

PART B
AIR AND AIR EMISSIONS TESTING

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PART B1
AMBIENT AIR QUALITY MONITORING

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1. Introduction

This Part (Part B1) of the B.C. Field Sampling Manual (the ‘BCFSM’ or the ‘Manual’) provides guidance and instructions for operators of ambient air monitoring stations. Ambient air monitoring stations that generate air quality data for submission to provincial agencies are required to design, operate and maintain their stations as specified in this Part of the B.C. Field Sampling Manual. Detailed information regarding ambient air monitoring methods is provided in Standard Operating Procedures (SOP) located in the appendices section of this *Part* of the BCFSM. Additional specifications and requirements may be prescribed in Permits issued by the Province of British Columbia.

The information presented in Part B1 of the BCFSM is derived in part from information published by the National Air Pollution Surveillance Program (NAPS), the United States (US) Environmental Protection Agency (EPA) 2013 *QA handbook for Air Pollution Measurement Systems Volume II Ambient Air Quality Monitoring Program*, and industry accepted best practices.

1.1. Purpose and Scope

The primary objective of the guidance provided in this section of the British Columbia Field Sampling Manual is Quality Assurance (QA). The scope of this section includes all aspects of air quality data generation. Air quality data collected by the Province is used to inform health advisories, air shed capacity decisions, permit decisions and policy development. Due to these important data usages it is essential that the quality of the data meets or exceeds Provincial Data Quality Objectives (DQO). The information presented within this section has been developed to ensure that air quality data generated in all regions of British Columbia is collected and reported consistently and is truly representative of the region in which it is generated. Air quality data meeting Provincial DQO’s provide reliable, defensible, high quality information.

Data quality is affected by every aspect of air quality monitoring. Location and siting requirements ensure the air being sampled is representative and consistent with the stations monitoring objectives. Also the instrumentation deployed at a monitoring station will determine the accuracy and precision of measurement and station maintenance will ensure the instrumentation is functioning at an acceptable level of performance producing consistent and reliable data. Consistency in siting, installation, operation, maintenance, reporting and data management procedures help to ensure that data generated across the Province meets the data quality objectives of comparability, accuracy, completeness and representativeness. The purpose of this section of the BCFSM is to provide the guidance necessary to achieve those essential elements.

2. Monitoring Station Design

Planning the design of a monitoring station involves several critical aspects such as location, siting, power requirements and instrumentation. All of these aspects are driven by the stations *monitoring objectives*. The development and understanding of a monitoring station's objectives is crucial and forms the first step in designing a monitoring station.

2.1 Monitoring Station Location

Monitoring locations for ambient air quality stations must meet the following conditions:

- Stations must meet the Provincial requirements of Worksafe B.C., B.C. Safety Authority, the Canadian Standards Association (CSA), provincial electrical and all applicable building codes. If any of the information or conditions presented in this section contravene or are interpreted to contravene or contradict applicable legislation, the applicable legislation takes precedence,
- Sites should be accessible and secure from unauthorized access,
 - Access to sites should not be impeded by snow or seasonal closures,
 - Ideally, access to sites should be 24/7,
 - Sites and any external equipment (sample inlets, etc.) should be protected as best as possible from vandalism.
- The shelter must protect the instrumentation from,
 - Precipitation and rodent issues,
 - Fluctuations in internal temperature, pressure or humidity that may be caused by over-sized air conditioning units, or intrusion of ambient air,
 - Excessive dust and dirt,
 - Environmental stress including temperature extremes, vibration, corrosive chemicals, intense light, or radiation pertinent to a manufacturer's specification.
- All monitoring in B.C. must be conducted using Pacific Standard Time. Analyzers, samplers and data loggers must not be adjusted for Daylight Savings Time. Sites sited locally in the Mountain Time Zone must still report in Pacific Time to maintain the consistency of the provincial data set.

2.2 Station Siting Considerations

General siting considerations should include the availability of communications systems and power as well as the long term viability of the site. All new ambient air quality monitoring sites,

whether Ministry or permittee owned, must be approved by the Regional Meteorologist, the Section Head for Environmental Quality, and the Regional Director of Environmental Protection.

Ministry siting approval will be granted based on an application of various criteria, including, but not limited to:

- NAPS, Environment Canada, and US EPA, siting criteria and quality assurance documents,
- Manufacturer's recommendation for siting / housing of equipment, and;
- Interpretation of local emission sources, climate patterns and rationale for monitoring (complaint resolution, impact to residential areas, traffic studies, etc.).

2.3 Installation Considerations

Instruments must be installed in a secure manner or as per manufacturer's direction. This includes designing housings, benches, outdoor enclosures, etc. to assure the instrument will stay secure and operate within the instrument manufacturer's specifications for criteria such as vibration, humidity and light intrusion. Similarly gas cylinders must be properly secured within the station's enclosure.

Outdoor or rooftop enclosures must be located at least 3 metres from the edge of a roof or significant elevation change to ensure the safety of those working on the equipment and to prevent non-representative sampling such as building influenced air currents.

2.4 Electrical Power Supply

Monitoring stations require a stable and reliable source of electrical power to help avoid unnecessary interruptions in monitoring and ensure that the instrumentation deployed at the station produces consistent, reliable data. A robust power source will reduce the potential for data gaps and prolong the life of the instrumentation providing that data. For these reasons the following aspects must be considered and addressed in the design of a monitoring station:

- The station should be powered by constant voltage transformers or regulators,
- Power distribution must comply with relevant electrical codes,
- Heaters, air conditioners, pumps and other inductive loads should be isolated from circuits supplying power to sensitive instrumentation such as data loggers,
- Line voltages supplies for each instrument should satisfy manufacturer's specifications,

- In areas where electrical supply interruptions are frequent or poor power conditions exist, the following options are available to help ensure data quality is not affected by transient power conditions:
 - Data loggers, station computers, routers, modems and ancillary data handling equipment should be protected by an Uninterruptible Power Supply (UPS) of sufficient capacity and the ability to provide a controlled shut down of equipment during extended outage events.
 - Monitoring stations in locations with known power issues can deploy UPS systems to keep gas analyzers, meteorological sensors and particulate monitor control units warm during short power interruptions, and provide controlled shut downs during extended outages.
- It is not recommended that pumps be protected by UPS units.

2.5 Internal Shelter Climate Control

Monitoring stations that house continuous monitoring equipment for particulate or gas analysis must be equipped with remote continuous monitoring of the stations internal temperature. The internal temperature probe must be located in such a manner that it is representative of overall station conditions. Internal temperature data must be recorded at equivalent time periods as that of the continuous monitors operating within the station. All stations require a HVAC system capable of maintaining a stable year-round internal temperature range of 20 °C to 30 °C that is stable to within $\pm 2^{\circ}\text{C}$. The ideal temperature range for monitoring stations is 20 °C to 25 °C.

In situations where single analyzer cabinets (external or outdoor installations) are used to house monitoring equipment, those shelters must have:

- Proper electrical connections and capacity, including a grounding wire installed by a professional electrician, and;
- Sufficient heating and cooling capacity to maintain a stable internal temperature of $\pm 2^{\circ}\text{C}$. This excludes certain kinds of monitors which are specifically designed to operate at ambient temperature to maintain the integrity of the sample (i.e. low flow rate samplers).

A basic consideration regarding climate control and instrumentation is; heat kills. Component and instrumentation life spans decrease with prolonged exposure to high heat environments.

