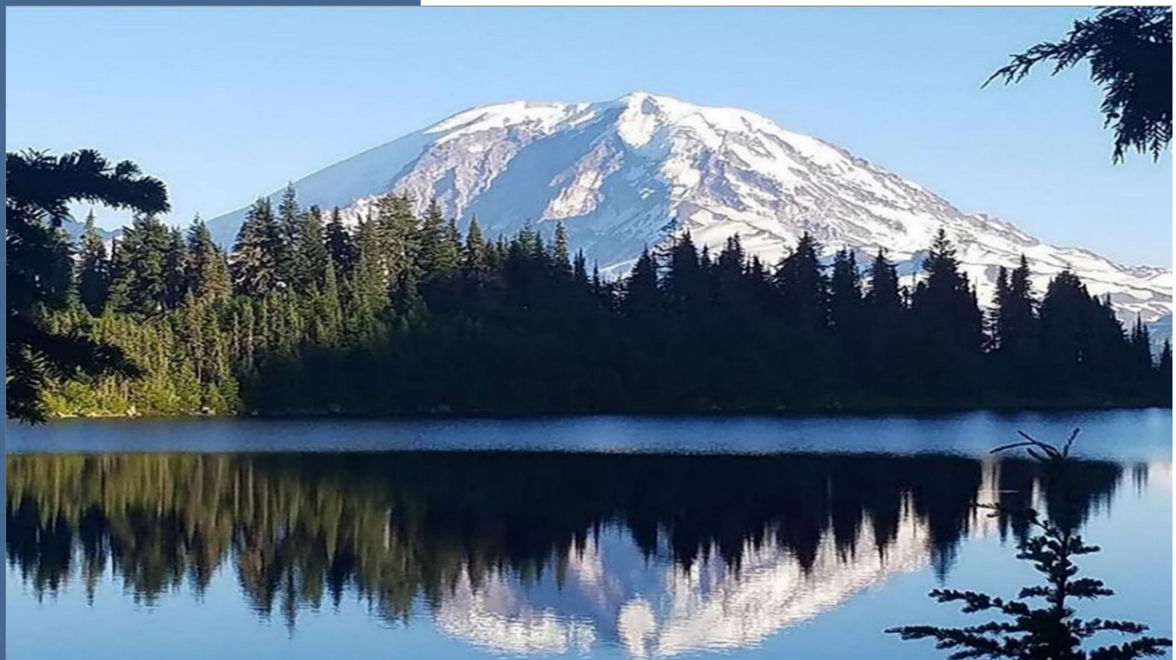

Particulate Matter Sensors Operating Procedures

By

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For the

Air Quality Program

Washington State Department of Ecology

Olympia, Washington

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State of Washington

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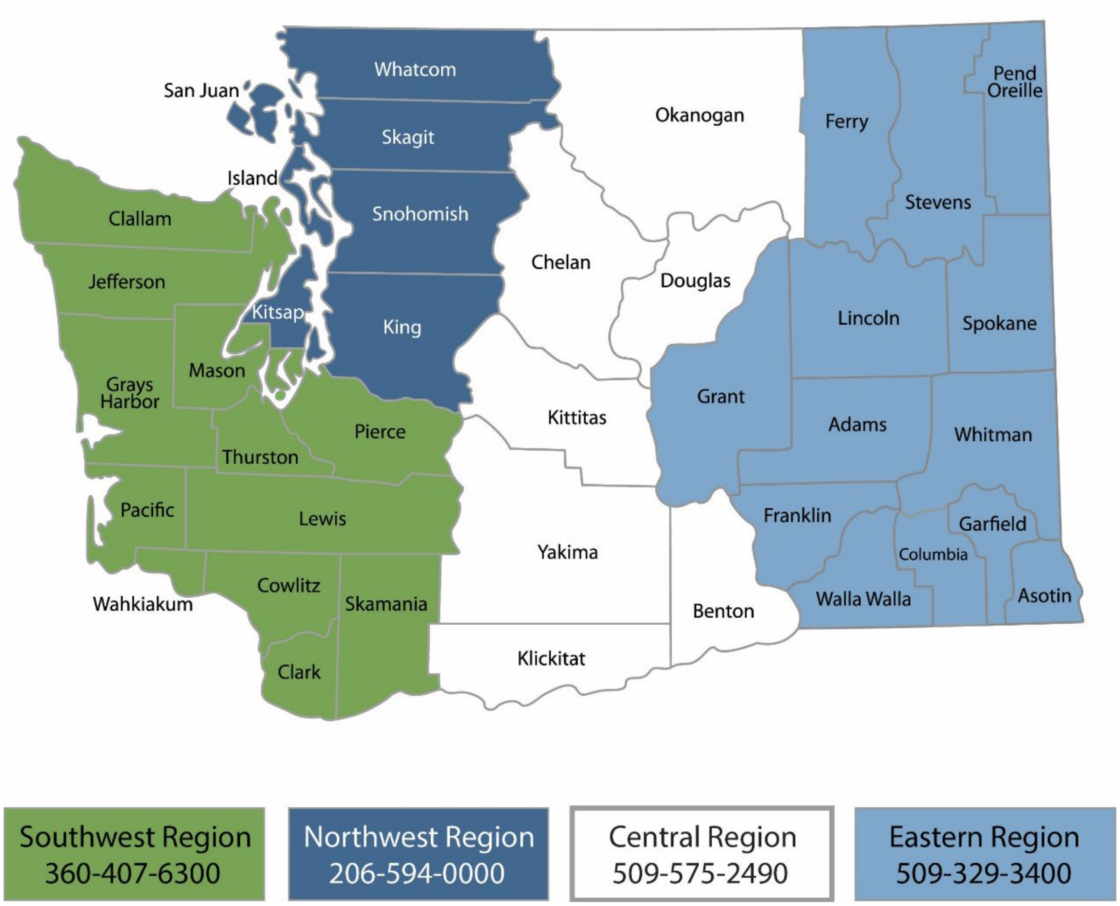
Department of Ecology's Regional Offices

Map of Counties Served



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

Particulate Matter Sensors Operating Procedures

Air Quality Program
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Olympia, WA

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DEPARTMENT OF
ECOLOGY
State of Washington

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1. Introduction

Purpose and Scope

This document describes the standard operating procedures for particulate matter (PM) sensor monitoring within the Washington State Ambient Air Monitoring Network (Washington Network) supported by the Washington State Department of Ecology (Ecology). It covers PM sensor measurement principles, the collocation-correction process used in place of calibration, as well as installation, quality control (QC) and maintenance. PM sensor applications include temporary monitoring of smoke from wildland fires, responding to isolated or emergent events, monitoring to aid in smoke management decisions, surveys or saturation studies of unmonitored areas, and high-density monitoring of overburdened communities.

Ecology's Air Sensor Policy approved by the Monitoring Advisory Committee defines three tiers of PM sensors based on model and level of QC. PM sensors in Ecology's Tier 1 (PurpleAir) are for informational purposes and are not covered here. This document only applies to the Ecology SensWA $PM_{2.5}$ sensor (Section 5) and QuantAQ MODULAIR-PM PM_{10} sensor (Section 6) that Ecology uses under the more rigorous monitoring standards of Tiers 2 and 3.

Ecology's choice of PM sensors relies on work from outside agencies such as the Environmental Protection Agency (EPA) and the South Coast Air Quality Management District. These agencies are funded and equipped to conduct extensive sensor evaluations; the results of which Ecology uses to select the highest-performing sensors. Ecology also evaluates selected PM sensors at monitoring sites in different regions of the Washington Network to understand their performance in the unique environmental conditions present.

PM Sensor Background

PM sensors are non-regulatory but can supply valuable air quality measurements. The lower costs, smaller size, and lesser maintenance demands of PM sensors compared to regulatory PM monitors allow Ecology to supplement and expand air quality monitoring in the Washington Network with greater ease.

