r^2 is ≤ 0.990, the audit is bad. Verify that no arithmetic errors were made. If no errors are apparent, the field technician must repeat the audit procedure, starting with step 7 of this section.
    d. If r^2 is > 0.990, the audit is good, and the field technician may continue with the audit procedure.

Figure 2 Module D Audit Diagram



FORM 2 Final Flow Rate Audit Form

Site Name:______________ Date of Audit :____/___/__ Sampler Serial #________________

elevation________ F(*elev.*)_______ (from Table) Field Technician: _____________________

Audit Device # _________ Audit Constants: a_o = _________ b_o = _________ T_______°C

audit mag. reading for nom. flow: $M_o = \left[\frac{Q_o}{F_{(elev)}} \frac{1}{10^{a_o}}\right]^{1/b_0}$ M_o(**A, B, C**) = ________ M_o(**D**) = _______

A Module: Q_o = 23 lpm

Flow Rate at sea level, 20°	Audit Magnehelic	System Magnehelic	System Vac. Gauge
Q_o	M_o=		
$Q_1=0.95*Q_o$	M_1=		
$Q_2=0.90*Q_o$	M_2=		
$Q_3=0.85*Q_o$	M_3=		

Magnehelic: r^2=___________

log(flow) = + * log(M)

Vacuum Gauge: r^2=___________

flow = + * (G)

Nominal flow @ site (sys):	mag. zero:	max vac:

C Module: Q_o = 23 lpm

Flow Rate at sea level, 20°	Audit Magnehelic	System Magnehelic	System Vac Gauge
Q_o	M_o=		
$Q_1=0.95*Q_o$	M_1=		
$Q_2=0.90*Q_o$	M_2=		
$Q_3=0.85*Q_o$	M_3=		

Magnehelic: r^2=___________

log(flow) = + * log(M)

Vacuum Gauge: r^2=___________

flow = + * (G)

Nominal flow @ site (sys):	mag. zero:	max. Vac.:

Flow Rate at sea level, 20°	Audit Magnehelic	System Magnehelic	System Vac Gauge
Q_o	M_o=		
$Q_1=0.95*Q_o$	M_1=		
$Q_2=0.90*Q_o$	M_2=		
$Q_3=0.85*Q_o$	M_3=		

Magnehelic: r^2=___________

log(flow) = + * log(M)

Vacuum Gauge: r^2=___________

flow = + * (G)

Nominal flow @ site (sys.):	mag. zero:	max. vac.:

D Module: Wedding (19.1) ☐ Sierra (16.9) ☐

Flow Rate at sea level, 20°	Audit Magnehelic	System Magnehelic	System Vac Gauge
Q_o	M_o=		
$Q_1=0.95*Q_o$	M_1=		
$Q_2=0.90*Q_o$	M_2=		
$Q_3=0.85*Q_o$	M_3=		

Magnehelic: r^2=___________

log(flow) = + * log(M)

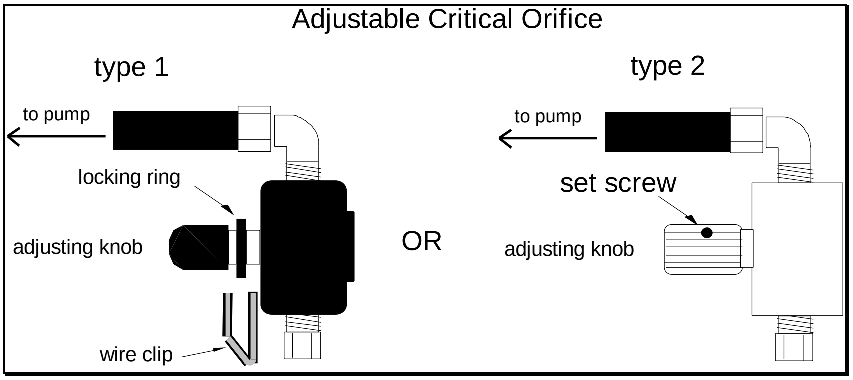
Vacuum Gauge: r^2=___________

flow = + * (G)