2.6 Sample Inlet Placement

Sample inlets are provided by instrument manufacturers or they are designed and fabricated specifically for a monitoring station. The placement of the inlet is crucial to providing

representative air samples and as such should be based on several factors including height, proximity to traffic corridors, traffic volumes, obstructions and distance between inlets.

The National Air Pollution Surveillance (NAPS) program's *Monitoring and Quality Assurance/Quality Control Guidelines* specifies minimum separation distances between roadways and sample inlets based on traffic volumes. The NAPS specifications are provided in the following table.

Average Vehicles/Day	≤ 10,000	≤ 15,000	≤ 20,000	≤ 40,000	≤ 70,000	≤ 110,000
Distance to nearest traffic lane	≥ 10 m	20 m	30 m	50 m	100 m	≥ 250 m

Sample inlets for ground level monitoring stations deploying gas and particulate instrumentation must be installed at a minimum height of two metres above ground surface to a maximum of 15 metres above ground surface. If obstacles to air flow are present the sample inlet must be configured to achieve a minimum distance from that obstacle equal to twice its height. With the exception of Polycyclic aromatic hydrocarbons (PAH), sample inlets for gas analyzers must be installed at a minimum distance of one metre from support structures. Sample inlets for PAH and Particulate Matter (PM) instruments must be installed at a minimum distance of two metres from support structures. Sample inlets with flow rates less than 20 litres per minute (lpm) must be separated by a minimum distance of one metre. Sampling inlets with flow rates greater than 20 lpm must be positioned at a minimum distance of two metres apart. Sampling inlets for co-located instrumentation must be positioned within four metres of each other.

Additionally sample inlets should not be placed near building ventilation ports, HVAC equipment, exhausts or stacks, exposed soil or gravel staging areas that are frequently traversed or areas susceptible to snow accumulation.

2.7 Manifold Design

Monitoring stations that deploy multiple gas analyzers should be equipped with a manifold and water trap are recommended and preferred to individual sample lines. Manifolds are not recommended for monitoring stations that deploy both continuous and integrated PM monitoring; in these situations the instruments should be equipped with individual inlets connected to tubing that is vertically oriented.

Where horizontally mounted manifolds are used they should be oriented with the ports facing upwards and water traps oriented vertically to reduce the risk of moisture entering an analyzer. Manifolds such as the “ARB style” must be mounted vertically. Regardless of the manifold type the monitoring station’s sampling inlet and manifold must meet the requirements of the most recent version of the National Air Pollution Surveillance (NAPS) Program’s *Monitoring and Quality Assurance/Quality Control Guidelines* Section 8.2 and Section 8.3.

2.8 Particulate Monitoring Considerations

Continuous PM_{2.5} monitors have specific siting requirements and inlet probe configurations that are outlined in the manufacturer’s manuals. Similarly, particulate samplers such as low flow samplers and high volume samplers have specific siting considerations and clearance distances. Method specific considerations are summarized in method-specific SOPs located in the appendices section of this Manual.

2.9 Passive Sampling Considerations

Passive samplers have a distinct set of siting criteria. It is important to establish applicable siting criteria and monitoring requirements prior to installation of a passive sampler and or network. Monitoring objectives should be discussed with the laboratory supplying the passive samplers to ensure this method is suitable and capable.

Passive sampler installations should conform to the following:

- The sampler housing shall be mounted to an adequate supporting structure in accordance with the manufacturer’s specifications and in a configuration that does not produce a restriction to airflow.
- The sampler shall be deployed in a manner that prevents the diffusion barrier from becoming wet, protects the diffusion barrier from the precipitation of suspended particulates, and protects the diffusion barrier from high wind speeds (i.e. use a housing/rain shield).
- The sampler housing shall be placed so that the diffusion barrier of the sampler body is at a height of two meters (m) to four metres above ground surface.
- Collocated samplers should be positioned within a 4 m horizontal distance of each other.
- Passive samplers within a monitoring network should be positioned at the same sampling height.
- Higher objects such as trees and buildings should not exceed 30 degrees from a horizontal plane as viewed from the sampler body. This is shown in Figure 2.9.1.

Figure 2.9.1 Passive Sampler Installation



Figure reference: Blair R. Irwin, ENV 2018

Detailed information regarding the siting and installation requirements for passive sampling instruments is provided in the Standard Operating Procedure the Passive Sample Collection of Air Compounds (SOP 13) located in the appendices of this Manual.

2.10 Rooftop Installations

When planning the design of a rooftop monitoring station, consideration should be given to the Occupational Health and Safety Regulation (OHSR). Working at height, safe working zones and roof access points must be considered and must comply with the applicable sections of the OHSR on a location specific basis. In addition to provincial regulatory requirements, there may be regional, municipal, and agency requirements applicable to a site. For example situations where school or fire station roofs are the intended station location. Preliminary planning must consider and assess the following safety aspects and where applicable, develop commensurate safety control measures:

Table 2.8.1: Rooftop Installation Site Specific Health and Safety Considerations

Risk	Site Specific Considerations
Working at Height	<ul style="list-style-type: none"> ▪ Review the OHSR to identify regulatory requirements and facility specific requirements, that may apply to the site, ▪ Confirm that the load-bearing capacity of the roof can accommodate the instrumentation package and work crew, ▪ Determine if fall protection is required, ▪ Determine if a fall protection plan is required, ▪ Determine if a control zone is required to establish a work area away from the elevated work surface, ▪ Determine if it is necessary to work with a partner or in teams, ▪ Identify rooftop hazards such as power lines, and; ▪ Secure objects/tools to prevent items dropping or falling from the roof.

Access	<ul style="list-style-type: none"> ▪ Ladder safety considerations such as three point contact, and; ▪ Equipment transportation to monitoring location.
Weather Conditions	<ul style="list-style-type: none"> ▪ Consider year-round weather conditions in terms of access and safety.

3 Continuous Monitoring and Sampling Methods

3.1 Methods and Performance Specifications

The information provided in this section of the Manual includes a summary of acceptable *methods* of ambient air monitoring within the provincial jurisdiction of British Columbia. The *Monitoring and Quality Assurance/Quality Control Guidelines* published by the National Air Pollution Surveillance (NAPS) program provides ‘minimum performance specifications and operating ranges’ that should be reviewed and considered during the instrument selection process.

Table 3.1.1 lists commercially available analyzers, monitors, and samplers that are considered suitable for ambient air monitoring. This list is not an endorsement nor does it exclude other commercially available instrumentation including those recognized by the United States (US) Environmental Protection Agency’s (EPA) Federal Reference and Equivalent Methods. Indeed as technology advances, new instrumentation will enter the market which may be suitable for use within the provincial jurisdiction of B.C. It is recommended, however, that you consult with the B.C. Ministry of Environment and Climate Change Strategy (ENV) if you intend to deploy instrumentation not listed in Table 3.1.1. Regardless of the equipment deployed all analyzers should meet the minimum performance specifications prescribed in Table 3.1.2.

Table 3.1.1: Continuous Ambient Air Equipment

Monitoring Parameter(s)	Operating Principle	Commercially Available Analyzer/Monitor/Sampler
CO	Non-dispersive Infrared Photometry with Gas Filter Correlation (GFC)	<ul style="list-style-type: none"> ▪ Thermo Environmental Instruments (TEI) Models 48, 48C, 48CTL analyzers. ▪ Serinus 30 Carbon Monoxide analyzer. ▪ Teledyne T300 analyzer.

