Ecotech Nephelometer Operating Procedure

Publication Information

Contact Information

Air Quality Program

P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6800
Website[1]: Washington State Department of Ecology

ADA Accessibility

---

[1] www.ecology.wa.gov/contact

Department of Ecology's Regional Offices

Map of Counties Served

| Southwest Region 360-407-6300 | Northwest Region 206-594-0000 | Central Region 509-575-2490 | Eastern Region 509-329-3400 |

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	P.O. Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	P.O. Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 West Alder Street Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 North Monroe Spokane, WA 99205	509-329-3400
Headquarters	Statewide	P.O. Box 46700 Olympia, WA 98504	360-407-6000

Ecotech Nephelometer Operating Procedure

Air Quality Program
Washington State Department of Ecology

Olympia, WA

November 2022 | Publication 09-02-005

Approved by:

Signature: _____ Date: _____
Rob Dengel, Air Quality Deputy Program Manager

Signature: _____ Date: _____
Sean Lundblad, Technical Services Section Manager

Signature: _____ Date: _____
Jill Schulte, Air Monitoring Coordinator

Signature: _____ Date: _____
Scott Dubble, NWRO/SWRO & Air Quality Operations Unit Supervisor

Signature: _____ Date: _____
Eric Beamesderfer, Air Quality Program Quality Assurance Coordinator

Signatures are not available on the Internet version

Table of Contents

List of Figures and Tables

Figures

Tables

Acknowledgements

Introduction

Nephelometers are used throughout the Washington State Department of Ecology's Ambient Air Monitoring Network (Washington Network) to provide estimates of $PM_{2.5}$ pollution and visibility. Two types of nephelometers are used within the Washington Network:

1. Radiance Research/Met One M903 nephelometer

2. Ecotech M9003 and Ecotech M9003 Aurora nephelometer.

The Puget Sound Clean Air Agency (PSCAA) uses the Ecotech M9003 and Aurora 1000G nephelometers within the Washington Network. This procedure describes PSCAA's operations.

The Ecotech M9003 and the smaller Aurora 1000G use the same measurement principles and thus are considered the same instrument for the purposes of this standard operating procedure. PSCAA uses this procedure along with the Ecotech nephelometer operations manual, service manual, training manuals, and technical memoranda. A picture of the Ecotech nephelometers can be seen in Figure 1.
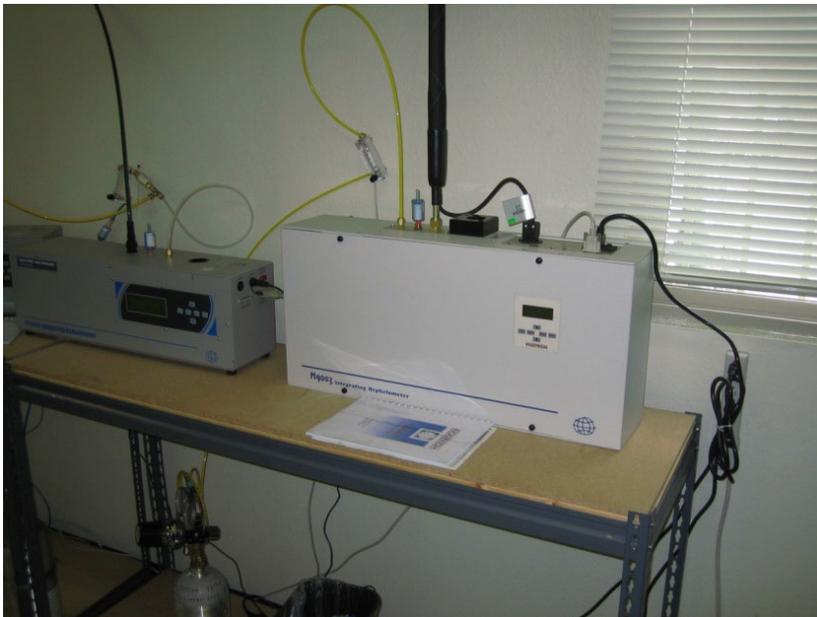
Figure 1. Ecotech Aurora 1000G (left) and M9003 (right) nephelometers

Method of Operation

A nephelometer measures particles suspended in an air mass. The Ecotech nephelometer uses an LED array as the light source. Sample air is drawn by the pump in through the sample inlet into the measurement volume and exits through the sample outlet. Light emitted from the source illuminates the sample air in the measurement volume. Gaseous and particulate components in the sample air will cause the light to scatter.

The baffles inside the cell are positioned such that only light scattered inside a narrow cone reaches the photomultiplier tube. This ensures that multiple scattered light is unlikely to reach the photomultiplier tube. The photomultiplier tube produces electrical signals proportional to the intensity of the incident light. Hence the signal produced by the photomultiplier tube is proportional to the scattering coefficient of the sample air.

The light trap and other baffles eliminate unwanted reflections from the light source and scattered light off the non-detecting end of the cell. The cell interior and baffles are coated with a special matte finish black paint to reduce any internal reflections. Light scattered by the particles suspended in the air sample can now be quantified and registered on the display screen as inverse megameters, or (Mm^{-1}). 10 Mm^{-1} is equal to 1.0 e^{-5} bscat on the Ecotech nephelometer. A more comprehensive explanation of the operations of the nephelometer can be found in the manufacturer's documentation

Siting Requirements

Nephelometers within the Washington Network are used primarily to obtain estimates of PM$_{2.5}$ due to their relative affordability and demonstrated strong correlation between 24-hour bscat readings and 24-hour concentrations from collocated Federal Reference Method (FRM) and Federal Equivalent Method (FEM) PM$_{2.5}$ monitors. Proper siting is essential to ensure that data collected are representative at the appropriate scale for the monitoring project. The majority of PM$_{2.5}$ monitoring in the Washington State Ambient Air Monitoring Network (Washington Network) is conducted at the neighborhood scale (0.5 – 4 km) in order to understand air pollution across a fairly large area with relatively consistent geography and land use. Siting criteria for neighborhood-scale PM$_{2.5}$ monitoring sites are described extensively in 40 CFR Part 58, Appendices D and E; the primary considerations are summarized in Table 1 below. Operators of sites at other monitoring scales should consult Appendices D and E for siting requirements.

Table 1. Siting criteria

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

Other factors must be considered when choosing a location for installation:

- The operator's personal safety.

- Site access during times of inclement weather.

- Availability of adequate power and telecommunication/internet.

- Security of the site and equipment.

- Reasonable egress to allow for transporting instruments, tools, and supplies in and out of the site.

- All sensitive electronic equipment must be kept in a temperature-controlled, moisture-free environment that isolates it from moisture and rapid temperature changes.

Equipment

- M9003 or Aurora 1000G model Nephelometer.

- Ecology-approved PC data logger and communications equipment. Serial or Ethernet connections are required to facilitate collection of critical diagnostic information.

- Probe material and mounting hardware.

- Cylinder of CO_2 span gas.

- Pressure regulator.

- Particulate filter, conditioning coil, and rotameter for controlling flow of the span gas.

- Q-tip sticks, forced air dusters, and no-lint cloth for maintenance of the sample chamber.

- Phillips screwdrivers.

- Flat head screwdriver.

- Crescent wrench.

- Black cloth or plastic bag

- Hex keys

Consumables

- Zero Air Pump inlet filter DFU (95%) pt: 036-040180

- Zero/Span Fine filter DFU (99.5%) pt: A-FIL-1050

Operators should visually inspect all nephelometer system components upon receipt to ensure all equipment is present and in good condition. Operators should notify the PSCAA Monitoring Team when equipment is discovered to be missing or damaged.

Installation

Install the nephelometer in a secure, dry location within the shelter that will not be directly impacted by the flow of air from a heater or an air conditioner. A wall mount is available from Ecotech and can be a good way to maximize space in a small shelter.

Proper installation of the sample probe is very important. Preventive measures must be taken to minimize the possibility of drawing in water or insects with the air sample. For this reason, the Ecotech nephelometer must be installed with the manufacturer's sample head that comes equipped with a wire mesh bug screen. The acceptable probe material consists of the anodized aluminum inlet tubing provided by the manufacturer along with 3/8"-1/2" plastic flexible tubing. If the anodized aluminum tubing is not being installed directly straight up through the roof of the shelter to the inlet head, any flexible probe material should be installed to minimize bends in the sample line and limit subsequent particulate loss due to impaction.