Upsides of PM sensors include minimal data loss, low inter-sensor variability, reasonable correlation with regulatory measurements, and reasonable life span. Downsides of PM sensors include less diagnostic information, humidity effects, non-linearity at high concentrations, sensitivity to PM optical properties, and the inability to adjust settings. PM sensors can provide accurate estimation of PM concentrations, but only with proper data correction and QC.

PM Sensor Measurement Principles

The term PM sensor describes an integrated set of hardware and software that uses one or more PM sensing elements (sometimes called PM sensors themselves) to measure PM concentrations. The terms PM sensor and particle counters are often used interchangeably, but this is inaccurate as they have been shown in practice to function similarly to a nephelometer (Kuula et al., 2020; Ouimette et al., 2022).

Like nephelometers, PM sensing elements use a diffuse light source oriented orthogonal to the detector to illuminate particles in the sample volume. The PM sensing element then isolates the particle ensemble scattering signal from by subtracting the scattering signal produced by the sample volume walls and air molecules. Unlike nephelometers, PM sensing elements do not define the method to isolate the particle ensemble scattering signal or allow for user adjustments.

PM sensing elements measure PM_1 (PM < 1 µm diameter) size and most accurately and estimate $PM_{2.5}$ (PM < 2.5 µm diameter) with reasonable accuracy. However, prior research (Kuula et al., 2020; Molina Rueda et al., 2023; Ouimette et al., 2022) shows that the PM_{10} (PM < 10 µm diameter) signals of PM sensing elements do not correlate with regulatory monitors. PM sensing elements are fundamentally unable to sense coarse PM (particles 2.5–10 µm) because:

- The truncated measured scattering angle, the wavelength of light, and other optical characteristics of PM sensing elements limits detection of light scattering from coarse PM.
- The inlet orientation of PM sensing elements can result in significant aspiration losses of coarse PM, with further loss of particles due to inertial impaction on internal walls. Particle losses result in a lower concentration of larger particles sampled than are in the ambient air.

Because of this known deficient performance of PM sensing elements in detection of coarse PM, Ecology does not use PM_{10} data from nephelometer-type sensors such as SensWA.

In contrast, true laser particle counters (such as the Alphasene model the QuantAQ MODULAIR-PM uses to measure PM_{10}) are designed to size and count individual particles via light scattering. The particle counter computes a particle size distribution and then converts it into mass concentration based on assumed particle density. PM_{10} measurements produced by particle counters are well correlated with regulatory monitors (Crilley et al., 2018; Kaur & Kelly, 2023; Sousan et al., 2016).

Currently, Ecology only uses the QuantAQ MODULAIR-PM PM sensor for PM_{10} measurements.

Factors Affecting PM Sensors

The sensitivity of PM sensors to factors affecting the interaction of light with PM, which are discussed below, can reduce data quality. However, prior research (Alfano et al., 2020; Barkjohn et al., 2021; deSouza et al., 2022; Ghamari et al., 2022; Giordano et al., 2021; Hong et al., 2021; Raysoni et al., 2023; Roberts et al., 2022) and Ecology evaluation in the Washington Network has shown these factors correctable and obtaining high-quality data from PM sensors possible.

Meteorology

Meteorological conditions such as ambient temperature (T) and relative humidity (RH) can affect PM sensor performance (Barkjohn et al., 2021; Tagle et al., 2020; Wang et al., 2021). Unlike other PM monitors in the Washington Network, PM sensors used by Ecology do not include a heater or dryer at their inlets. As a result, the PM sampled by the PM sensor may include water. Uptake of water onto PM can significantly interfere with the scattering signal in the PM sensing element and lead to invalid data. Fog, which consists of water droplets or ice crystals, can also interfere with the scattering signal and lead to invalid data.

RH typically affects PM sensor data quality when it exceeds 75%, though effects may start lower. Extreme high or low temperature alone shows minimal effects on PM sensors. However, Ecology has found PM sensors deployed in the Washington Network report false high concentrations when freezing temperatures and high humidity are co-occurring. In other regions, false high concentrations have been routinely reported during periods when elevated temperatures and humidity co-occur, and nationwide studies have typically focused on correcting interference from these conditions (Barkjohn et al., 2021). However, since Washington rarely experiences such conditions in the summer, sensors can meet or exceed data quality targets with straightforward data correction methods.

PM Physiochemical Properties

PM size, shape and chemical composition also play a significant role in PM sensor linearity and overall sensitivity. PM size, shape, and chemical composition inherently change particle scattering properties, such as refractive index, and thus can significantly affect any light-based PM measurements. Similarly, particle density differences also affect light-based measurements and complicate the connection between particle size and mass. These effects significantly affect light-scattering responses and sensor accuracy during real-word uses (Hagan & Kroll, 2020).

Ambient Deployment

Ambient deployment for one year or less generally does not affect PM sensor performance. However, multi-year deployments may affect PM sensor performance (deSouza et al., 2023). In addition, prior research (Tryner et al., 2020) and Ecology evaluations has shown that exposure to high concentrations of PM impairs their performance.

Collocation-Correction Process

All regulatory air monitors require periodic checks to ensure they are functioning correctly and generating high-quality data. Through the process of calibration, regulatory air monitors are evaluated with known standards and the results are used to adjust the instrument settings to match the standard. We regularly repeat and check this process to ensure highly accurate data.

PM sensors also need periodic checks, but we cannot calibrate them in the same way as regulatory monitors because we cannot adjust their instrument settings. In addition, PM sensors do not respond to gases used to calibrate nephelometers (CO_2 and Suva®) (Ouimette et al., 2022). Instead, we run PM sensors side-by-side with a regulatory monitor to see how their data compare in a process we call “collocation.” We then adjust the raw data produced by a PM sensor (such as applying a multiplier and additive factor to the raw data) to improve accuracy. We call this data adjustment process “correction.”

Together, the collocation-correction process helps elevate the quality of Ecology’s PM sensor measurements closer to the level of regulatory PM monitoring.

Continuous Subset Strategy

To organize the PM sensor collocation-correction process, Ecology adapted the "Continuous Subset Strategy" from the EPA's Enhanced Air Sensor Guidebook. Under this approach, we will first collocate clusters of PM sensors at reference sites equipped with a Met One Instruments Beta Attenuation Monitor 1020 or 1022 (BAM 1020/1022) for a minimum of 30 days. The EPA designates the BAM 1020 and 1022 as a Federal Equivalence Method (FEM) for measuring 24-hour $PM_{2.5}$ and PM_{10} (73 FR 22362, EQPM-0308-170).

$PM_{2.5}$ sensors will collocate with BAMs configured for $PM_{2.5}$ monitoring and PM_{10} sensors will collocate with BAMs configured for PM_{10} monitoring. See Figure 1 for pictures of $PM_{2.5}$ and PM_{10} sensors collocated with BAMs. PM sensor data are corrected based on the cluster averaged results of an ordinary least squares linear regression of 24-hour averaged collocation data. The 30-day duration of cluster collocations exposes PM sensors to a range of ambient concentrations, while allowing for quick deployment to host sites.

After 30-day cluster collocation, operators can deploy PM sensors to their host sites in the surrounding area with the cluster correction applied to data. A subset of PM sensors per cluster continues collocation measurements alongside with the reference instrument while the majority are deployed. The collocated subset serves as reserves for rotation to host sites as needed. At least one PM sensor will always be active at the collocation site.

The Air Sensor Calibration & Repair Specialist and Quality Assurance (QA) staff will use the 24-hour averaged data from the subset of PM sensors to check and adjust the accuracy of the cluster correction. To check for inter-sensor variability, operators will move each PM sensors in a cluster back to collocation with the reference instrument for at least one 30-day period annually.

Results from PM sensors vary based on weather conditions and PM optical properties. To account for this, we conduct the collocation-correction process in the environment where the sensors will measure. Air Sensor Calibration & Repair Specialist and QA staff select collocation sites representative of the airsheds chosen for PM sensor deployment. We keep a subset of PM sensors per cluster collocated so that we can detect performance changes over time. To monitor the effects of weather, we obtain meteorological conditions (T, RH) from the collocation site and wind conditions (speed, direction) from the nearest weather station.