Monitoring Parameter(s)	Operating Principle	Commercially Available Analyzer/Monitor/Sampler
H ₂ S/TRS	Ultraviolet fluorescence	<ul style="list-style-type: none"> Thermo Environmental Instruments (TEI) Models 45A, 45C, 450i H₂S analyzers with converter model numbers 340 for H₂S and CDN 101 for TRS; operating in single channel mode. Teledyne Advanced Pollution Instrumentation Models 101E (H₂S), 102E (TRS), 101/101A (H₂S) 102/102A (TRS)
Oxides of Nitrogen (NO/NO ₂ /NO _x)	Chemiluminescence	<ul style="list-style-type: none"> Thermo Environmental Instruments (TEI) Models 42, 42C, & 42i NO_x Teledyne API T200 Serinus 40
O ₃	Selective Absorption of Ultraviolet (UV) Photometry	<ul style="list-style-type: none"> Thermo Environmental Instruments (TEI) Models 49, 49C, 49i Serinus 10 Teledyne API T400
PM ₁₀ and PM _{2.5} Continuous Monitor	Beta Attenuation Monitor (BAM)	<ul style="list-style-type: none"> Met One BAM-1020 with Smart Heater System Thermo Scientific 5014i
	Nephelometry and BAM	<ul style="list-style-type: none"> Thermo Scientific SHARP Model 5030 and 5030i
SO ₂	Ultraviolet fluorescence	<ul style="list-style-type: none"> Thermo Environmental Instruments (TEI) Models 43A, 43C & 43i SO₂ Teledyne API T200 Ecotech EC9850T
NH ₃	Chemiluminescence	<ul style="list-style-type: none"> Thermo Environmental Instruments (TEI) Model 17C Ammonia Analyzer Thermo Scientific Model 17i Ammonia Analyzer Teledyne API Model T201 Ammonia Analyzer
BTEX	Gas Chromatography (GC) With Detector	<ul style="list-style-type: none"> Syntech Spectras Analyzer GC 955
CH ₄ /NMHC	Gas Chromatography	<ul style="list-style-type: none"> Thermo Scientific Direct Methane, Non-Methane Hydrocarbon Analyzer, Model 55i Synspec GC's Alpha 115
Formaldehyde (CH ₂ O)	Adsorbent Cartridge	<ul style="list-style-type: none"> Cartridge Sampler
PM ₁₀ and PM _{2.5} Low Flow Sampler	Low Flow Rate Filter Collection and Gravimetric Mass Determination	<ul style="list-style-type: none"> Thermo Scientific Partisol™ Various Models Rupprecht & Patashnick Partisol™ Model 2000
TSP and PM ₁₀ High Flow Sampler	High Volume Filter Collection and Gravimetric Mass Determination	<ul style="list-style-type: none"> Ecotech HiVol 3000 High Volume Air Sampler Tisch Environmental High Volume Air Sampler (Various models)
Various	Passive Sampler	<ul style="list-style-type: none"> Available from laboratory

Additional information regarding the operating principles of instruments listed in Table 3.1.1 is provided within method-specific SOP located in the appendices section of this Manual.

Analyzers should meet the performance specifications described within Table 3.1.2 and the associated SOPs in Appendix 2. The performance specifications are based on current technology and on manufacturer's information. It is recognized that technology continues to evolve in this area, and therefore over time, performance specifications may change (typically improve).

Table 3.1.2: Continuous Ambient Air Equipment – Minimum Performance Specifications

Monitoring Parameter	Instrument Range	Operating Range in BC	Lower Detection Limit	Zero Noise	Zero Drift (24 hours)	Span Drift (24 hours)	Rise/Fall Time (max.)
CO	0-10 ppm	0-50 ppm	0.04 ppm	0.02 ppm RMS	< 0.1 ppm	< 1% full scale	60 sec
H ₂ S/TRS	0-200 ppb	0-200 ppb	0.5 ppb	< 0.02 ppb RMS	0.5 ppb	< 0.5% full scale	-
Oxides of Nitrogen (NO/NO ₂ /NO _x)	0-500 ppb	0-500 ppb	0.4 ppb	0.2 ppb RMS	< 0.5 ppb	< 1% full scale	80 sec
O ₃	0-500 ppb	0-500 ppb	1 ppb	0.3 ppb RMS	< 1 ppb	< 0.5% full scale	20 sec
PM ₁₀ and PM _{2.5} Continuous Analyzer	0 – 200 µg/m ³	0 – 200 µg/m ³	2 µg/m ³ (24 hour period)	n/a	n/a	n/a	n/a
SO ₂	0-500 ppb	0-100, 0-200 or 0-500 ppb	0.1 ppb	< 0.06 ppb RMS	< 0.2 ppb	< 0.5% full scale	140 sec

4 Instrument Installation

4.1 Pre-Deployment Testing

Prior to installation and deployment, instruments should be tested within a controlled environment to ensure they are operating properly. Pre-deployment testing will help to prevent on-site equipment issues following installation. Pre-deployment testing should follow the requirements specified in the manufacturer supplied equipment manuals.

4.1.1 Continuous Gas Analyzers

Pre-deployment testing should be conducted for a minimum duration of one week to verify the effectiveness of multi-point calibrations and zero spanning. Where applicable, conduct internal diagnostics checks in accordance with the instruments operational specifications. During the pre-deployment testing period, identify and compile an inventory list of auxiliary and ancillary equipment such as zero span gases, calibration gases, environmental enclosures, etc., that will be required for the monitoring station. Clear and unambiguous line tagging should be installed to help with station operation, particularly for monitoring stations equipped to monitor multiple parameters.

4.1.2 Particulate Matter Instruments

Prior to installation PM analyzers should undergo a full instrument calibration and verification of flow rate, temperature and pressure parameters. Continuous PM_{2.5} analyzers equipped with HEPA zero filters, should be operated over a one week period to determine instrument response.

4.2 Station Start-Up Records

A *Station Start-Up* record must be completed during the installation of each monitoring station. Start-up records should be maintained as part of the quality control process. A copy of the record should be forwarded to the B.C. ENV for reference. The station start-up record should be updated when significant changes to the station occur such as station relocation and instrument replacement.

In general station installation records should include the following information: Station operator information,

- Station Name
- Site Location with GPS Coordinates
- Date and time that data polling commenced
- A description of the surrounding environment
- Station equipment/instrumentation

A station start-up record template is provided in Appendix 1. Additional equipment-specific installation requirements are provided in SOPs located in the appendices section of this manual.

5 Routine Operations

5.1 Operational Plans

It is recommended that a *Station Operational Plan* or *Manual* be produced for each monitoring station. Station operational plans will provide auditors and new station operators with information pertaining to the characteristics of the monitoring station and any special functions or operating conditions of the station. The station operational plan and any checklists included within the plan will assist station operators in identifying the requirements of routine operations and the frequency of scheduled inspections and planned maintenance routines. The station operational plan can also act as a record of the routine inspections, maintenance activities, calibrations and repairs carried out at the station.

5.2 Inspections and Maintenance

The purpose of routine inspections is to check that monitoring equipment and associated environmental enclosures are operating and or functioning as designed. The frequency of routine inspections should be set to an interval that effectively mitigates the potential for data loss. The frequency of routine inspections will be a function of monitoring method/s, site constraints, and availability of remote diagnostic data.

Routine operation of a monitoring station's equipment is the responsibility of the monitoring station operator. In general a monitoring station's routine operations include:

- Scheduled and non-scheduled inspections,
- Preventative and planned maintenance,
- Scheduled calibrations, and;
- Repairs and calibration.

Preventative maintenance undertaken during routine inspections can assist in reducing missing data; will provide more confidence in the monitoring results produced by the station, and assist in identifying potential problems.