All nephelometers include a heating chamber or heated probe that reduces the relative humidity of the sample before it enters the sample chamber. Only the factory designed heater should be used. The relative humidity sensor and heat controls are integrated into the nephelometer design.

Connecting to the Data Logger

Data logging at sites within the Washington Network is done using Envitech Ultimate software installed on a computer. The Puget Sound Clean Air Agency has created a standard Ecotech nephelometer data logger configuration that is approved for use within the Washington Network data loggers to collect data from the Ecotech nephelometers. If it becomes necessary to change the configuration of the data logger, contact the Air Quality Program's IT Unit.

To connect the Ecotech nephelometer to the data logger, connect a standard serial cable between the nephelometer serial output (RS232 Multi-Drop connection) and the computer's 4 or 8 port DB9M serial cable to the cable. After connecting the serial cable, use the Envidas Ultimate Viewer to verify that communications between the nephelometer and the data logger have been successfully established. If communication with the nephelometer cannot be successfully established, call the Air Quality Program's IT unit for assistance.

Plumbing for Automated Quality Control

All Ecotech nephelometers are equipped with an internal automated QC system. A regulated flow of particulate-free CO2 span gas (cylinder) is necessary to use the nephelometer QC system. Experience has shown that there must be a conditioning coil of 1 meter in length along with a particulate filter and a rotameter in series between the calibration gas regulator and the instrument's calibration gas inlet port. Figure 2 shows the basic plumbing and connections.

- Connect the regulator to the CO_2 cylinder

- Connect the regulator's output port to the brass conditioning coil using PFA grade Teflon tubing (rated above 100 lbs./in.^{2}). PFA is the same material used as sample probe

material for criteria gaseous pollutant monitoring and will not interact with the CO_2 span gas.

- Install a particulate filter (balston filter type) to ensure a particle free zero measurement.

- Install the rotameter between the particulate filter and the Ecotech nephelometer's span gas inlet to ensure adequate calibration gas flow. The flow of span gas during a quality control check or calibration should be roughly between 2-3 lpm to ensure a proper flow of gas and residence time.
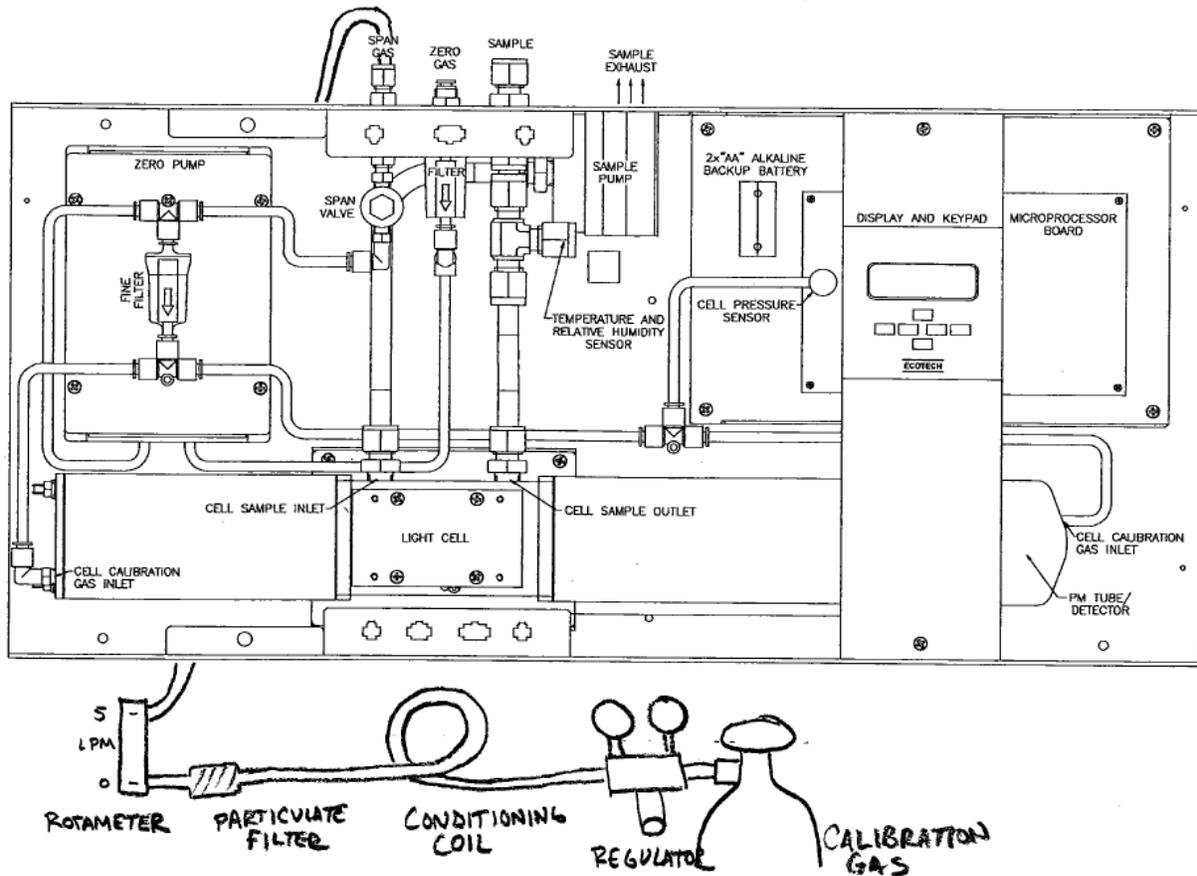
Figure 2. Ecotech nephelometer calibration gas setup

Envidas Ultimate Configurations

Envidas Ultimate must be configured for serial communication with the Ecotech nephelometer in order to retrieve ambient air monitoring data and for performing automated and manually initiated quality control (QC) checks. Configuring Ultimate for conducting automated zero adjustments (i.e., zero calibrations) is optional. This function allows for remote (i.e., over the internet) recalibration of the zero and is generally needed only at the most polluted and dusty sites where zero drift is more common.

Envidas Ultimate QC Configurations

Because the Ecotech nephelometers are equipped with an internal QC/calibration system, the data logger sequences are set up to issue commands to the Ecotech to perform each phase of the QC check sequence. This requires setting up the Ecotech nephelometer as a *Calibrator* in Envidas Ultimate Setup. Calibrator commands (**J commands) are used to trigger the zero and span check (**3J4 for zero and **3J3 for span) modes of the Ecotech. The **J command set is used to initiate these checks (as opposed to DO commands) as the **J commands allow both Envidas Ultimate (via the Reporter) as well as the Ecotech itself (via the Ecotech's internal diagnostics) to capture the QC check results. It's important to note that typically, these results will be nearly identical. However, on occasion, there will be slight variations in the results. The Ecotech's diagnostic data is generally the more accurate representation of the instrument's calibration and is therefore used by the PSCAA for documentation purposes.

DO commands are not used to trigger QC checks or calibrations. Envidas Ultimate is capable of using the DO commands as specified in the Operator's manual, but the disadvantage of the DO commands is that the nephelometer will not capture the last span and zero check or stability information correctly because the DO commands only control the valve operations and do not set the instrument mode. However, DO commands are useful for putting the nephelometer back into sample mode at the conclusion of a QC check and are programmed to do so as part of the *Auto Z & Span Check Sequence*.