Figure 1. One SensWA $PM_{2.5}$ sensor collocated with a BAM $PM_{2.5}$ (left) and two QuantAQ MODULAIR-PM PM_{10} sensors collocated with a BAM PM_{10} (right) at the Spokane – E. Broadway Ave. monitoring site.

Collocation Exceptions

Typically, PM sensors in the Ecology network must undergo a minimum 30-day collocation with a BAM 1020/1022 before deployment to host site. However, the following exceptions are allowed with prior approval by the Air Sensor Calibration & Repair Specialist and QA staff:

- Deployment of a SensWA for an extended (>1 year) collocation at an existing nephelometer site. Ecology examines the comparability of SensWA to nephelometers for PM2.5 monitoring through collocations in the Washington Network. If collocation shows SensWA can achieve comparable data quality to nephelometers at a monitoring site over a year, SensWA may replace the nephelometer at that monitoring site. Air Sensor Calibration & Repair Specialist and QA staff will correct SensWA data to the nephelometer data with an ordinary least squares linear regression based on the collocation data.
- Temporary PM monitoring in response to isolated or emergent events, including wildfires. The Air Sensor Calibration & Repair Specialist and QA staff will decide the proper correction to apply to PM sensor data from the nearest and most representative collocation.

2. Operator Considerations

Coordination with Air Sensor Specialist

Before you travel to a PM sensor collocation or host site, for first setup or later maintenance, do the following:

- Call, email, text, or Teams message Air Sensor Calibration & Repair Specialist (360-529-6396) to confirm your plans.

Before you leave the sensor site, after first setup or later maintenance, do the following:

- Confirm the indicator light on the front of SensWA or MODULAIR-PM shows a slow breathing cyan light.
- Call, email, text, or Teams message Air Sensor Calibration & Repair Specialist (360-529-6396) to confirm data transmission or to troubleshoot.

Equipment & Supplies

The supplies necessary to install and support PM sensors includes:

- Zip ties or pole mount kit (supplied by Calibration & Repair Laboratory)
- Alternative mounting hardware (screws, nuts, bolts, washers) (Optional)
- Various hand tools (flat and Phillips head screwdrivers, hexagonal wrenches)
- Battery-powered drill
- Cotton-tip applicators
- Rubbing alcohol
- Lint-free lab wipes
- Wire cutters, scissors, or other tool to cut zip ties.

Data Quality Control

Operators perform preliminary level review and validation of PM sensor data. Operators should review data in a prompt fashion to catch problems early. We recommend that operators review PM sensor data for reasonability via the data acquisition system software weekly, preferably Monday morning. Operators should notify Calibration & Repair Laboratory staff via email when invalid data are found.

When performing an assessment of PM sensor data quality, operators and Calibration & Repair Laboratory staff must consider the following:

- Correlation with nearby PM monitors (FEM, nephelometers, and PM sensors).
- Agreement of PM sensing elements paired in unit.
- Completeness of data.
- Quality of data.

To aid in your assessment of the quality of PM sensor data, the table below presents common indicators of poor-quality and their causes. This table reflects Ecology's experience of deploying PM sensors in the Washington Network over multiple years.

Indicators of Poor-Quality PM Sensor Data	**Causes**
Consistently lower PM concentrations measured over time.	- Deposited PM on the optics of the sensing element reduces scattering signal intensity. Most common after high PM concentration events.
Odd patterns, especially sporadic periods of high concentration spikes inconsistent with ambient concentrations.	- Bug or spider infestation in sample airflow. - Water damage to PM sensing element or circuit board from exposure to precipitation or high humidity. - Resuspended PM previously deposited on the walls of the airpath during high concentration periods.
Increased noise in data.	- Water damage to PM sensing element or circuit board from exposure to precipitation or high humidity.
Data transmits, but all concentrations are zero.	- Loss of power to PM sensing element airflow fan or scattering laser, due to fault in circuit board electronics. - Obstructed sample airflow.
Missing data.	- Lost connection to cellular network, either due to loss of power or poor signal.

After review by operators and Calibration & Repair Laboratory staff, QA will conduct the final data validity evaluation using a systematic criterion. QA will use electronic logbook entries (Figure 2) in their final review. Operators manage documenting site activities and ensuring that all required QC and maintenance activities occur as required by this procedure.

Maintenance

Good maintenance processes can help maximize and sustain PM sensor performance over an extended period. PM sensors in the Ecology network are on a quarterly and annual maintenance schedule.

Quarterly maintenance

Operators must visit the site at least quarterly and perform maintenance according to the following steps:

1. Wipe any accumulated dirt off the PM sensor.
2. Inspect the inlets for spider webs, bugs, and wasp nests, as well as water damage. Wipe the sensor inlet clean.
3. For the SensWA, open the enclosure to ensure all internal wires are connected and secure, which includes the cell antenna, Sensirions (2x), RH&T sensor, and USB power. Inspect internals for spider webs, bugs, and wasp nests, as well as water damage.
4. Ensure the secure attachment of the PM sensor to its support.
5. If powering the PM sensor by solar:
    a. Wipe the Voltaic solar panel clean.
    b. Confirm external power connections are secure and inspect for water damage.
    c. Open the battery enclosure and inspect for wear. Make note of the status of the battery level indicator light on the pair of Voltaic batteries and replace with a fully charged backup pair if below 50% capacity.
        i. Operators should expect to perform Voltaic battery replacement in November every year due to lack of sunlight near the winter solstice.

Operators should record in EnvistaARM the activities conducted during their site visit and any notable observations (spider webs, bugs, wasp nests, water damage, loose electrical connections or mounting, low batter level if solar powered). See Figure 2 for an example logbook entry.

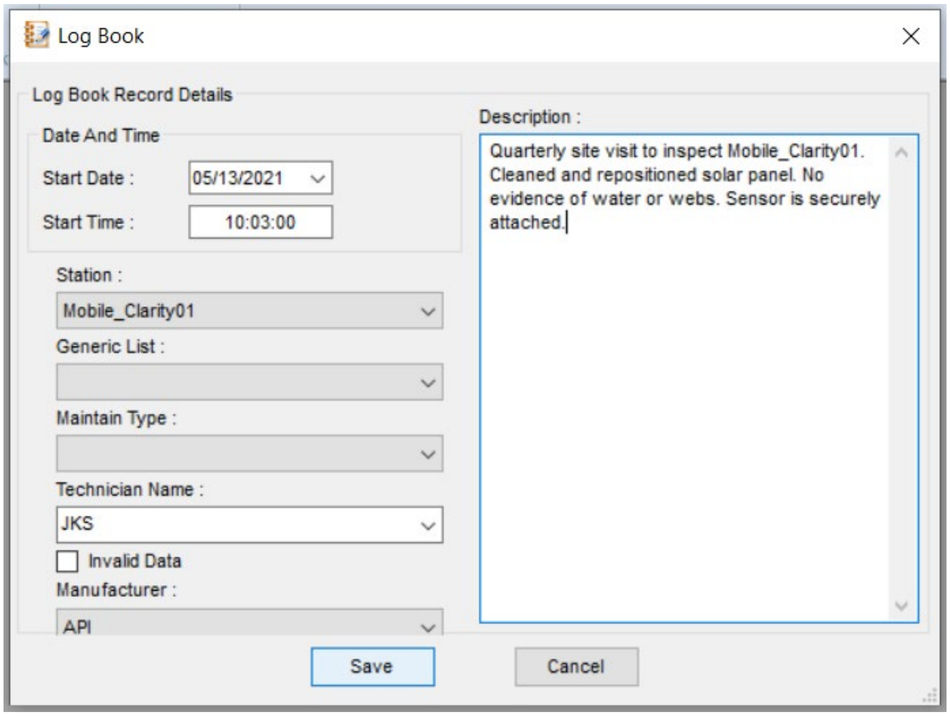


Figure 2. Example logbook entry for quarterly site visit using EnvistaARM.