A general description of routine inspection and maintenance activities is provided in Table 5.1.1. Routine inspection and maintenance activities are divided into two categories: short term and long term. Short term checks can be undertaken weekly, every two-weeks, or monthly. Long term checks are conducted quarterly or semi-annually. Remote diagnostic testing and data analysis can be incorporated within the short term checks to assist in identifying potential

problems. Quarterly/semi-annual inspections and maintenance should be undertaken by field trained technicians.

Table 5.1.1: Routine Inspection/Maintenance Summary

Short term - Weekly, Bi-Weekly, Monthly	Long Term - Quarterly/Semi-Annual
<ol style="list-style-type: none"> 1. Check shelter integrity and security. 2. Check/test communications array. 3. Check/test Battery Backup system; clean filters as necessary. 4. Inspection of manifold apparatus and sample lines to the analyzers, clean if needed. 5. Check all equipment fans and filters. 6. Inspect equipment specific parameters (sample tape, inlet filter, water catch jars). 7. Inspect and replace drying equipment as necessary. 8. Check to ensure adequate supply of consumables (e.g., desiccant, filters, gloves, etc.). 9. As applicable, check station temperature is within designed operating range. 10. Review any instrument alarms, instrument issues and/or data issues identified since the last visit. 11. Verify that any maintenance undertaken on the last visit is still effective. 12. Check the fire extinguisher. 13. Verify instrument SOPs, manufacturer information and Routine operation plan/checklist is up-to-date. 14. Complete routine operation checklist 15. Check call down list; station documentation. 	<ol style="list-style-type: none"> 1. Review routine operation checklists since last visit, verify that checks are complete and follow up with appropriate actions. 2. Inventory of all equipment onsite, compare against previous visit and update accordingly; this includes manufacturer’s information and SOPs. 3. Carry out short term checks. 4. If applicable check zero air supply system for each analyzer and change/correct if necessary. 5. Perform multi-point verification checks if applicable. 6. Perform flow verification/calibration checks if applicable. 7. Check time stamps in the data and in all equipment data loggers. 8. Complete routine operation checklist. 9. Function checks for abnormal performance (excessive signal noise, unstable baseline, positive and/or negative drift, spiking, long response time, incorrect flow/pressure readings, warning light indicators and power or pump failure).

Details of routine inspections and maintenance must be recorded and maintained within the monitoring station. An *Inspection and Maintenance* template is provided in Appendix 1.

Additional operational requirements specific to monitoring methodologies are provided in Standard Operating Procedures (SOP) located in the appendices of this Manual.

5.3 Non-Conformance and Corrective Action

For the purposes of this Manual, a non-conformance is defined as “the failure of an output, product or process to conform to the standards or specifications detailed in the equipment manufacturers specifications or any part of the B.C. Field Sampling Manual”. If a problem or a non-conformance issue is identified during routine inspections, the details of the problem or non-conformance must be recorded. For each non-conformance issue or incident a root-cause analysis must be conducted to identify the source of the non-conformance. The information gleaned from the root-cause analysis must then be used to develop a corrective action plan. Root-cause analyses and corrective action plans should be commensurate with the non-conformance to avoid excessive and erroneous detail and resource expenditures. Details of both the root-cause analysis and the implementation of the corrective action must be recorded and maintained within the monitoring station (preferably within the *Station Operational Plan* or *Manual*). An electronic copy of the corrective action record must be sent to the B.C. ENV.

A *Non-Conformance and Corrective Action* template is provided in Appendix 1.

6 Gas Analyzer Calibrations and Verifications

6.1 General Descriptions

General descriptions of the various categories of calibration checks are described below. Specific calibration instructions are provided in instrumentation manuals and SOPs located in the appendices of this Manual.

Zero check: A zero check tests an instrument’s response to pollutant-free air at concentrations below detection limits. The zero check generally involves exposing the instrument to pollutant free air from either a zero air supply or a zero air system (i.e. a scrubber). The zero check is compared to the zero reference value established at the time of the multi-point check or calibration. If the zero value is outside of the tolerance level provided in Table 6.4.1, a zero adjustment must be performed.

Span check: A span check tests an instrument’s response to a known concentration of a pollutant. The span gas, which is used as a surrogate for the pollutant, should be at a concentration that is higher than expected monitoring values, and near the analyzer’s range. The span gas can be generated using a permeation device, a span gas supply or a high concentration gas with a dilution calibrator. The span check point is compared to a reference span value that is established at the time of a multi-point verification, calibration or when the span source is replaced. If the span is found to be outside of its tolerance level, which is provided in Table 6.4.1, an “as-found” multi-point verification should be carried-out. For significant span value

differences from reference span values a root-cause analysis and corrective action plan should be conducted.

Two-point check: The two-point check tests an instrument’s as found response at the 0% point and the 80% point of an instruments calibration range.

Multi-point linearity verification: The multi-point linearity check tests an instruments accuracy and linear response to air pollutants at regular concentration intervals to verify data prior to an instruments calibration. A multi-point verification is required prior to instrument calibration. The verification must include a pre-zero, post-zero, 100%, 60% and 30% concentration intervals.

Calibration: Calibrations are conducted to establish an instrument’s response to a known concentration. A calibration generally occurs when a multi-point check indicates that an instrument’s response is outside of defined tolerance levels or acceptance criteria. Calibrations include both a zero and a highpoint (upper calibration limit) adjustment. Calibrations should follow the instrument manufacturer’s instructions.

6.2 Calibration Frequency

The triggers for, and frequency of instrument checks and calibrations are summarized in Table 6.2.1. Note that the frequency of calibrations may be increased at the request of the B.C. ENV.

Table 6.2.1: Gas Analyzer Calibration Frequency and Triggers

Zero and Span Check	Two-Point Check	Multi-point Check	Calibration
<ul style="list-style-type: none"> ▪ Weekly minimum, Daily preferred (23 to 25 hours) 	<ul style="list-style-type: none"> ▪ Before analyzer repairs/maintenance that may affect instrument performance. 	<ul style="list-style-type: none"> ▪ After installation (or relocation); allow a 24 to 72 hour warm up period prior to, ▪ Bi-annually if zero and span checks are conducted daily, ▪ Quarterly if zero and span checks are conducted weekly, ▪ Before and after analyzer repairs/maintenance that may affect instrument performance, ▪ Prior to instrument calibration, ▪ Prior to instrument shut-down, ▪ When span drift exceeds 10%, ▪ For new analyzers, after the first 3 months of operation, and; ▪ When daily zero deviation is greater than $\pm 2\%$ of the range, and troubleshooting indicates that the analyzer is causing the deviation. 	<ul style="list-style-type: none"> ▪ Quarterly ▪ Failure of Span check ▪ Failure of multi-point check

6.3 Zero and Span Checks

Continuous monitoring instruments must perform daily zero and span checks (once per 24 hour period). Preferable cycle times are 23 hour or 25 hour to ensure that hourly specific events are captured. Alternate zero and span check cycles are approved on a case by case basis by the B.C. ENV.

Manual quality control assessments and corrections must be completed before the monitoring data is submitted as *validated data*. Data corrections for significant zero and span drifts that occur between zero and span tests do not need to occur in real time. Data corrections can be applied during routine data reviews, such as those following a full month of monitoring. If zero and span checks are controlled automatically, the data can be corrected at near real-time; however, until the corrections are applied the data must be identified as *preliminary*.