In order to ensure the proper communication of the **J commands the datalogger channel and the QC check sequence must be configured correctly. The Envidas Ultimate Ecotech nephelometer *BSCAT* channel as well as the Ecotech nephelometer must be set to use the same Device Address in order for the devices to communicate properly. Figures 3 through 11 show an example of the correct configuration for the Channel and Calibration sequence for the automated two-point QC check. Note that in the example case, the Address 3 is used in both the command line in the calibration sequence and in the Address under General Channel configuration. The instrument has been set to address 3 under the menu option: Serial IO > Module Addr (address for multidrop RS232 port: 0-7). Figures 12 and 13 present the optional configuration for the automated zero adjustment.
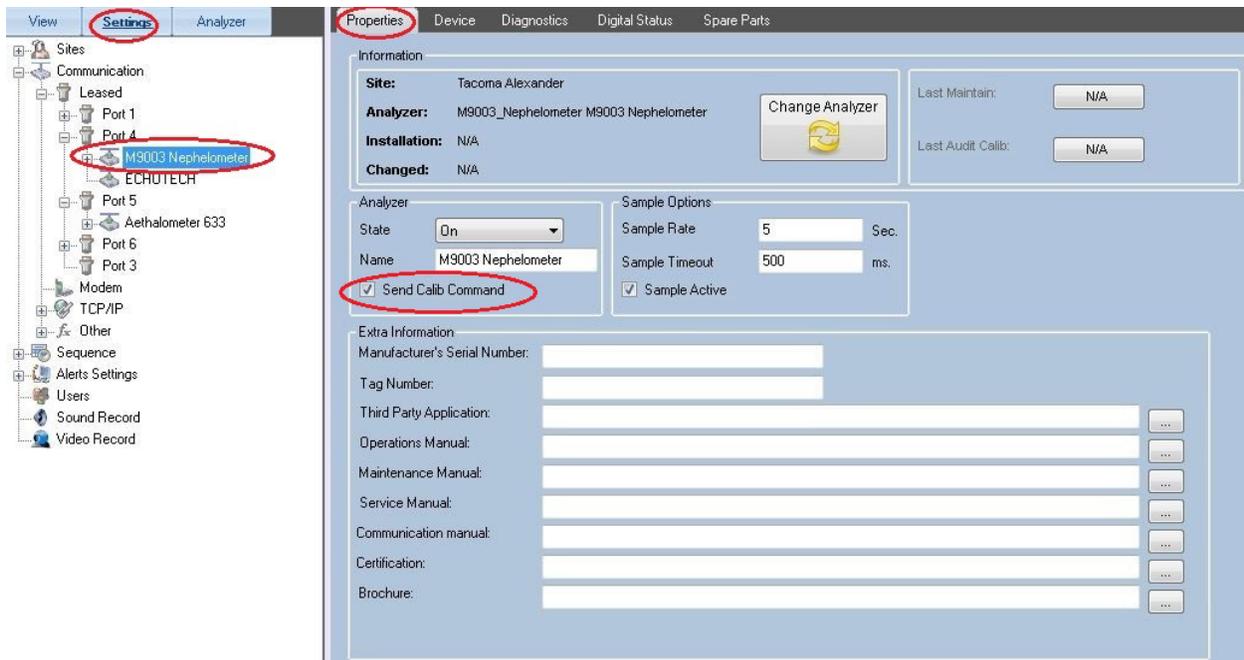
Figure 3. Ecotech nephelometer properties configuration
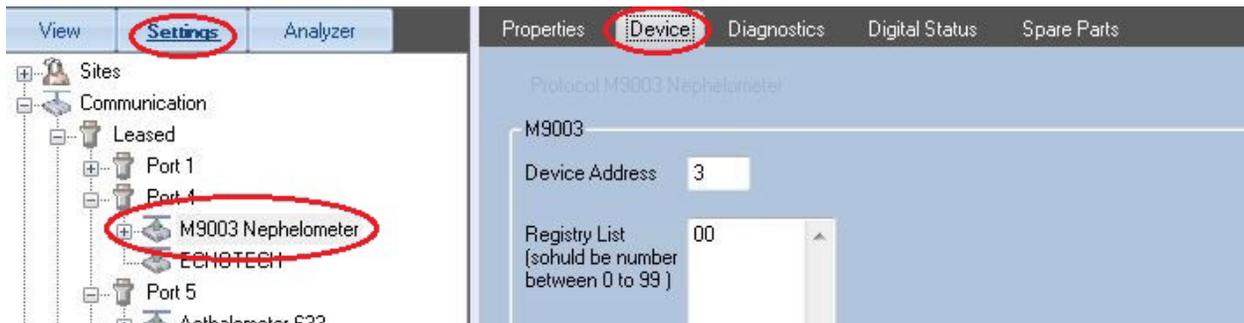
Figure 4. Device configuration
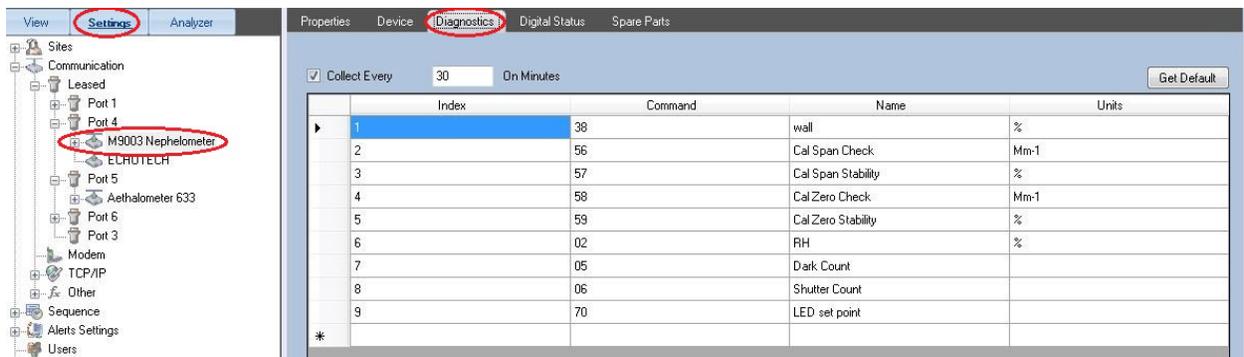
Figure 5. Diagnostic data configuration
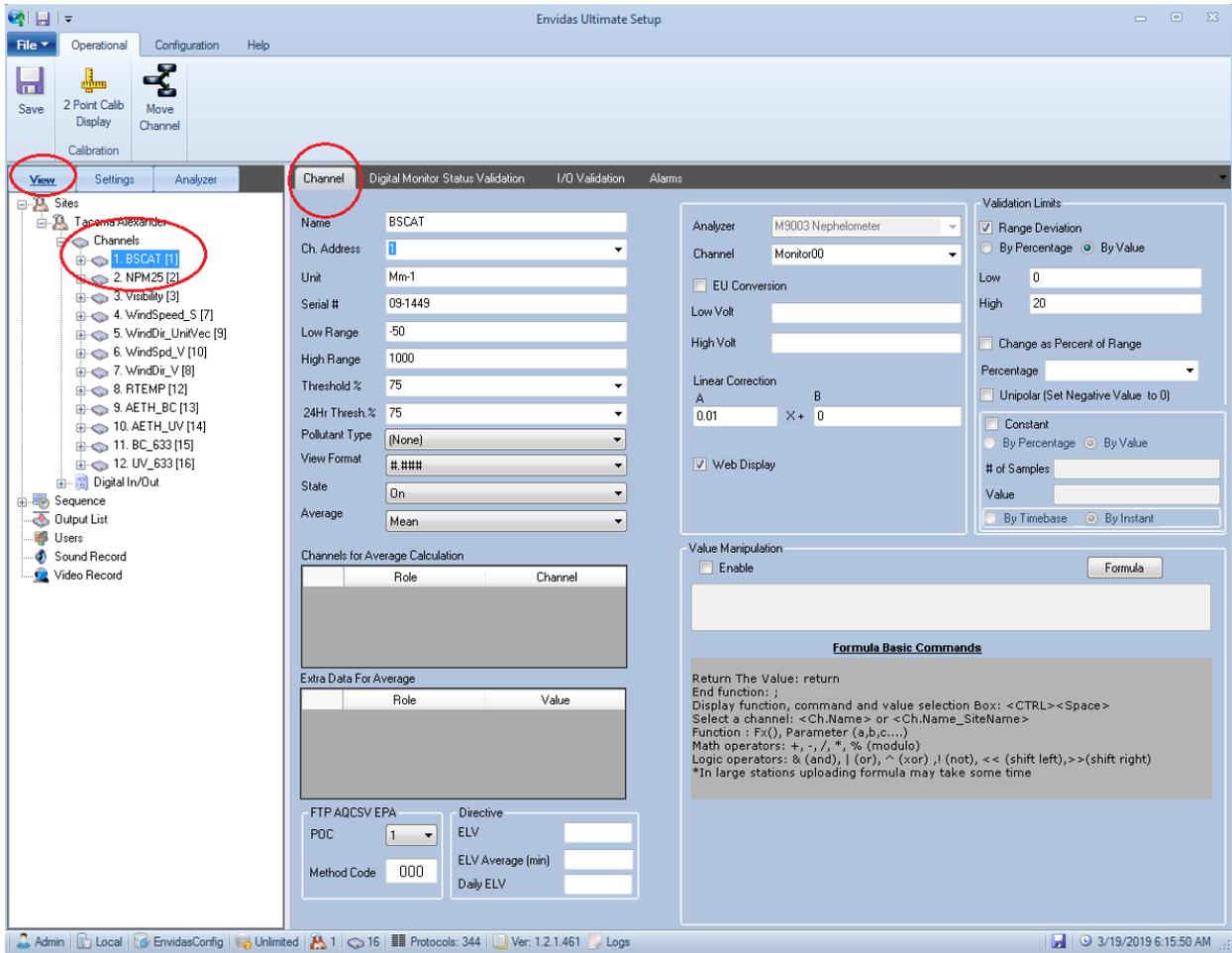
Figure 6. Channel configuration
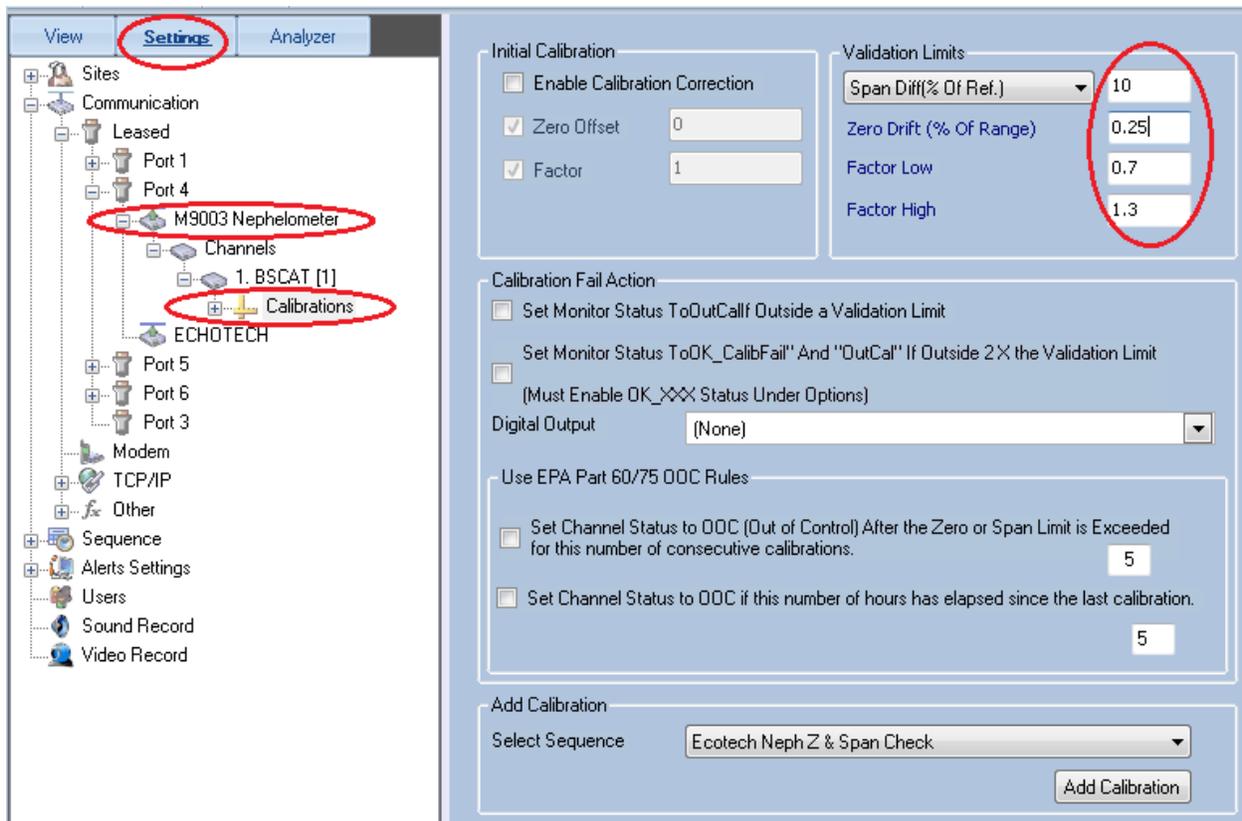