Annual maintenance

The Air Sensor Calibration & Repair Specialist will perform 12-month maintenance in the Calibration & Repair Laboratory. The Calibration & Repair Laboratory will keep records of 12-month maintenance completed. This maintenance consists of the following steps:

1. Clean the inside and outside of enclosure, paying special attention to airflow path.
2. Check integrity of seals on cable gland and air vent, looking for signs of degradation or water intrusion. Tighten as needed and replace if compromised.
3. Clean bug screens:
    a. Remove visible dirt and cobwebs with a brush.
    b. (SensWA only) Re-apply glue if not secure.
    c. (SensWA only) Replace screen if any holes are present.
4. Clean PM sensor airflow:
    a. Clean visible dirt and cobwebs with a brush
    b. Check for signs of water damage.
    c. Blow with compressed air.
5. (SensWA only) Replace SPS30 PM sensing element if significantly dirty, water damaged, or deployment data shows reduced performance. See Section 5 for description and location of the SPS30 PM sensing element.
6. (SensWA only) Clean the RH and temperature sensing element and replace if significantly dirty, water damaged, or deployment data shows reduced performance. See Section 5 for description and location of the RH and temperature element.

7. (SensWA only) Connect SPS30 sensing elements to computer with Sensirion Control Center software installed using USB connectors.
    a. Enact “Manual Cleaning” function. This function runs internal fan at maximum speed for ten seconds. Repeat five times.
    b. Leave SPS30 sensing element connected to computer for zero test (next section).

Annual (12-month) zero test for SensWA

After annual maintenance, the Air Sensor Calibration & Repair Specialist will perform a zero test of the Ecology SensWA PM sensors. To do so, place the PM sensor (or the Sensirion SPS30 sensing element) in a vented chamber filled with particle free air for 240 minutes (4 hours). the Air Sensor Calibration & Repair Specialist will analyze the PM concentrations from this time to verify the PM sensor performance.

The Calibration & Repair Laboratory keeps records of all annual (12-month) zero tests completed.

Annual (12-month) collocation

After annual maintenance (and zero test for SensWA), the Air Sensor Calibration & Repair Specialist will collaborate with operators to arrange the annual 30-day collocation test at the designated reference site before deployment at a host site. We will collocate PM sensors will in clusters with either a $PM_{2.5}$ (for Ecology SensWA) or PM_{10} (for QuantAQ MODULAIR-PM) and a BAM 1020 or 1022 for a minimum of 30 days. Air Sensor Calibration & Repair Specialist and QA staff will use an ordinary least squares linear regression of 24-hour averaged data from this collocation for cluster correction.

The Calibration & Repair Laboratory keeps records of all annual (12-month) collocations completed.

To reduce variability during collocation, install the PM sensors as close to the BAM 1020 or 1022 and to each other as possible. Ideally, operators should install PM sensors and BAM 1020 or 1022 within ten meters (30 feet) of each other, with inlets should at similar height. No other structure or device should block the movement of air around the PM sensor.

3. PM Sensor Site Setup

Siting Guidance

When possible, site PM sensors at the collocation and host sites following 40 CFR, Part 58, Appendix E siting criteria for $PM_{2.5}$ monitoring. This helps elevate the quality of Ecology's PM sensor measurements closer to the level of regulatory PM monitoring. In addition to 40 CFR, Part 58, Appendix E, consider the following siting guidance for PM sensors:

Unrestricted airflow

- Install PM sensors as far as possible from obstructions, including trees and buildings.
- A pole, fence, or railing offers the least restriction of airflow.
- If you cannot attach to a point with unrestricted airflow, use the outside corner of a building with 270 degrees of unrestricted airflow.
- If prior options are unavailable, install on a flat wall with 180 degrees of unrestricted airflow (both horizontal and vertical).
- Never install PM sensors inside corners where two walls meet or under large eaves or awnings.

Representative area

- Choose a PM sensor installation location representative of the area of interest.
- We typically conduct PM monitoring in residential areas because people spend the majority their time there.
- Good choices for representative sites include parks, schools, community centers, libraries, or other central public locations.
- Avoid installing PM sensors near sources that can interfere with ambient measurements (e.g., HVAC and other exhaust vents, smoking areas)
- Consider the suitability of the PM sensor location to yield representative data that meets the monitoring goal, including the effects of:
    - Topography— Do terrain or obstructions impact airmasses?
    - Pollutant considerations – Do nearby sources influence the site?
    - Atmospheric conditions – Do wind patterns around the site affect sampling?

Planning & Safety

- PM sensors must have access to wall power within 10 or 15 ft (longer with request to Calibration & Repair for power cord extension solutions). Alternatively, the siting location must have means to mount a Voltaic solar power system consisting of a battery pack and panel (Section 4. Voltaic Solar Power).
- Site PM sensors in a location with adequate cellular service.
- Figure out if personnel associated with the property must help operators access the PM sensor site and if they limit site access hours.

- We prefer ground-level sites over rooftop installations. Only consider rooftop sites if no suitable ground-level site exists. Installation of PM sensors as far away as possible from HVAC or other exhaust vents due to the high likelihood of interference.
- When possible, install PM sensors behind fencing or other barriers to deter vandalism or theft.
- All fixed or step ladders must meet Occupational Safety and Health Administration safety requirements. Choose a suitable height step ladder for the height of the rooftop, as well as the physical stature and strength of the site operator. Secure the step ladder to prevent unauthorized access.
- Find slip hazards and rectify where possible or clearly label with warning.

Site Selection Process

The Air Monitoring Coordinator will help the project manager or designated site operator in finding a suitable site that meets the PM monitoring goals and siting guidance through:

- The use of mapping software.
- Evaluation of monitoring and modeling data.
- In person visits to potential sites found through online tools.

Once a PM sensor site has been found, the project manager should work with the Air Monitoring Coordinator to contact property owners to obtain permission to use land and facilities. Mounting onto utility poles also requires approval of the relevant utility company.

Site operators must supply basic location information (e.g., address, latitude, and longitudinal coordinates) to the Air Monitoring and QA Coordinators via email prior to any PM sensor site installation. The Air Monitoring and QA Coordinators will review and approve locations that meet siting criteria and achieve stated monitoring goals of proposals approved by the Monitoring Advisory Committee.

Once a suitable PM sensor site location has been approved, the Air Monitoring Coordinator will work with the property owner to set up a rental agreement and arrange for payment of rent if necessary. The site operator responsible for the site should visit in person and evaluate the proposed location before installing the PM sensor.

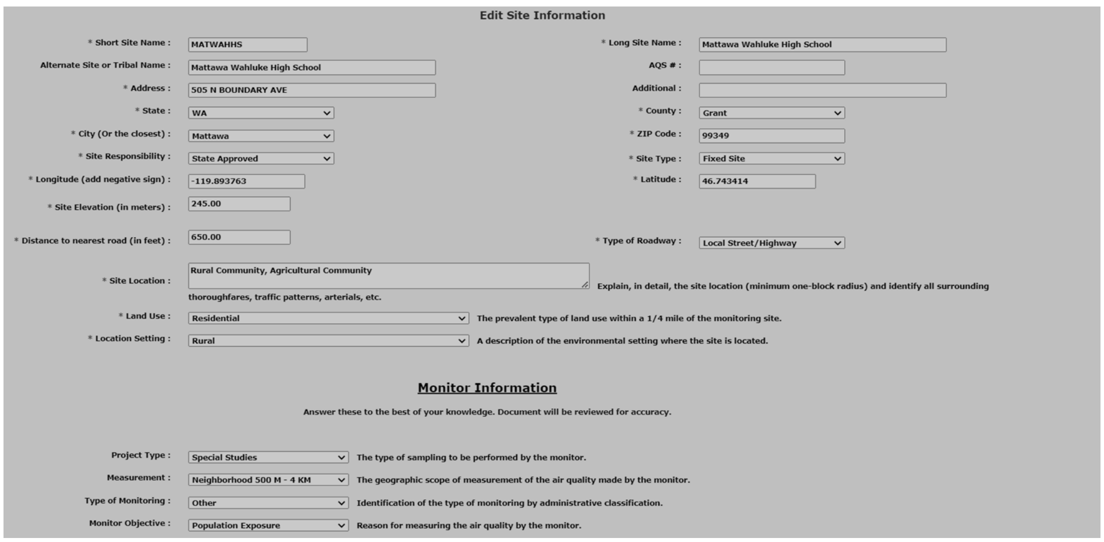
Site Information Management System (SIMS)

The Air Quality Program uses the Site Information Management System (SIMS) as the repository for all site and parameter information. Station operators must update SIMS site information whenever setting up or stopping a site, and when monitored parameters or physical conditions at the site change. IT and Calibration & Repair staff keep the Equipment Inventory part of SIMS. See Figure 3 for an example of a SIMS entry.