Zero checks need to be recorded and logged, either electronically or within log books, each time a check is performed. If zero checks indicate a consistent drift in one direction, an investigation must be launched to identify the reason for the drift. Routine reviews of drift charts will help identify equipment drifts. During operation, the zero response from the zero and span test should not exceed 2% of the analyzer's range. Should an exceedance occur, data tracing back to the last compliant *zero* check (resulting from zero, span or calibration) must be flagged until it can be appropriately evaluated for validity. Similarly, data generated following a failing zero test must also be flagged and evaluated.

If a monitoring station's zero-air-supply relies on equipment with consumables such as filters and scrubbers, the station operator should regularly confirm that the zero air supply is operating as expected. To validate the zero air supply, the zero air supply can be connected directly to the sampling port to assess the difference in the instruments response.

For monitors and software with the capability of performing automatic zero checks and zero resets, the 'zeroing frequency' should be set to 6 hours although a zeroing frequency of 24 hours is allowed. Generally a typical zero span takes 30 minutes to complete; 20 minutes to stabilize the zero reading and 10 minutes exposure of the stable reading. If possible the instruments zero point value should be recorded prior to the zero check and again after the zero check. If the equipment is not capable of recording both zero points, operator initiated zero checks should be undertaken to ensure that the zero check values are close to zero. As an example, following calibration a zero and span test can be run to establish new span values, and the internal zero point can be compared to the calibrated zero point to ensure the analyzer zero system is operating properly.

Span checks should be conducted after zero checks. Span concentrations are assessed against the most recently established control values which are established during the most recent multi-point verification. Trends and sudden shifts in an analyzer's zero and span response should be investigated prior to a span response exceedance of 10% of a control value. In cases where this exceedance does occur, data tracing back to the last compliant span response (resulting from zero, span or calibration) must be flagged until it can be validated. Data following a failed span response must be similarly flagged.

Zero and Span check control charts should be maintained to log weekly analyzer drift. The control charts will allow operators to monitor the analyzers performance. An audit of an analyzer's response using a certified calibration standard and a zero air generator is the only way to confirm that routine zero and span tests are tracking the actual drift in an analyser's response when compared to the previous calibrated response. True percent deviation can be established by comparing the upscale as-found calibration point response to the last calibration upscale point. In the circumstance where deviation exceeds 4%, recalibration is recommended; if deviation exceeds 10% recalibration is mandatory. In the circumstance of a 10% exceedance, all data generated after the most recently recorded compliant deviation is invalid. Data generated for the NAPS program is acceptable with deviations up to $\pm 15\%$.

6.4 Two-point check

A two-point check must be conducted prior to analyzer maintenance and repairs to ensure the integrity of the data generated since the instruments last valid data check/calibration. This can often be achieved by conducting a two-point check which tests the zero and the upper reading (80% of operating range) of the instrument.

If a two-point check indicates that an instrument is operating outside of the tolerance level or acceptance criteria listed in Table 6.4.1, the instrument should be calibrated following the instructions provided in the manufacturer supplied operating manual.

Table 6.4.1: Gas Analyzer Tolerance Levels and Acceptance Criteria

Analyzer	QC Check	Tolerance Levels	Acceptance Criteria
CO	Zero Check	± 0.1 ppm	$\leq \pm 2\%$ of range
	Span Check	10% of reference value	$\leq \pm 10\%$ of control value
	Multi-point Check (each upscale point)	$> \pm 4\%$	$\leq \pm 15\%$
	Point error (% difference)	$> \pm 4\%$	$\leq \pm 10\%$

SO₂	Zero Check	± 1.0 ppb	≤ ± 2% of range
	Span Check	10% of reference value	≤ ± 10% of control value
	Linearity Check	N/A	≤ ± 10%
	Point error (% difference)	> ± 4%	≤ ± 10%
NO_x	Zero Check	± 2.0 ppb	≤ ± 2%
	Span Check	10% of reference value	≤ ± 10% of control value
	Multi-point Check	> ± 4%	≤ ± 15%
	Multi-point Check (each upscale point)	> ± 4%	≤ ± 10%
O₃	Zero Check	± 2.0 ppb	≤ ± 1.5% of range
	Span Check	10% of reference value	N/A
	Point Error (% difference)	N/A	≤ ± 7%
H₂S/TRS	Zero Check	N/A	≤ ± 2% of range
	Span Check	N/A	≤ ± 10% of control value
	Multi-point Check	N/A	Within ± 10% of the least squares regression slope

6.5 Multi-point Checks/Calibration

Analyzer calibrations must include a zero adjustment and an upscale adjustment at the calibration range of the analyzer. A checklist outlining the general process for calibrating continuous gas monitors is provided in Appendix 1 of this Manual.

Requirements and specifications for zero and span gas air supplies and gas regulators are summarized in Table 6.5.1 below.

Table 6.5.1: Zero Air and Span Gas Supply and Regulator Requirements

Component & Aspect		CO	O ₃	SO ₂	NO ₂
Zero Air	Minimum Flow	10	10	10	10

Component & Aspect		CO	O ₃	SO ₂	NO ₂
Supply	Rate (L/min)				
	Pressure (psig)	20	20	20	20
	Particulate filter efficiency	99%	99%	99%	99%
Gas Regulator	Material	Brass or stainless steel	Stainless steel or Teflon	Stainless steel	Stainless steel
	Model	Two-state design with non-reactive diaphragm and internal parts		Two-state design with non-reactive diaphragm and internal parts	Two-state design with non-reactive diaphragm and internal parts
Span Gas	Mixture	CO in Nitrogen	Ozone generator	SO ₂ in nitrogen or Permeation tubes	NO in nitrogen or Permeation tubes
	Concentration range	60 – 80%		60 – 80%	60 – 80%

6.6 Parameter Specific Calibration Requirements

The following sub-sections provide additional information regarding gas specific calibration requirements.

6.6.1 Hydrogen Sulphide & Total Reduced Sulphur

This sub-section of the Manual provides calibration information that is specific to analyzers of hydrogen sulphide (H₂S) and total reduced sulphur (TRS).

- H₂S/TRS analyzers can be calibrated using either the dilution or permeation method.
- The analyzer is adjusted for zero reading and for a reading of 1:1 at the highest scale point in the calibration.

6.6.2 Oxides of Nitrogen (NO_x)

For NO_x analyzer calibrations, the NO calibration regulator must be purged to remove all oxygen (O₂). The presence of O₂ results in the formation of NO₂, which produces a biased (increased) value.

6.6.3 Gas Phase Titration (GPT)

After NO and NO_x calibrations, a gas phase titration (GPT) of NO with ozone is employed to calibrate the analyzer for NO₂ and to determine converter efficiency. A brief outline of how to determine converter efficiency is provided below.

1. Generate a NO concentration at approximately 50% of full range for at least 10 minutes.
2. Generate O₃ at an approximate concentration of 50% of the NO concentration and wait until a stabilized reading has been achieved.
3. The converter loss is then calculated as follows:

$$\text{Converter Efficiency} = 100 \times \frac{[(\text{final NO} - \text{initial NO}) - (\text{final NO}_x - \text{initial NO}_x)]}{(\text{final NO} - \text{initial NO})}$$

Replacement of the converter may be required if the calculated converter efficiency is outside of the 96 to 104% range.

4. Generate at least one additional NO₂ audit point at a lower concentration.
5. Perform a zero and span check immediately following calibration.
6. Determine if span gas cylinders/permeation wafers need to be replaced based on the results of zero and span checks.

6.6.4 Ozone (O₃)

Ozone (O₃) analyzers must be calibrated using a calibrator with a UV photometer.