Figure 7. Calibrations configuration
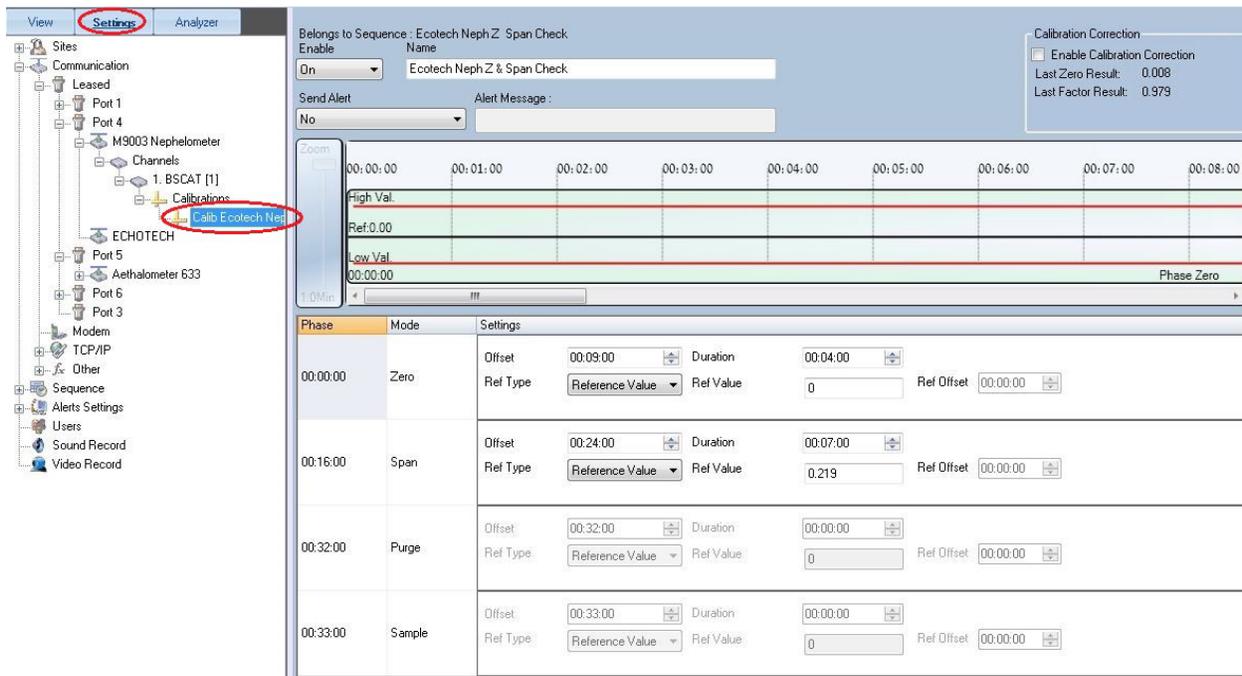
Figure 8. Calibrations setup for QC check
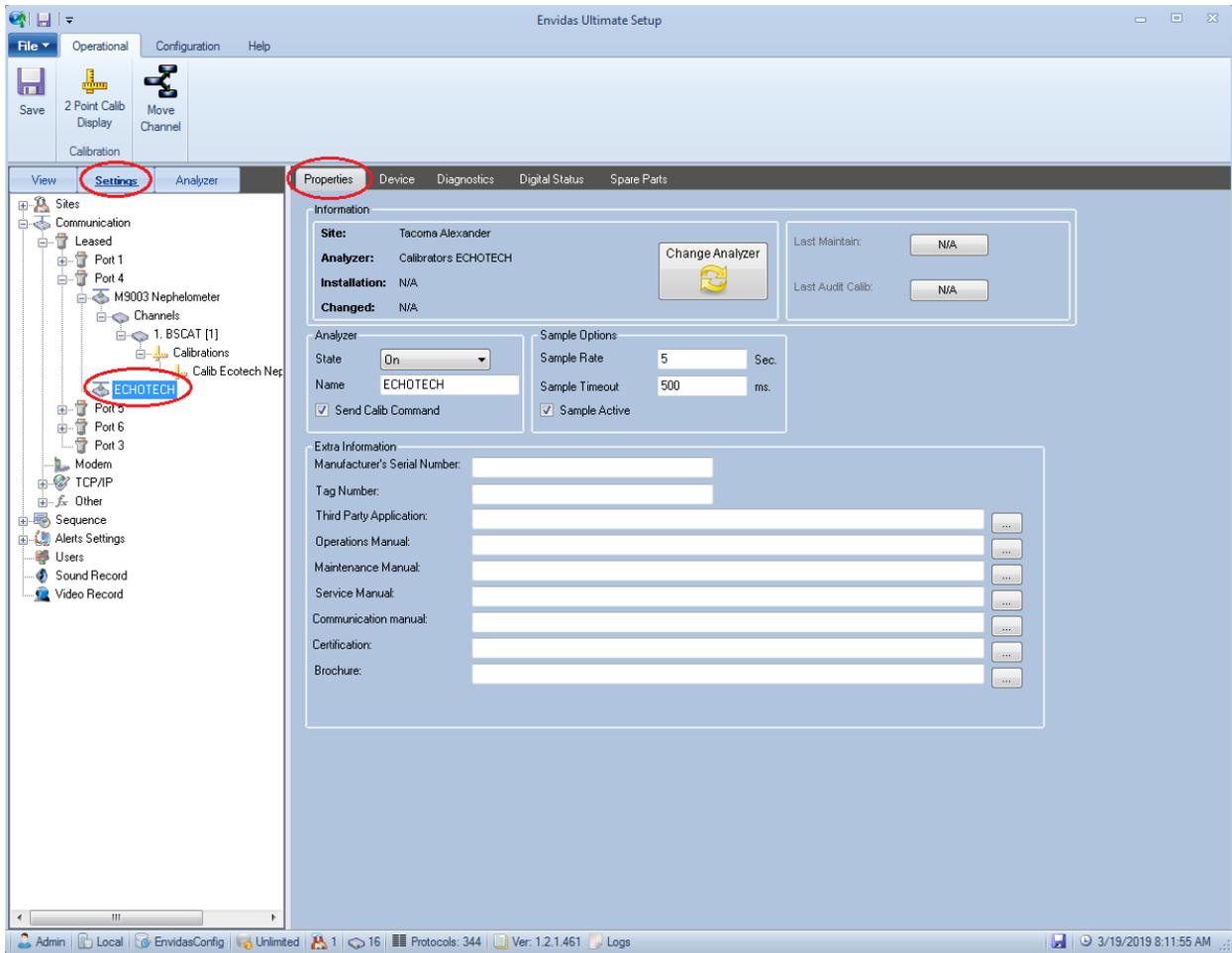
Figure 9. Calibrator definition
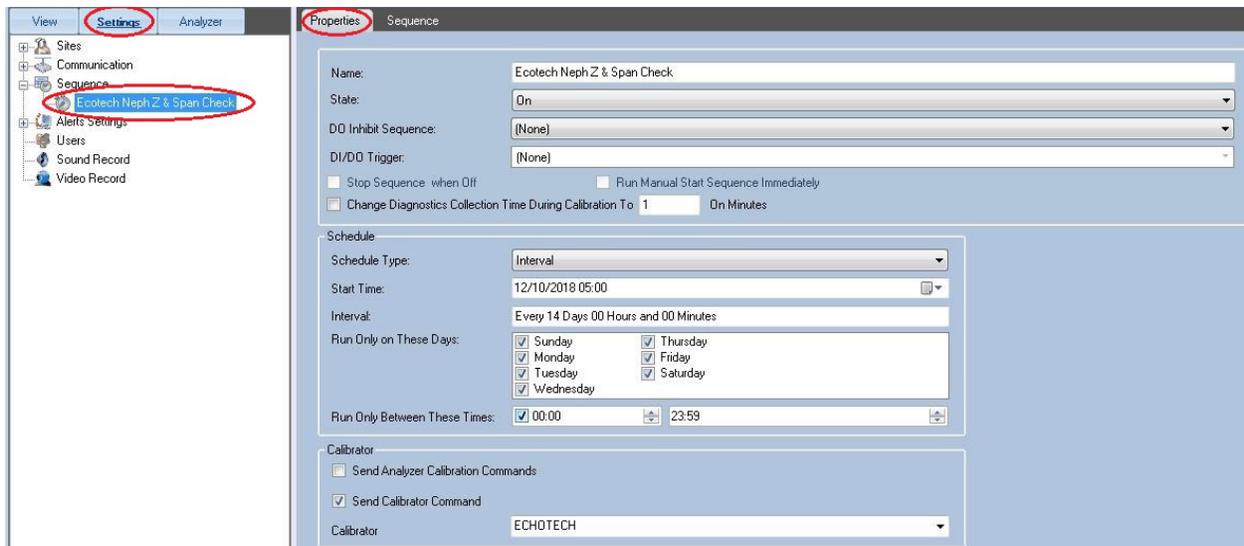
Figure 10. Sequence properties for QC check
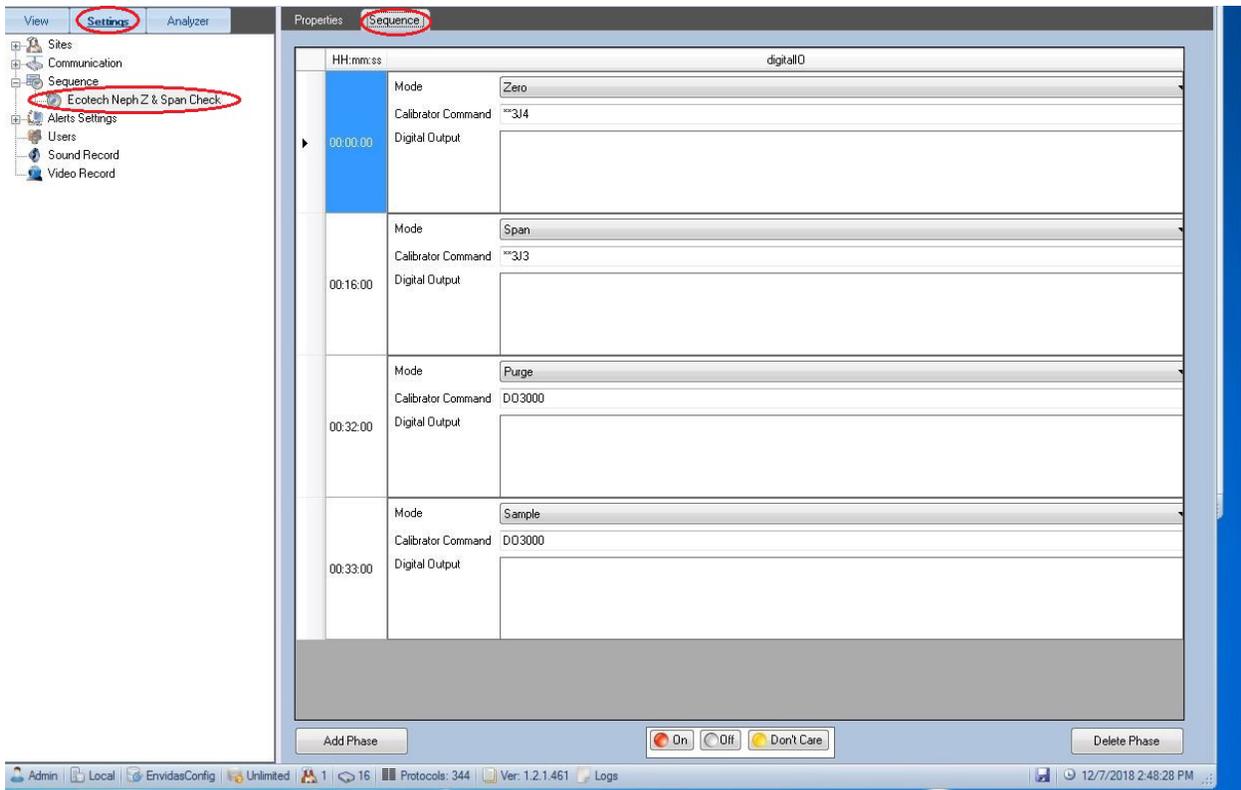
Figure 11. Sequence phases and commands for initiating QC checks
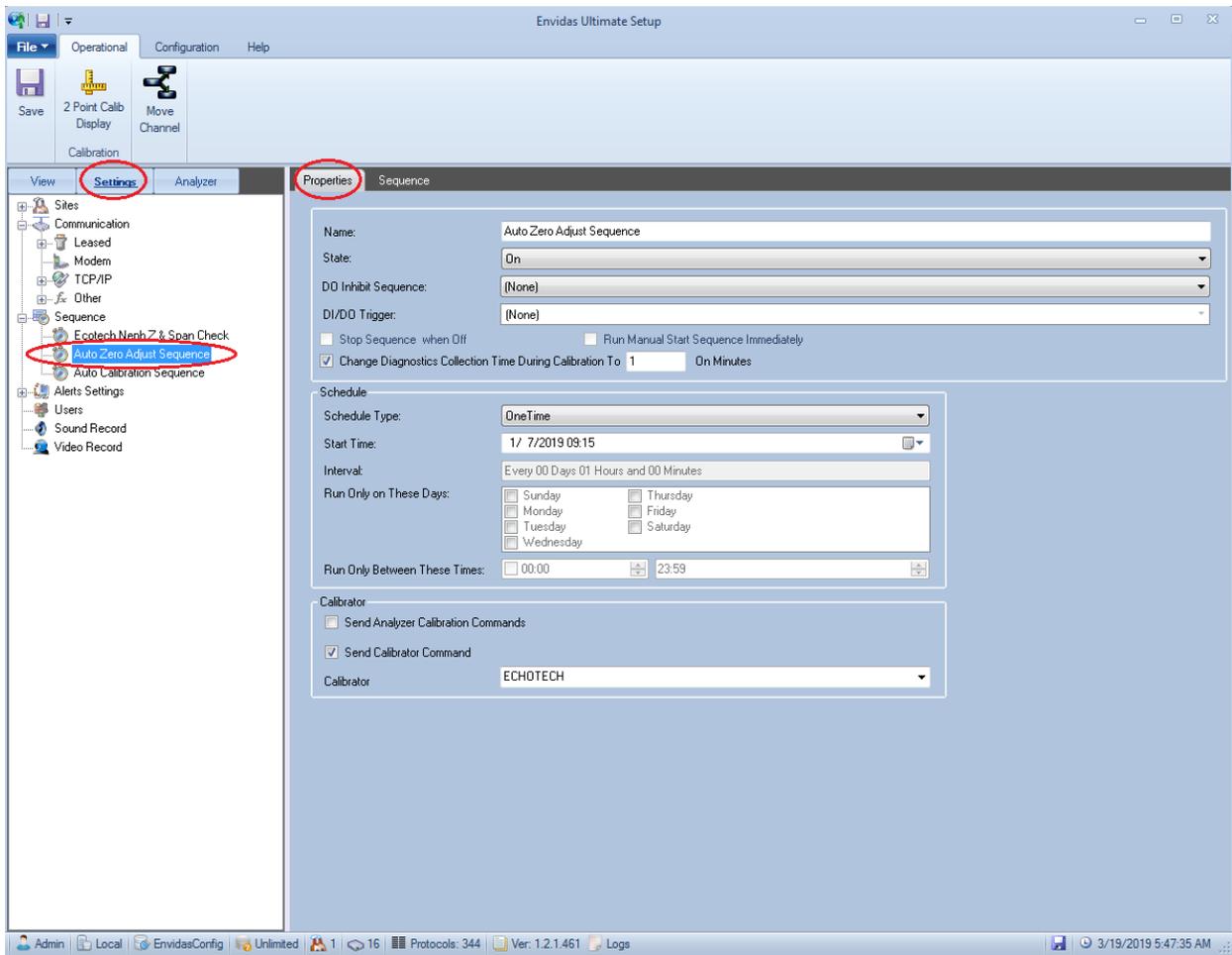
Figure 12. Sequence properties for performing a zero adjustment
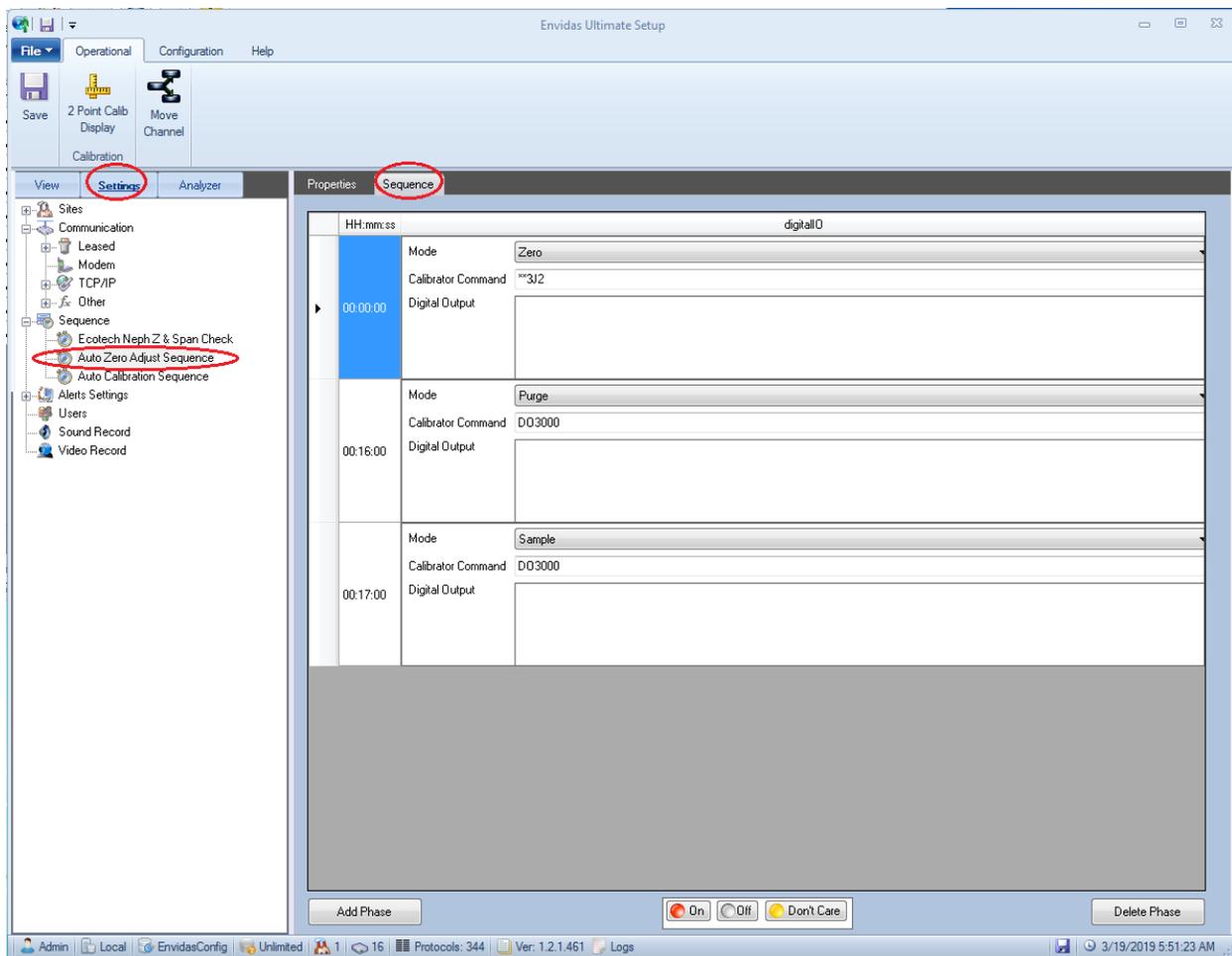
Figure 13. Sequence phases and commands for the zero-adjustment sequence