SIMS for PM sensors includes:

- Site Information (address, physical location, type of monitoring site, probe information, monitored parameters)

- Instrumentation and methods (pollutant being measured, equipment manufacturer make and model, solar power)
- Measurement scale (micro, middle, neighborhood, regional)
- Land use (industrial, commercial, residential, agricultural)
- Location setting (urban, suburban, rural)
- Monitoring objective
- Telemetry and telecommunication information (cellular, connected to data logger)
- Physical location and characteristics (address, latitude and longitude coordinates, elevation, nearby obstructing features)
- Probe location (top of building, ground level, attached to ___)
- Equipment inventory


Edit Site Information

* Short Site Name : MATWAHHS
* Long Site Name : Mattawa Wahluke High School
Alternate Site or Tribal Name : Mattawa Wahluke High School
AQS # :
* Address : 505 N BOUNDARY AVE
Additional :
* State : WA
* County : Grant
* City (Or the closest) : Mattawa
* ZIP Code : 99349
* Site Responsibility : State Approved
* Site Type : Fixed Site
* Longitude (add negative sign) : -119.893763
* Latitude : 46.743414
* Site Elevation (in meters) : 245.00
* Distance to nearest road (in feet) : 650.00
* Type of Roadway : Local Street/Highway
* Site Location : Rural Community, Agricultural Community
Explain, in detail, the site location (minimum one-block radius) and identify all surrounding thoroughfares, traffic patterns, arterials, etc.
* Land Use : Residential
The prevalent type of land use within a 1/4 mile of the monitoring site.
* Location Setting : Rural
A description of the environmental setting where the site is located.

Monitor Information

Answer these to the best of your knowledge. Document will be reviewed for accuracy.

Project Type : Special Studies
The type of sampling to be performed by the monitor.
Measurement : Neighborhood 500 M - 4 KM
The geographic scope of measurement of the air quality made by the monitor.
Type of Monitoring : Other
Identification of the type of monitoring by administrative classification.
Monitor Objective : Population Exposure
Reason for measuring the air quality by the monitor.

Figure 3. Example PM sensor site entry in Ecology’s Site Information Management System (SIMS).

In addition to SIMS, Ecology’s Envidas ambient air monitoring website includes more site information:

- Site photos, including the eight compass cardinal points (N, NE, E, SE, S, SW, W, NW)
- A map showing the location of all monitoring locations in the Washington Network
- Washington Air Quality Advisory (WAQA) information

4. Solar Power

A Voltaic solar power system can power Ecology SensWA or QuantAQ MODULAIR-PM in locations without access to a fixed power outlet. The Voltaic solar power system consists of the following components, which the Calibration & Repair Laboratory assembles:

- Voltaic 20 W solar panel with mounting bracket
- Weatherproof battery enclosure with screw-on front panel and cable gland port. Figure 4 shows a picture of the internal components of the battery enclosure, which includes:
  - Voltaic red extension cable (connects to solar panel externally, feeds through cable gland, connects to splitter internally)
  - Voltaic red splitter cable (connects extension cable from solar panel to two batteries inside enclosure)
  - 2 x Voltaic V75 USB batteries attached to the mounting plate and each other with Velcro strips (charged to full capacity by Calibration & Repair before shipment)
  - Black USB splitter (connects two batteries together for USB power, with receptacle to plug in sensor power embedded in cable gland)
- Mounting hardware (high strength zip ties, hose clamps, screws, nuts, bolts, washers)
- Backup of 2 x Voltaic V75 USB batteries and charging cables (operator responsibility to keep charged to full capacity)

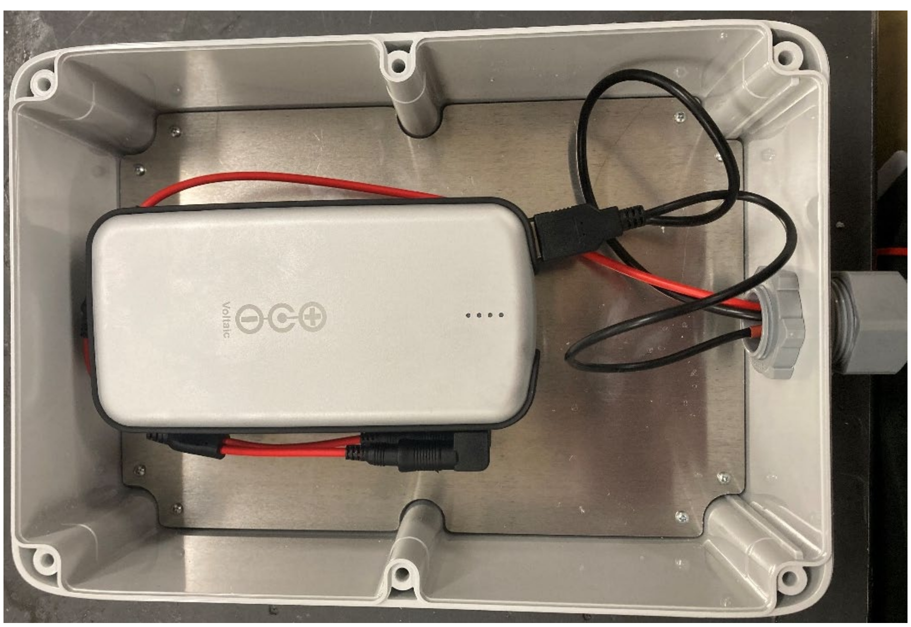


Figure 4. Internal components of the battery enclosure for the Voltaic solar power system (top on left, bottom on right).

Follow these steps to set up the Voltaic solar power system for a SensWA or MODULAIR-PM:

1. Ensure you have fully charged the two Voltaic V75 USB batteries inside the enclosure before going to the monitoring site.
2. When mounting, orient the Voltaic solar panel to face true south to maximize sun exposure. Changing the mounting angle seasonally maximizes sun exposure (Figure 5). However, we do not currently have means to easily adjust the mounting angle of our Voltaic solar panel. The angle of the solar panel will remain fixed unless operators make other arrangements with the Calibration & Repair Laboratory.
3. Mount the Voltaic solar panel securely with bracket to a pole, railing, or weighted tripod stand, using high strength zip ties or hose clamps. Alternatively, mount with screws directly into a pole, railing, or wall.
4. Mount the battery enclosure securely with bracket to a pole, railing, or weighted tripod stand, using high strength zip ties or hose clamps. Alternatively, mount with screws directly into a pole, railing, or wall.
5. Ensure the security of power connections between the Voltaic solar panels, battery enclosure, and PM sensor.

See Figure 6 for a picture of SensWA with Voltaic solar power systems mounted directly to a utility pole and on a tripod stand. Obtain permission from property owners and utility companies before mounting to an existing structure or utility pole. If mounting to a tripod, weight the bottom with securely attached cinder blocks or bolt to an existing platform.