6.6.5 Sulphur dioxide (SO₂)

When conducting an SO₂ analyzer calibration, it is critically important to purge the SO₂ calibration regulator to remove all traces of H₂O, as even small amounts of H₂O will lead to stability problems. If the cylinder is suspected of containing moisture, the cylinder should be deemed as compromised and unusable.

6.6.6 Ammonia (NH₃)

Ammonia analyzers require a 3-stage calibration, which is unique among gas analyzers. The first stage of the calibration is typical of other continuous gas analyzer types and involves a serial dilution of a NO standard to verify analyzer NO and NO_x response.

In the second calibration stage, the analyzer's NO₂ response is verified by gas phase titration. This involves titrating the NO standard used in the first stage with a known concentration of ozone. The introduced ozone converts the equivalent amount of NO into NO₂, which is

converted back into NO by the analyzer's converter oven and read as NO_x. To verify the linearity of the analyzer two levels of ozone are generated and calibrated in the gas phase titration. As the NO and NO_x channels were calibrated and verified in the first stage, the analyzer's response to the remaining NO, not converted by ozone, can be accepted as accurate. Comparison of the introduced ozone concentration with the analyzer's NO_x and NO response therefore allows for a determination of converter efficiency, and verification of the NO₂ channel.

In the third and final stage, a known concentration of NH₃ is used to verify the catalytic conversion process of the analyzer. Similar to the second stage of calibration, four different levels of NH₃ are generated to verify the linearity of the analyzer.

6.6.7 BTEX

To calibrate the gas chromatograph (GC) a BTEX calibration mixture is needed as well as zero air. The calibration is undertaken to determine the conversion factor that is used to calculate concentrations of BTEX compounds from the GC outputs. The calibration is undertaken in two sequential stages:

- 1) Measurement of calibration gas diluted to the desired concentrations
- 2) Determination of the conversion factor

6.6.8 Methane/Non Methane Hydrocarbons

Calibration is undertaken to establish the relationship between the detectors output signal and the compound being measured. The detector's output signal can be affected by a number of different operational parameters, and as such requires calibration on a regular basis. If possible, a calibration gas standard with a similar composition to that expected in the actual sample should be used.

6.6.9 Calibration Gas Standards

Analyzers must be calibrated using certified calibration mixtures. For conventional analyzers, the mixtures should be certified to $\pm 2\%$ accuracy by direct comparison to a Standard Reference Material (SRM) provided by organizations such as the Netherland's National Metrology Institute (VSL) and the U.S. National Institute of Standards and Technology (NIST). For trace level analyzers, the mixtures should be certified to $\pm 2\%$ accuracy by comparison to a certified traceable reference standard.

All calibration standards must be verified against traceable standards every two years and at any time when there is found to be a significant discrepancy between station or operator equipment and audit standards.

In addition to gases, dilution calibrators and flow meters should undergo third party calibration annually.

6.7 Method Specific Calibration Requirements

6.7.1 PM_{2.5} Continuous Monitors and Filter Based PM Samplers

For continuous PM_{2.5} monitors and filter based PM samplers, several parameters require calibration including flow, temperature, ambient pressure, time and date. In addition, relative humidity requires calibration on continuous PM_{2.5} monitors. In general the calibration procedure comprises the following sequential steps:

- Step 1 – Verification (as-is calibration) of flow, temperature and pressure
- Step 2 – Leak checks
- Step 3 – Adjustments (multi-point)
- Step 4 – Verification (final calibration)

The first step in the calibration process (Step 1 verification) is used to validate samples obtained since the instruments last calibration by verifying that flow, temperature and pressure are still within acceptable tolerance levels. The verification step comprises checks against known standards. The flow verification check should be performed using a flow meter which has been calibrated or certified annually against a National Institute of Standards and Technology (NIST) traceable standard. Similarly, temperature and pressure verifications should be performed using a temperature and pressure standard which is calibrated or certified annually against a NIST traceable standard.

In Step 2 a leak check is undertaken to ensure there are no leaks in the sample train before conducting the calibration. If leaks are detected during this step they must be addressed, and the flow re-verified as in Step 1.

Tolerance levels (or ‘pass criteria’) for low flow rate and high volume samplers assessed in Steps 1 and 2 are provided in the following table.

Table 6.7.1: PM_{2.5} Continuous Monitors and Filter Based PM Sampler Tolerance Levels

Parameter	Low Flow Rate Sampler	High Volume Sampler	Continuous PM _{2.5} and Integrated PM
Flow	±4% of 16.7 lpm (16.00 to 17.34 lpm)	Between 1.13 to 1.70 m ³ /min with a correlation coefficient of 0.990 or better.	±4% of 16.7 lpm (16.00 to 17.34 lpm)

Parameter	Low Flow Rate Sampler	High Volume Sampler	Continuous PM _{2.5} and Integrated PM
Temperature	±2 °C	As per instrument manual.	±2 °C
Ambient pressure	±10 mmHg	As per instrument manual.	±10 mmHg
Relative Humidity	N/A	N/A	±10%
Clock and date verification check	Clock should be within ±2 minutes of standard time, and the date should be correct.		
Internal Leak check	Leak rate should not exceed 140mm Hg/minute	As per instrument manual. No air leakage detected by operator	As per instrument manual.
External Leak check	Leak rate should not exceed 25mm Hg/minute	N/A	N/A

Parameters that do not meet the pass criteria specified in Table 6.7.1 above must be adjusted in Step 3. After adjustment a final verification (Step 4) is undertaken to confirm that the instruments parameters are within the required criteria.

If the verification undertaken in Step 1 exceeds the acceptance criteria provided in Table 6.7.2 below, data obtained during the period since the instruments last successful calibration must be invalidated.

Table 6.7.2: PM_{2.5} Continuous Monitors and Filter Based PM Sampler Acceptance Criteria

Parameter	Low Flow Rate Sampler	High Volume Sampler	Continuous PM _{2.5} and Integrated PM
Flow	±7%	±7%	±7%
Leak check	As per instrument manual.	As per instrument manual.	As per instrument manual.

6.8 Documentation

The minimum documentation required for the checks and calibrations discussed in this section are summarized in Table 6.8.1. Note that other documents such as permits may have additional documentation requirements. Templates for these and other records required for ambient air monitoring are provided in Appendix 1.

Table 6.8.1: Calibration Documentation

Zero check and Span Gases	Multi-point check	Calibration
<ul style="list-style-type: none"> ▪ Record in logbook ▪ Use routine maintenance record 	<ul style="list-style-type: none"> ▪ Record in logbook ▪ Complete routine maintenance record 	<ul style="list-style-type: none"> ▪ Record in logbook ▪ Complete gas calibration activity record

6.9 Measurement Uncertainty

The determination of measurement uncertainty in continuous air monitoring data is a function of many factors. During an instrument’s calibration, there are uncertainties associated with instrument precision, calibration standards, and accuracy of the dilution process.

Instrument manufacturers specify instrument precision by various methods; typically, however, precision is specified as a value or as a percentage of an instruments reading. Regardless of the method used to specify precision, calibration standards and the accuracy of the dilution process play a much larger role in determining an instrument’s measurement accuracy and precision. The accuracy of the calibration gas and calibrator (dilution process) are certified against a respective standard.

Immediately following calibration, the linearity of the calibration will assist in estimating instrument uncertainty. Linearity specifications are often provided by the manufacturer as a percentage value of the calibration range. Pending any future, formal statistical calculation of uncertainty, concentrations of the target pollutant following calibration should not exceed 5% of the calibrated range. The measured uncertainty is expected to grow over time due to uncorrected drifts (span drifts) and or maintenance issues.