Station Visits

Station visits and a quality control check are required every 30 days for all Washington Network Ecotech nephelometer stations. During site visits, the operator must document all site visit activities (QC results, maintenance, unusual site conditions, etc.) in the electronic logbook available through Envidas Ultimate Reporter. During every station visit the site operator should visually inspect the probe inlet screen to ensure that it is free of insects and debris, verify that the nephelometer time is consistent with the data logger, check the sample line for any cracks or leaks, and verify an adequate supply of span gas.

Quality Control

Automated and manually initiated two-point quality control checks (zero and span) are used to verify that the nephelometer and data collection system are operating correctly. Multi-point quality control checks are not required due to the M9003's proven linearity.

Span Gas

CO_2 is the calibration gas used throughout the Washington Network due to its known light scattering coefficient, low cost, availability, and negligible impact on the environment. Use of an alternate span gas requires the approval of Ecology's Quality Assurance Coordinator. Through the use of the 1-meter conditioning coil in the span gas delivery system, CO_2 is delivered to the Ecotech nephelometer at or near monitoring shelter temperature (20 – 30 degrees C). Most PSCAA monitoring sites that are part of the Washington Network are within a few hundred feet of sea level so ambient pressure is relatively constant. For these reasons, PSCAA assumes the bscat value to be constant at 2.19 e-6.