Optimum Tilt of Solar Panels by Month

Figures shown in degrees from vertical

Jan	Feb	Mar	Apr	May	Jun
27°	35°	43°	51°	59°	66°
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
59°	51°	43°	35°	27°	20°

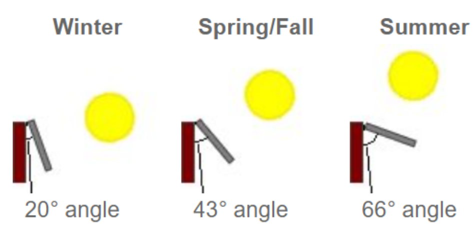


Figure 5. Optimum tilt of solar panels by month. From http://www.solarelectricityhandbook.com/solar-angle-calculator.html.

Figure 6: Pictures of SensWA with Voltaic solar power systems

Figure 6 shows photos of the SensWA with Voltaic solar power systems(Voltaic solar panel on top, SensWA in middle, battery enclosure on bottom) mounted directly to a utility pole in Winthrop, WA (left) and on a tripod stand inside the Calibration & Repair Laboratory (right). Mounting the SensWA below the Voltaic solar panel reduces sun and weather exposure to the SensWA.

5. Ecology SensWA

Instrument Layout

External view

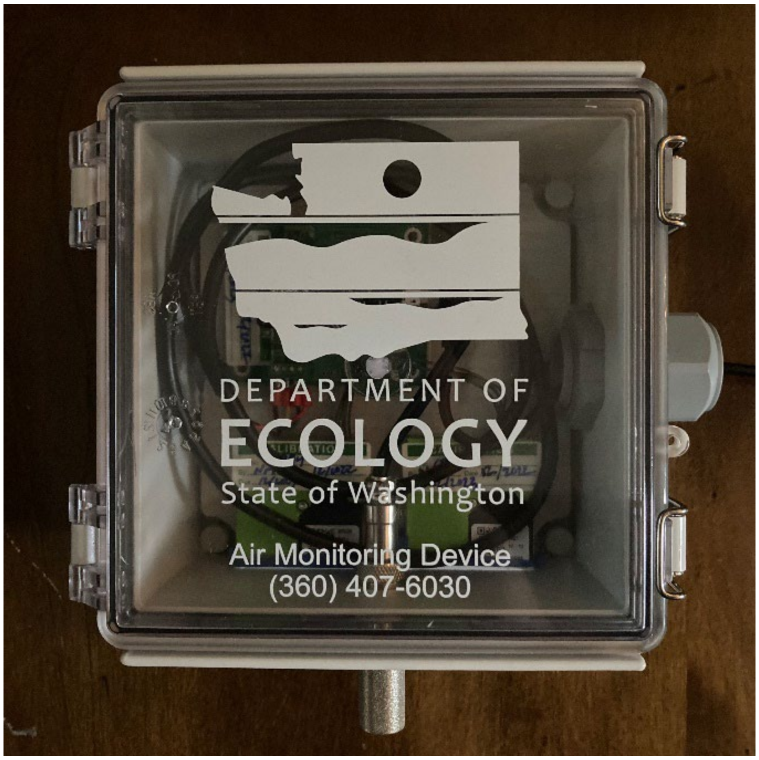


Figure 7. Ecology SensWA PM sensor enclosure, viewed from the front.

For ambient monitoring, mount the SensWA should with the relative humidity and temperature (RH&T) probe and inlets on the bottom, such as in the orientation pictured in Figure 7. You can see the following components externally on the SensWA:

- The cylindrical aluminum sintered RH&T probe protrudes from the center-bottom of the SensWA.
- The bottom of the SensWA also has two rectangular holes that allow airflow to the two Sensirion PM sensing elements. A bug screen glued in place covers these rectangular holes. The Sensirion SPS30 PM sensing elements have an aluminum face with air intakes visible behind their bug screens. Each Sensirion SPS30 has two smaller intake cutouts and two larger exhaust flow cutouts.
- The grey power cable gland on the right side supplies a watertight entry for the power and data cable into the SensWA interior.
- The air vent on the left side helps prevent condensation inside the SensWA and normalizes internal conditions with ambient, while preventing bugs or spiders from entering.

Internal view

Figure 8. Ecology SensWA PM sensor internal components.

You can access the following internal components of the SensWA, pictured in Figure 8, if you open the front panel:

- The Particle Boron LTE communication board (Boron) transmits data via cellular service to the cloud from the SensWA. The black Boron with blue lettering connects to an antenna and a USB power cord. The Boron also has an LED that lights up to show cellular communications status. After setup and plugin, make sure to note the status of the LED on the board. See next section for more details on the Boron status LED.
- The Boron connects to a larger green (later production runs) or purple (original production run) circuit board custom designed for the SensWA and manufactured by Screaming Circuits. Velcro connects the board to the mounting plate.

- The cellular antenna (black rectangle) adheres to the inside of the enclosure and connects to the Boron by a thin black wire and gold circular connector. You will feel a snap in to place when connecting to the Boron. Do not push too hard if misaligned as pins can easily bend. The antenna can easily disconnect from the Boron. Handle with care and ensure proper connection before closing the enclosure.
- The aluminum RH&T probe connects by a thick black cable ending in four wires to the green connector on the circuit board. The four wires connect to the circuit board in the following order (left to right): black, yellow, green, red. A zip tie secures the excess RH&T probe wire in a loop and a clip attaches it to the mounting plate.
- Two Sensirion SPS30 PM sensing elements (lime green squares) connect to the circuit board by sets of five thin grey cables with green connectors. The Sensirion SPS30s uses a polarized 660 nm laser to scatter light of particles and a photo diode detector to measure the scattered light, with an internal fan for airflow. Double-sided adhesive squares secure the Sensirion SPS30s centered on the rectangular airflow cutouts.
  - For more information on the SPS30, see Sensirion documentation.
  - For laboratory and field evaluation results, see South Coast Air Quality Management District's Air Quality Sensor Performance Evaluation Center results.
- On the inside of the wall, you will find a sticker (bright green) with SensWA identification number and date of next annual maintenance at the Calibration & Repair Laboratory.

Boron LTE Cellular Communications

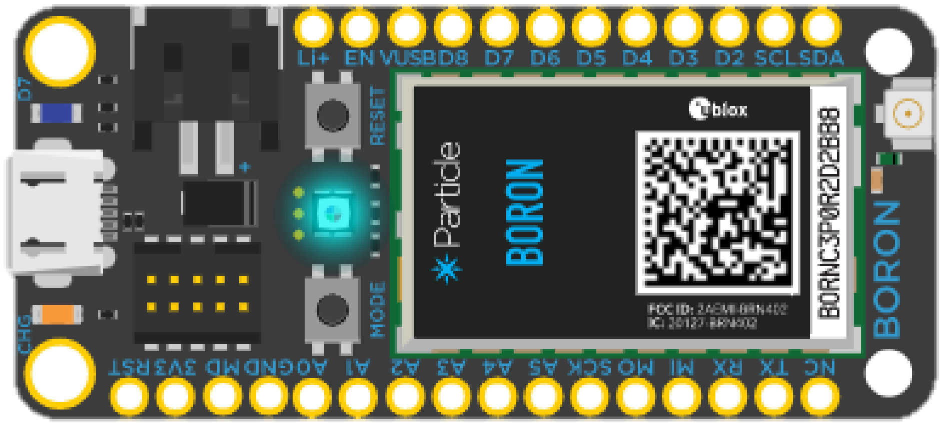


Figure 9. Boron LTE communications board, with LED illuminated in cyan, which transmits data for the Ecology SensWA PM sensor.

The Boron LTE communications board (Figure 9) connects the SensWA to the Particle Device Cloud and streams data via cellular signal. You will use the indicator light on the Boron as the primary means of diagnosing SensWA telecommunications status.