Another factor of measurement uncertainty stems from the variation of an instruments performance over time. This uncertainty can be measured by undertaking a statistical analysis of the instruments zero and span check data. The uncertainty caused by instrument performance over time, is necessarily, calculated after the fact. The detailed statistical determination of an instrument’s performance is beyond the scope of this manual, however, method details are available in various documents such as ISO Standards, the US EPA 2013 QA Handbook for Pollution Measurement Systems, and Chapter 5 of the Alberta Government’s 2014 Air Monitoring Directive.

Currently there is no requirement to determine or estimate measurement uncertainty for operators of Ambient Air Monitoring stations in the ENV’s jurisdiction.

7 Data Collection and Validation – Continuous Data

7.1 Data Collection and Management

Data generated by Ambient Air Monitoring stations is collected and stored on Data Acquisition Systems (DAS) or “dataloggers”. Data can be accessed from the data logger by manually connecting to the data logger, or via commercially available hardware and software packages using devices such as a telephone and modem, internet access, or satellite telemetry.

Data output options can be analog or digital. Digital data acquisition methods and instrumentation are subject to less noise which allows for greater sensitivity than analog systems. In addition digital systems are capable of handling greater volumes of metadata. Based on these two advantages digital systems are typically the preferred method of data collection and storage.

Data should be stored with a minimum of 1-hour and 1-minute averaging periods. The 1-hour averaging period is required for reporting purposes; the 1-minute averaging period facilitates the validation process. Data loggers averaging 60 minute time intervals or greater should be configured to capture a minimum of 75% of the data from the shorter time interval. As an example, during a 60 minute time interval at least 45 minutes of 1-minute data is required.

Data should be reported to the ending hour (i.e. 8:00 covers data from 7:01 to 8:00).

7.2 Data Validation Process

The data validation process involves actions and decisions which result in the transition of the *as-collected* data to a final dataset with an established level of data validity. Data validation is a progressive four step process which begins with preliminary verification activities at level 0 and concludes with an independent data review at level 3. Data validation responsibilities for the monitoring station’s operator and field trained technician are limited to Level 0.

The data validation process prescribed for operators of ambient air monitoring stations within the B.C. ENV’s jurisdiction is generally consistent with that undertaken in the NAPS program, although recommendations specific to monitoring data collected within the ENV’s jurisdiction do exist.

An overview of the validation process is shown in Figure 7.2.1. The validation process including frequency, and data review intervals is summarized in Table 7.2.2.

Figure 7.2.1: Overview of Data Validation Process

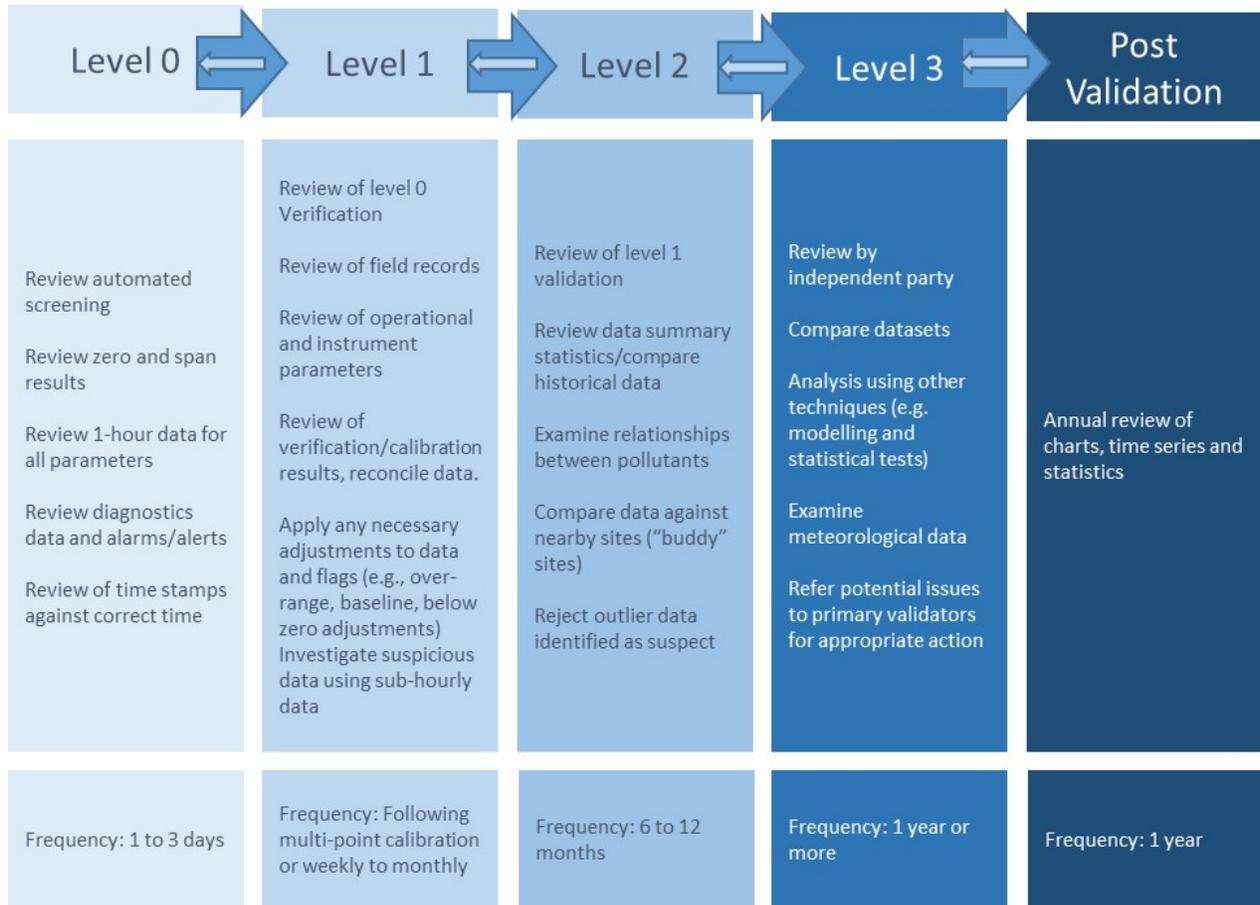


Table 7.2.2. Summary of Data Validation Requirements

Process Level	Level 0	Level 1	Level 2	Level 3
Data Description	Raw data	Level 0 Validated Data	Level 1 Validated Data	Level 2 Validated Data
Frequency	1 to 7 days (1 to 3 days preferred)	Following multi-point calibration Weekly or monthly	6 to 12 months	Annual
Period of Data Reviewed	1 to 6 days	1 to 6 months	6 to 12 months	1 or more years
Summary of Requirements	<p>Review automated screening</p> <p>Review zero and span results</p> <p>Review 1-hour data</p>	<p>Review of level 0 Validation</p> <p>Review of field records</p> <p>Review of operational</p>	<p>Review of level 1 Validation</p> <p>Review data summary statistics/compare historical data</p>	<p>Independent review</p> <p>Compare datasets</p> <p>Analysis using other techniques (e.g. modelling and</p>

Process Level	Level 0	Level 1	Level 2	Level 3
	for all parameters Review diagnostics data and alarms/alerts Review of time stamps against correct time	and instrument parameters Review of verification/calibration results, reconcile data Apply necessary adjustments to data and flags (e.g., over-range, baseline, below zero adjustments) Investigate suspicious data using sub-hourly data	Examine relationships between monitoring parameters Compare data against nearby sites Reject outlier data identified as suspect	statistical tests) Examine meteorological data Refer potential issues to primary validators for appropriate action

7.3 Data Flags & Logs

Data flags are typically used at all data validation levels to identify individual data points as valid or invalid. Codes should be established to define the meaning of the data flags. Flags are used to identify aspects and events such as calibration, instrument failure, zero span, maintenance, recovery and power failures. Codes should be established prior to the data validation process and documented in the data validation records/logs. Ambient air monitoring station operators must maintain *Data validation records/logs*. Data validation records summarize data flagging activities and record the justification for the data flags. The data validation record provides evidence of the validation process which must be available for audit and investigation purposes. Data flags can be applied automatically, however, data should be reviewed manually to verify each flag. Records of manual and automatic data edits or adjustments contained within the validation logs provide an audit trail between the as-collected data and the final dataset.