Quality Control Limits

If the zero point is less than ± 2.50 Mm^{-1} and the span point is within 10% of the calibration gas value set point, then the nephelometer is operating within acceptable limits. However, allowing the nephelometer to operate close to these limits is not recommended as a minimal amount of drift could lead to an unacceptable level of error in the data and subsequent data invalidation. For this reason, Action Levels have been established to alert the station operator of the need for an adjustment. If the zero point is greater than or equal to plus or minus 1.5 e-6 (Mm^{-1}) or the span point is greater than or equal to 7% of the calibration gas value set point, the nephelometer should be recalibrated. The Action Levels and Acceptance Limits are summarized in Table 2.

Table 2. Quality control limits

Quality Control Check	Action Level	Adjust bscat To	Acceptance Limits
Zero Point	≥ ± 1.5 e-6 (Mm-1)	< ± 1.5 e-6 (Mm-1)	< 0.25E$^-$5
Span Point	≥ 7%	= 21.9 e-6 (Mm-1)	<10%

If the *as-found* QC are found to be above action limits, the operator should recalibrate the nephelometer. If the as-found QC results indicate a failure to meet Acceptance Limits, the operator must recalibrate the nephelometer. A flowchart of the logic can be seen in Figure 14.
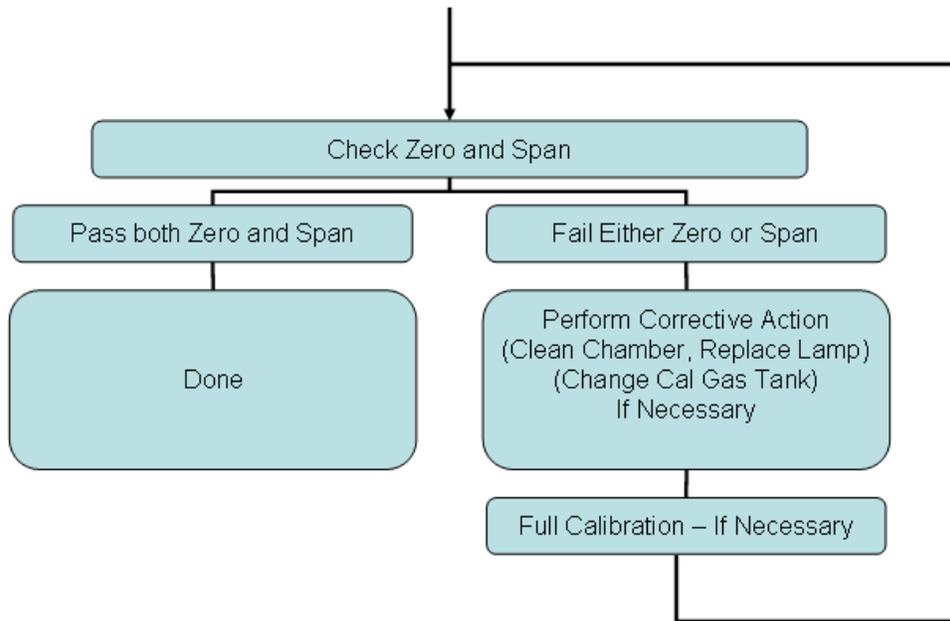
Figure 14. Calibration logic flow chart

Quality Control Checks

Automated QC Checks

Washington Network data loggers are all programmed to automatically initiate a quality control (QC) check of the Ecotech nephelometers every 14 days via the Envidas Ultimate Setup. All automated QCs are 32 minutes in duration and consist of a 16-minute zero, 16-minute span, and a 1-minute purge. Automated QCs are scheduled to occur at the same day and time, typically beginning at 0500 PST every other Monday. This scheduling limits ambient air monitoring data loss during times when $PM_{2.5}$ pollution is most likely to be elevated and ensures consistency of quality control processes across Ecotech (and other model) nephelometer monitoring sites. The 16-minute duration of both the zero and span points have been chosen to ensure that the Ecotech nephelometer will have sufficient time to achieve stable readings (stability > 96%).

On the same morning on which the automated QC check (whether automated or manual) occurred, the station operator must:

- Review the results of the automated QC check via Envidas Ultimate Reporter's Calibration Report and Diagnostics Report. While the Calibration Report will record the results of the QC check, the Ecotech's diagnostic data available through the Diagnostics Report are believed to offer a more accurate representation of the calibration check results.

- Make an entry in the station's electronic logbook via Envidas Ultimate Reporter noting the results of the quality control check, status of the instrument, and any concerns as to the quality of recently collected data

- Complete an Ecotech Nephelometer QC Data Sheet (an example is provided in Appendix A of this document) recording the zero and span check results as taken from the Diagnostics Report.

- Review calibration gas pressure and verify that the Ecotech's diagnostics parameters are within the manufacturer's specifications.

Manually Initiated QC Checks

Manually initiated QC checks are triggered by the operator via the Envidas Ultimate Viewer. There is no set schedule for performing manually initiated QC checks although a manually initiated *as-left* QC check must be performed following any calibrations (zero and or span adjustments). Manually initiated QC checks are triggered by selecting the *Ecotech Z and Span Check* from the drop-down list of the Sequence button on the ribbon in Ultimate Viewer as shown in Figure 15. Manually initiated QC results must be reviewed and documented according to the steps described in the Automated QC checks section.
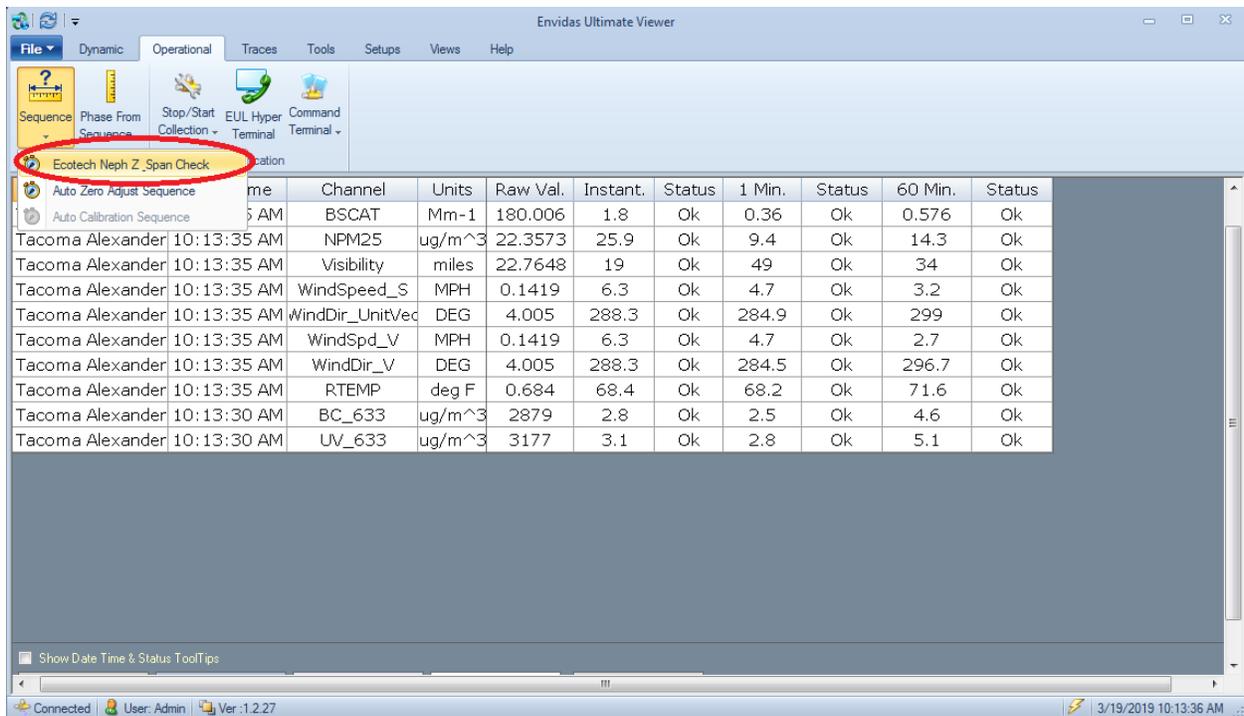
Figure 15. Manually initiated QC check

Calibration

Periodic adjustments to the zero and/or span are necessary when the Ecotech nephelometer approaches or exceeds Action Limits. Calibrations must be performed when Acceptance Limits are exceeded in order to bring the instrument back into proper operation and prevent data invalidation. Any adjustment to the nephelometer must be followed by an *as-left* QC check.