Indicator light

- Breathing Cyan - When breathing (slow blinking) cyan, the device successfully set up cellular connection to the cloud.
- Rapidly Blinking Cyan – When rapidly blinking cyan, the device is connecting to the cloud. This mode is typical when the device is first connected to a network, after it has just blinked green.
- Blinking Green - If blinking green, the device is trying to connect to cellular and is not currently streaming data. If this state persists, contact Air Sensor Calibration & Repair Specialist.
- Blinking Magenta (Red/Blue) - If blinking magenta (red and blue at the same time), the device is currently loading an app or updating its firmware. This mode may occur when the device is connected to the cloud for the first time.
- Breathing Magenta (Red/Blue) - If breathing magenta (red and blue at the same time), the device is in safe mode and is connected to the device to the cloud but does not run any application firmware. This mode is one of useful for development or for software troubleshooting. If this state persists, contact Air Sensor Calibration & Repair Specialist.
- Blinking Dark Blue – When blinking dark blue, the device is in Listening Mode and awaits further configuration. If this state persists, contact Air Sensor Calibration & Repair Specialist.

- Breathing White - If the device is breathing white, the cellular module is off. If this state persists, contact Air Sensor Calibration & Repair Specialist.
- Blinking Red or Yellow – A variety of faults, bugs, or errors can cause red or yellow blinks. If this state persists, contact Air Sensor Calibration & Repair Specialist.
- Solid Colors - Solid colors are rare. In most cases, solid colors are the side effect of a bug or crash. If this state persists, contact Air Sensor Calibration & Repair Specialist.
- No Status LED - A corrupted bootloader or physical damaged can cause your device status LED to not comes on when connected to power. Contact Air Sensor Calibration & Repair Specialist.

Troubleshooting failed cellular connection

- Tapping the MODE button on the Boron will blink out the bars of signal strength. More blinks show a stronger signal.
- Check the connection between cellular antenna and the USB power cord.
- Poor or inconsistent power supply reduces cellular signal strength. Plug the SensWA into different power outlets to improve cellular signal strength.
- We may need to deploy SensWA in areas with unavoidably poor signal strength. Work with Air Sensor Calibration & Repair Specialist to find a solution, which may require a signal booster or change in siting location.

SensWA Installation

The best SensWA mounting configuration depends on the monitoring site characteristics. The Calibration & Repair Laboratory recommends operators use high-strength zip ties or pole mount kit (supplied by Calibration & Repair Laboratory) to secure the SensWA to a post, fence, or crossbar. Alternatively, operators can use the mounting hardware to screw the SensWA directly to a post, crossarm, or wall. Contact Air Sensor Calibration & Repair Specialist for help. See Figure 10 for pictures of SensWA mounted with high strength zip ties.

If possible, avoid south-facing installation to reduce direct sunlight. Excessive sunlight through the clear front panel of the SensWA could degrade electronics over time. Consult with the Air Sensor Calibration & Repair Specialist if you have concerns about sun exposure at a site.

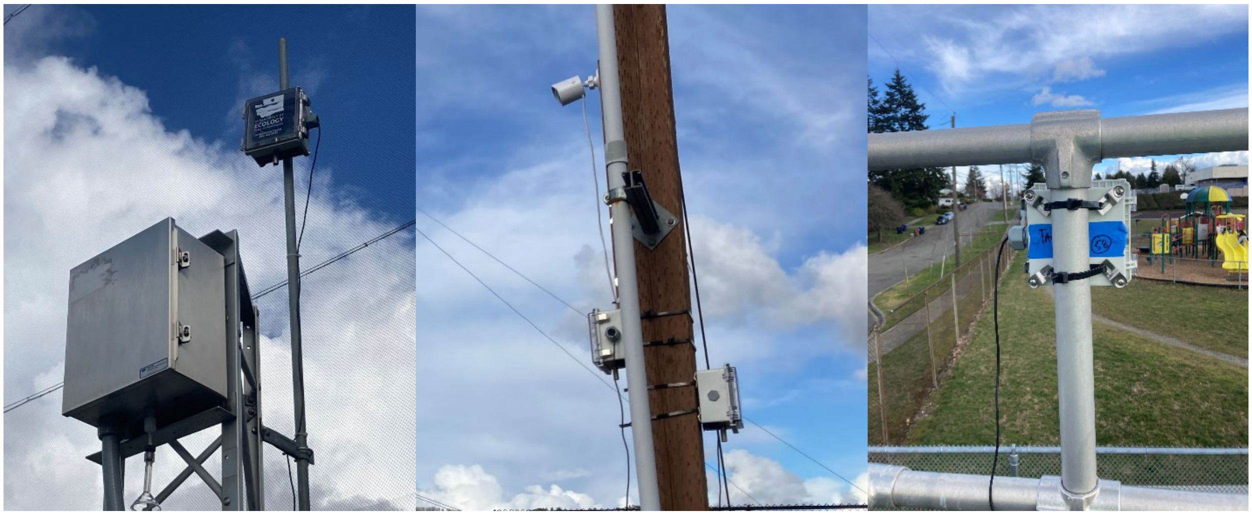


Figure 10. Pictures of SensWA mounted with high-strength zip ties.

Once you mount the device, complete the following steps:

1. Plug in the USB power supply to a weatherproof power outlet.
2. Upon receiving power, the Boron LED indicator will flash green and eventually begin a sequence of slowly breathing cyan; this shows active cellular connection to the cloud server. This process will take longer when powering the device on in a new location. Typically, devices connect within 10 minutes, but may take 30 or more minutes.
3. The device will log data locally during this period and push the data to the server when the device connects.
4. If the LED indicator does not eventually begin breathing cyan, the device has a cloud connectivity problem. Contact Air Sensor Calibration & Repair Specialist.
5. Operators must notify the Air Sensor Calibration & Repair Specialist when deploying or relocating SensWA. The Air Sensor Calibration & Repair Specialist will configure the device, coordinate with the IT unit to begin polling and web display and notify the QA unit to begin data review.

6. QuantAQ MODULAIR-PM

Instrument Layout

External view

For ambient monitoring, mount the MODULAIR-PM with the inlet on the bottom, such as in the orientation pictured in Figure 11. You can view access the following components externally on the MODULAIR-PM enclosure:

- On the bottom, you can see a square inlet that leads to the airflow path to the PM2.5 and PM10 sensing elements. A metal bug screen covers the square airflow inlet.
- You can also access the USB power connection on the bottom of the enclosure.
- On the right side of the enclosure, you can see the air vent for the exhaust airflow from the Alphasense PM10 sensing element.

Figure 11. Picture of the MODULAIR-PM PM sensor, with optional solar panel power, mounted on a pole for ambient monitoring.

Front panel

Access the front panel of the device by opening the lid of the enclosure. The panel supplies access to the ON/OFF switch, Menu, LED indicator, and access to the onboard µSD card. Figure 12 presents a photo of the front panel with components labeled. A Boron LTE communications board, which the SensWA section above discusses in detail, powers the LED indicator light.

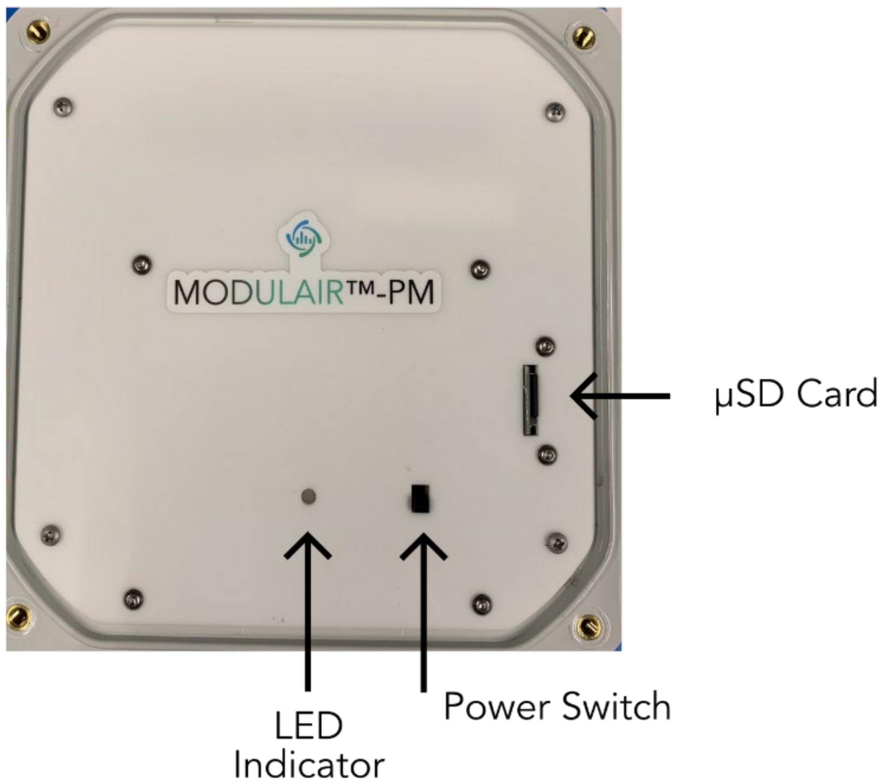


Figure 12. Labeled picture of the MODULAIR-PM Front Panel consisting of an LCD screen, power ON/OFF switch, LED indicator, and access to the onboard µSD card. From QuantAQ documentation.