Nominal flow @ site (sys.):	mag. zero:	max. vac

B Module: Q_o = 23 lpm

Figure 3 Adjustable Critical Orifice Configuration



4.2 Final Flow Rate Audit

1. Fill in the requested information on Form 2, the Final Flow Rate Audit Form.
   a. Fill in the site name or 5 character code, the current date, and the sampler serial number. The serial number is in the controller module and is generally inside the module on the lower side of the left wall. Note that some samplers do not have serial numbers.
   b. Record the site elevation and the elevation factor. Generally, these values are copied from the previous calibration sheet, though they should be verified against the elevation correction factor table.
   c. Record the name of the field technician responsible for the audit.
   d. Record the audit device number, listed on the face of the audit magnehelic. Also, record the audit constants from the audit magnehelic calibration equation.
   e. Record the current temperature in °C.
   f. Using the equations on the final audit form, calculate the nominal audit device reading, M_0 for the A, B, and C modules (Q = flow rate = 23 lpm for modules A, B, and C).
   g. Using the equations on the final audit form, calculate the nominal audit device reading, M_0 for the D module (Q = flow rate = 19.1 lpm for modules having Wedding PM_{10} inlets and 16.9 lpm for modules having Sierra Anderson PM10 inlets).
2. Install an audit cassette on the cyclone of each module being audited. Connect it to solenoid #1 (the solenoid farthest to the left). The audit cassette must have the same substrate and pressure drop as the standard cassette for that module. Verify that all cyclone ports either have filters mounted on them, or are covered by port caps to prevent leaks.
3. Adjust the magnehelic gauges such that they read 0.00” H_2O.
4. Review Figure 1, A, B, C Module Audit Diagram, and Figure 3, Adjustable Critical Orifice Configuration.
5. Turn on the pumps:

- for a Module A Controller, flip the pump override switch on the face plate from "auto" to "manual" (off to on) to turn the pumps on.

- for a Controller Module, turn the dial on the 25 minute timer past 5 minutes to turn the pumps on. Note, the pumps will turn off when the timer reaches zero.

6. Record the maximum vacuum reading (Max. Vac.) from the vacuum gauge for each module on the final audit form, Form 2. Tap the vacuum gauge to ensure the needle is not sticking.
7. Remove the knurled plug at the base of the module A inlet stack as indicated in Figure 1.
8. Insert the probe of the audit device into the base of the inlet stack. Push the probe in as far as it will go so that both O-rings are inside the inlet. Be careful not to restrict the orifice of the audit device probe in any way.
9. Place the audit device gauge on a LEVEL SURFACE, FACE UP (see Figure 1).
10. Remove the wire clip from the adjustable critical orifice (type 1 only) and press the red locking sleeve gently inward. If the adjustable orifice is type 2 (brass body) loosen the set screw on the control knob with a 5/64" allen wrench.
11. Press the channel 1 toggle switch to the left to allow flow through the audit cassette.
12. While holding the toggle switch open to allow flow, adjust the critical orifice until the audit device reads the calculated nominal flow reading M_o.
13. Release the toggle switch and pull gently outward on the red locking sleeve on the adjustable critical orifice (type 1) or tighten the set screw (type 2). Slip the wire clip between the red sleeve and the body of the critical orifice to hold the lock in place (type 1 only).
14. Press the channel 1 toggle switch open and verify that the audit device reads the calculated nominal flow reading M_o. If the flow is off, repeat steps 10 through 14 until the correct setting is reached.
15. Remove the audit device probe from the bottom of the inlet stack.
16. Flip the filter #1 toggle switch and record the system magnehelic and system vacuum gauge readings on the Final Audit Form. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
17. Install a flow restricting device between the filter and the solenoid.
18. Replace the audit device probe in the bottom of the inlet stack. Push the probe in as far as it will go so that both O-rings are inside the inlet. Be careful not to restrict the orifice of the probe in any way.
19. Flip filter #1 toggle switch and adjust the flow restricting device installed in step 17 to reduce the audit device reading to the calculated reading M1.
20. Remove the calibration probe from the bottom of the inlet stack.
21. Flip the filter #1 toggle switch and record the system magnehelic and system vacuum gauge readings corresponding to the audit device nominal flow M_1 in the same row in the module calibration table. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
22. Repeat steps 18 through 21 for calculated calibration magnehelic readings M_2 and M_3.
23. Perform a quality control check on the calibration. The steps are as follows:
    a. Linearly regress Log_{10}(flow rate Q) against Log_{10}(system magnehelic)