Zero Adjustment Using Envidas Ultimate

PSCAA has found that some of the more polluted Ecotech nephelometer monitoring sites experience a greater degree of zero drift while the span point generally stays within calibration. At these sites, PSCAA has established a sequence in Envidas Ultimate that is used to perform only an adjustment (calibration) of the zero point when the nephelometer QC results show the zero is at or near the Action Limit.

As shown in Figure 16, to trigger a zero only adjustment:

1. Open Envidas Ultimate Viewer on the data logger
2. Choose the Operational tab
3. Click on the Sequence button on the ribbon
4. Choose *Auto Zero Adjust Sequence*

Following the zero adjustment, the operator must perform an *as-left* QC check, confirm proper calibration of the nephelometer, and document the results per the steps described in Automated QC Checks.
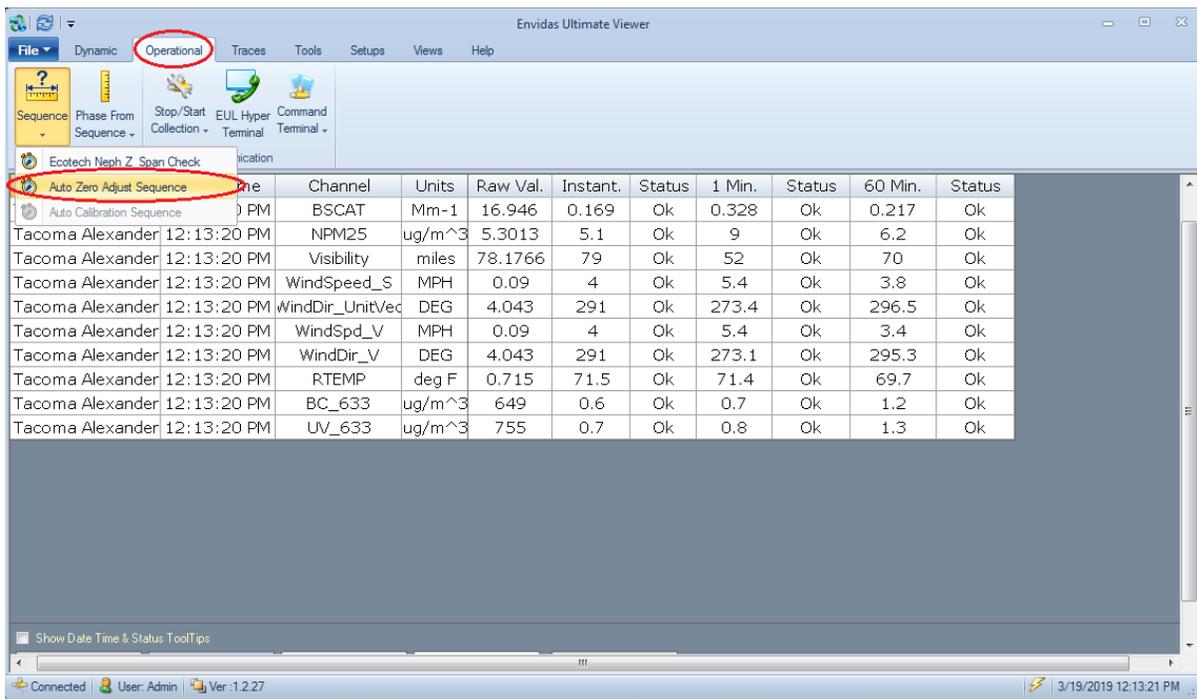
Figure 16. Auto zero adjust sequence

Full Calibration (Zero and Span)

A full calibration (zero and span adjustment) of the Ecotech nephelometer is performed via the Ecotech's interface.

Full calibrations are not done on a set schedule and are only performed when QC results indicate that the zero and span points are at or above Action Levels or have failed the acceptance limits shown in Table 2.

To initiate a calibration from the Ecotech's menu tree: Enter > Calibration > Do full cal.

The instrument will automatically perform the full calibration. The values displayed by the Ecotech nephelometer during the calibration are zero and span results before the new calibration is mathematically calculated and set into the instrument's memory.

Following the calibration, set the Ecotech data channels to On and initiate an *as-left* QC check via the Envidas Ultimate Viewer. Confirm that the instrument is properly calibrated, operating within Action and Acceptance Limits, and document the results as described in the Automated QC Check section of this document.

Maintenance

Probe lines must be cleaned every 365 days. The inlet head and bug screen should be cleaned or replaced as needed by the site operator. Ecotech recommends that the sample and zero pumps be inspected or replaced every 6 months. In any event, the sample pump and zero pump must be replaced when they exhibit poor performance. When there is increased variability in the zero or span checks (for example, the stability is ≤ 96.0%), or as needed, the operator must clean the measurement chamber of the nephelometer. Instructions for this are found in the Service Manual (Reference 6). Materials needed include Q-tip sticks, forced air dusters, no-lint cloth. If the Shutter Count or Dark Count is abnormal, the nephelometer may need service. Service and troubleshooting should be conducted by a trained technician, or by the manufacturer.

As-found and *as-left* QC checks must be performed prior to major maintenance (sample chamber cleaning for example) on the Ecotech nephelometer.

Data Validation

All PSCAA Ecotech Nephelometer QC Data Sheets must be sent to the Quality Assurance Coordinator by the 10th of the month following the end of the month of data collection.

- Preliminary data validation is done by the PSCAA via the EnvistaARM. Preliminary data validation includes, but is not limited to:

- Reviewing auto-QC results on Monday mornings.

- Using the EnvistaARM to review collected data for reasonability and comparability with other area monitors.

- Invalidating data that is collected during times when the nephelometer is known to be operating in error or outside QC acceptance limits.

The Quality Assurance unit is responsible for final data validation. Data validity is evaluated using a number of criteria including comparability to collocated and nearby nephelometers and PM2.5 monitors as well as the results of quality control checks. Data not meeting the QC acceptance limits will be invalidated.

Data Quality Assessment

The Air Quality Program's Quality Assurance Unit prepares quarterly Data Quality Assessment Reports. These reports are used to identify issues with data quality and are used by Washington Network partners and the Quality Assurance Unit to make systematic improvements as needed to ensure adequate data quality. Improvements in this SOP are a result of the lessons learned from years of operation of these systems.

References

"Aurora 1000 Single Wavelength Integrating Nephelometer, User Manual", Ecotech, Version 1.3

"M9003 Integrating Nephelometer, Operation Manual", Ecotech, Version 3.2, November 2005.

"M9003 Nephelometer Service Manual", Ecotech, Revision 1.1, October 2007.

"Probe and Monitoring Path Siting Criteria for Ambient Air Quality Monitoring." *Code of Federal Regulations* Title 40, Pt. 58, Appendix E, 2018 ed.

U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. *Quality Assurance Handbook for Air Pollution Measurement Systems Volume II: Ambient Air Quality Monitoring Program*. Research Triangle Park, 2013 (EPA-454/B-17-001).

Appendix A

Ecotech Nephelometer QC Data Sheet

Station #: _____ Date: _____

Location: _____ Time: _____

Operator: _____

Sampler Serial #: _____ Current σ_{sp} _____

Time Check

Data Logger _____ Neph _____ Difference _____ min (Change if > 5 min)

Time reset to data logger time? Yes [ ] No [ ]

Last Span and Zero Check

Wall Signal _____

Last Zero Check _____ e^{-6} Last Zero Stability _____ %

Last Span Check _____ e^{-6} Last Span Stability _____ %

Diagnostics (should include a look for abnormal values or trends)

RH Av _____ Dark Count Average _____

Shutter Count Average _____

Final Checks

Do the Logger & Nephelometer values compare? [ ]

Did you schedule next AZSP and Restart Service? Is the Logger channel enabled?   [ ]

Cal Gas Pressure – High side (>500psi). Low side (5-10psi)[ ]

Action and Failure Levels

Parameter	Action Level	Failure Level
SPAN STABILITY:	≤ 96.000% – recalibrate or fix	None
ZERO:	> ± 1.50e^{-6} – recalibrate or fix	> ± 2.50e^{-6}
SPAN:	≤ 20.4e^{-6} and ≥ 23.4e^{-6}	≤ 19.7e^{-6} and ≥ 24.1e^{-6}