Internal views

Mounted on the underside of the front panel are the Core Circuit Board and µSD circuit board and Particle Boron LTE communications board (Figure 13). The sample flow path with $PM_{2.5}$ and PM_{10} sensing elements (Figure 14) are mounted to the base of the enclosure. Consult with Calibrations & Repair Laboratory staff before touching these internal components.

For laboratory and field evaluation results of the Alphasense OPC utilized as the PM10 sensor in the ModulairPM, see South Coast Air Quality Management District's Air Quality Sensor Performance Evaluation Center results.

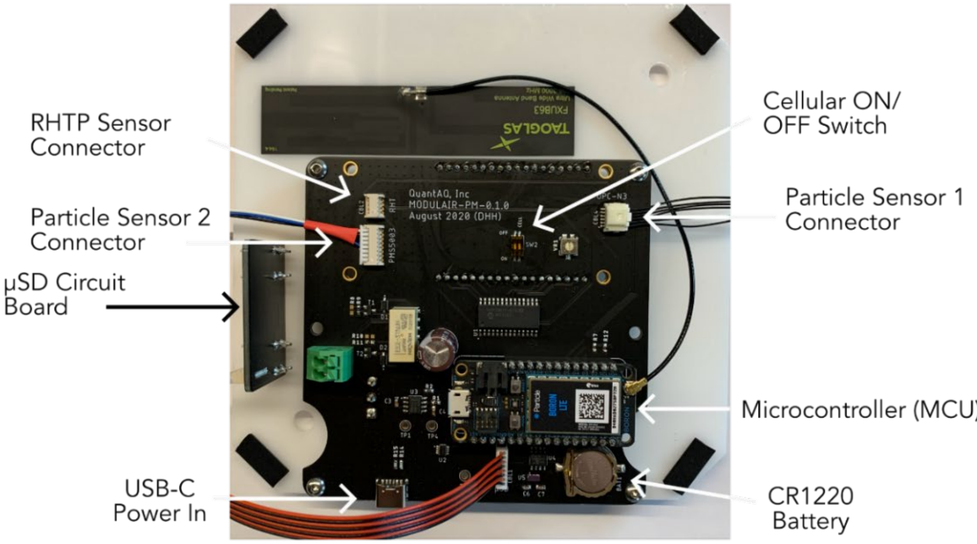


Figure 13. Labeled Picture of the MODULAIR-PM core circuit board includes connectors for two PM sensing elements, a relative humidity, temperature, and pressure sensing elements, and the µSD circuit board. From [QuantAQ documentation](#).

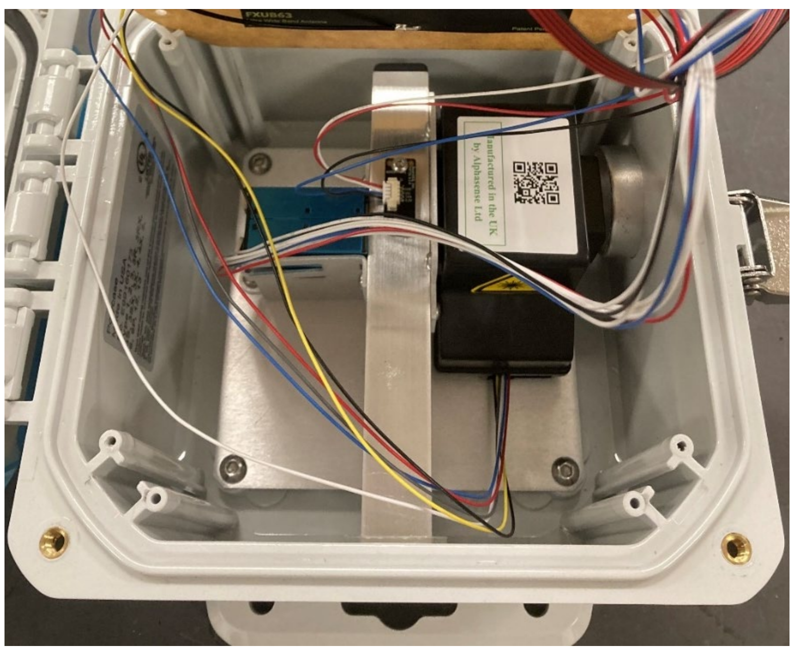


Figure 14. Picture of the MODULAIR-PM sample flow path (silver, center) with the Plantower $PM_{2.5}$ sensing element (blue, left) and the Alphasense optical particle counter PM_{10} sensing element (black, right).

MODULAIR-PM Installation

The best MODULAIR-PM mounting configuration depends on the monitoring site characteristics. The Calibration & Repair Laboratory ships the device with mounting flanges. Two stainless steel screws (included) secure the flanges to the back of the device. Each flange includes three slots for mounting hardware. See QuantAQ documentation for more info. The Calibration & Repair Laboratory recommends operators use high-strength zip ties or pole mount kit (supplied by Calibration & Repair Laboratory) to secure the MODULAIR-PM to a post, fence, or crossbar. Alternatively, operators can screw the MODULAIR-PM directly to a post, crossarm, or wall. Contact Air Sensor Calibration & Repair Specialist for help.

Once you mount the device, complete the following steps:

1. Turn the power switch to the OFF position, then plug in the power supply and connect the USB-C cable into the bottom of the device.
2. Connect the power cable to the device and to a weatherproof power enclosure, then flip the power switch to the ON position.
3. Upon receiving power, the LED indicator (Figure 12) will flash green and eventually begin a sequence of slowly breathing cyan; this shows active cellular connection to the cloud server. This process will take longer when powering the device on in a new location. Typically, devices connect within 10 minutes, but may take 30 or more minutes.
4. The device will log data locally during this period and push the data to the server when the device connects.
5. If the LED indicator does not eventually begin breathing cyan, the device has a cloud connectivity problem. Contact Air Sensor Calibration & Repair Specialist.
   Operators must notify the Air Sensor Calibration & Repair Specialist when MODULAIR-PM sensors are deployed or moved. The Air Sensor Calibration & Repair Specialist will configure the devices in the QuantAQ Cloud, coordinate with the IT unit to begin polling and web display. In addition, they will notify the QA unit to begin data review.

7. Final Data Validation and Quality Assurance

QA and Air Monitoring Coordinator perform final data validation in EnvistaARM. Data validation includes:

- Reviewing auto-QC results from R statistical analysis package.
- Using the EnvistaARM to review reports from operators.
- Using the EnvistaARM to review collected data for reasonability and comparability with other area monitors.
- Invalidating data collected during times when PM sensor run in error or outside QC acceptance limits.

QA staff evaluates data validity using a systematic criterion including comparability to collocated and nearby PM sensors, nephelometers and $PM_{2.5}$ monitors, as well as the results of quality control checks. QA staff manage final review and data validation.

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