b. Calculate r^2.
c. If r^2 is ≤ 0.990, the calibration is bad. Verify that no arithmetic errors were made. If no errors are apparent, the field technician must repeat the final audit procedure.
d. If r^2 is > 0.990, the calibration is good, and the field technician may continue with the calibration procedure.

24. Replace the knurled plug securely into the bottom of the inlet stack.
25. Repeat steps 7 through 24 for Module B and for Module C.
26. Review Figure 2 for D module audit
27. Remove the manifold plate from the funnel in the sampler by pulling down on the cassette hold-down plate until the manifold plate pops off the funnel. If it is too firmly seated for this, you can insert a long screwdriver between the manifold plate and the cassette hold-down plate and use this as a lever to help pop the manifold off the funnel.
28. Attach the manifold plate to the audit funnel by pressing the two parts together until no gap exists between the two pieces.
29. Unscrew the white nylon tip of the audit device probe and set it aside.
30. Insert the audit probe, with the tip removed, into the top of the audit funnel, pressing firmly and twisting to ensure an o-ring seal. Be careful not to restrict the orifice on the probe in any way.
31. Place the audit device on a level surface, face up. (see Figure 2: D module audit diagram)**.**
32. Verify that the audit cassette is mounted on the cassette manifold and connected to solenoid #1.
33. Remove the wire clip from the adjustable critical orifice (type 1 only) and press the red locking sleeve gently inward. If the adjustable orifice is type 2 (brass body) loosen the set screw on the control knob with a 5/64" allen wrench.
34. Press the channel 1 toggle switch to the left to allow flow through the audit cassette.
35. While holding the toggle switch open to allow flow, adjust the critical orifice until the audit device reads the calculated nominal flow reading M_o for the D module.
36. Release the toggle switch and pull gently outward on the red locking sleeve on the adjustable critical orifice (type 1) or tighten the set screw (type 2). Slip the wire clip between the red sleeve and the body of the critical orifice to hold the lock in place (type 1 only).
37. Press the channel 1 toggle switch open and verify that the calibration magnehelic gauge reads the calculated nominal flow reading Mo. If the flow is off, repeat steps 32 through 36 until the correct setting is reached.
38. Flip the filter #1 toggle switch and record the system magnehelic and system vacuum gauge readings corresponding to the audit device nominal flow Mo. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.
39. Install a flow restricting device between filter #1 and solenoid #1.
40. Flip filter #1 toggle switch and adjust the flow restricting device installed in step 38 to reduce the calibration magnehelic reading to the calculated reading M1.
41. Flip the filter #1 toggle switch and record the system magnehelic and system vacuum gauge readings corresponding to the audit device nominal flow M1. Be sure to tap the gauges before recording final readings to eliminate errors due to sticking indicators.

42. Repeat steps 39 and 40 for calculated audit device readings M2 and M3.
43. Perform a quality control check on the audit. The steps are as follows:
    a. Linearly regress Log_{10}(flow rate Q) against Log_{10}(system magnehelic)
    b. Calculate r^2.
    c. If r^2 is ≤ 0.990, the calibration is bad. Verify that no arithmetic errors were made. If no errors are apparent, the field technician must repeat the audit procedure.
    d. If r^2 is > 0.990, the calibration is good, and the final audit is complete.