Validation logs should include, at minimum, the following information:

- Name of the person who performed the validation action,
- Date of validation action was completed,
- Monitoring Parameter(s) affected,
- Description of any data adjustments and/or flag modifications,
- Brief description of any actions performed to address monitoring system/data issues,
- Identification of the validity of anomalous data or outliers, and;

- Justification for changes made after validation has been completed.

Monitoring data that has been invalidated through the validation process should be reported as a blank value. Note this is different from other jurisdictions such as NAPS which report invalid data as -9999.

7.4 Level 0 - Preliminary Validation

A Level 0 validation process usually involves both automatic and manual data screening and subsequent flagging. However, in some instances the level 0 validation process may be entirely automated. Recommended level 0 data validation activities are provided in the following table.

Table 7.4.1: Level 0 Verification Checklist

Check #	Activity	Comment
Automatic Checks		
1	Identify periods of missing data.	Could be due to power/instrument/communication failure.
2	Identify data outside of instrument's monitoring range or expected range.	Outside of instrument operating range, negative values, or outside of an established historical expected range.
3	Review rate of change to assess if data changes too rapidly, or not at all.	Can be compared to predefined rate of change thresholds.
Manual Checks		
4	Review of 1-hour data for all parameters.	View in tables and graphs.
5	Review of 1-hour data for completeness and instrument performance.	
6	Review of automated screening flags.	(Typically checks #1-3 above), instrument diagnostics and alarms.
7	Verification that zero and span are within specifications.	
8	Verification of time stamps against correct time.	

Data that has been flagged for exclusion should be investigated. Investigations will assist in identifying the root cause of flagged data and help develop corrective actions where applicable. Corrective actions should be implemented as soon as possible to minimize data loss. Corrective actions must be recorded in the *validation log*.

7.5 Level 1 - Primary Validation

Level 1 validation generally occurs between consecutive multi-point verifications, at an interval of 1 to 6 months, and after any instrument repairs or adjustments. Level 1 validation activities build on the data screening and flagging conducted during the Level 0 validation process. Level 1 validation

activities provide a more thorough evaluation of available information and documentation. During Level 1 validation data should be flagged, issues identified and corrective actions undertaken. Recommended level 1 data validation activities are provided in the following table.

Table 7.5.1: Level 1 Validation Checklist

Check #	Activity
1	<p>Review of field records that were not available at the time of the level 0 checks. Review to identify issues or incidents with the potential to affect data quality. This information may be recorded in station logs, instrument maintenance records, multi-point verification and calibration records.</p>
2	<p>Review of operation and instrument parameters The review considers any instrument specific limitations that may invalidate data. These limitations may be specified by the manufacturer or in SOPs. Examples include leak checks and environmental temperature and pressure controls.</p>
3	<p>Review of multi-point verification results Compare zero and span check results with the multi-point verification results for consistency. If results are inconsistent determines, if the data has been invalidated or flagged than adjust the data based on the multi-point verification.</p> <p>If the multi-point verification results are outside of the B.C. ENV acceptance criteria provided in Table 6.4.1, the data should be invalidated to the most recent point in time where the data has been verified as valid. If this action is not taken a sound justification must be developed and recorded. Where data has been invalidated, corrective actions should be developed and implemented. Corrective actions should specify a timeline to minimize data loss and identify the qualified person charged with implementing the corrective action.</p>
4	<p>Review of over-range values There may be circumstances where an instrument monitors an unusually high reading. Where the high reading is triggered by a real event such as widespread woodstove use during a period of cold weather it is termed as an over-range value. Over-range data points should be preserved in the dataset and flagged as reading(s) that are attributable to a direct event. Over-range flags that are kept should be noted in the validation log.</p>
5	<p>Review of automatic zero adjustments If automatic zero adjustments are made automatically by an instrument, the adjustments should be reviewed manually to verify that zero equipment is functioning as required.</p>

Check #	Activity											
6	<p>Baseline adjustments Drift in the zero is typical in most instruments. Instrument drift can be identified by reviewing zero checks using graphs and tables, and confirmed during the multi-point verification or by checking for a depletion of zero air consumables. Baseline drifts correction of data should be undertaken if tolerance levels provided in the following table are exceeded.</p> <table border="1"> <thead> <tr> <th>Pollutant</th> <th>Zero Point Tolerance</th> </tr> </thead> <tbody> <tr> <td>CO</td> <td>0.08 ppm</td> </tr> <tr> <td>O₃</td> <td>1.0 ppb</td> </tr> <tr> <td>NO_x</td> <td>1.0 ppb</td> </tr> <tr> <td>SO₂</td> <td>0.5 ppb</td> </tr> </tbody> </table> <p>Zero checks should be evaluated individually if they are used in data adjustment. The following points highlight additional considerations for corrections of drift:</p> <ul style="list-style-type: none"> ▪ Excessive correction to hourly data increases uncertainty in short-term monitored data, although long term (annual) averages may be reasonably accurate. ▪ Frequent adjustment of the instrument zero results in higher data uncertainty and possible data invalidation. ▪ A rapid or excessive change in zero signals an instrument malfunction and possible data invalidation; not instrument drift which would be seen over days to weeks. ▪ Corrections due to drifts in span results are not recommended by B.C. ENV and are not allowed by NAPS. <p>Baseline adjustments are made to the data by either: 1) adjusting the data by the verified drift amount and applying that adjustment to all data during the period between consecutive compliant zero checks; or 2) interpolating zero adjustments between consecutive zero checks to gradually adjust the baseline.</p>	Pollutant	Zero Point Tolerance	CO	0.08 ppm	O ₃	1.0 ppb	NO _x	1.0 ppb	SO ₂	0.5 ppb	
Pollutant	Zero Point Tolerance											
CO	0.08 ppm											
O ₃	1.0 ppb											
NO _x	1.0 ppb											
SO ₂	0.5 ppb											
7	<p>Below zero adjustments Instruments are subject to zero noise, which is a measure of the deviations from zero while sampling zero air.</p> <p>Care should be taken to distinguish zero noise data from operational issues, since operational issue data should be invalidated. Zero noise corrections should be made on valid hourly data where readings less than zero should be adjusted to zero. The following table summarizes the zero adjustment criteria.</p> <table border="1"> <thead> <tr> <th>Averaging Interval</th> <th>Parameter</th> <th>Validation Criteria</th> </tr> </thead> <tbody> <tr> <td>Sub Hourly</td> <td>All parameters</td> <td>All negative values determined valid shall remain negative prior to aggregation into hourly averages</td> </tr> <tr> <td rowspan="2">1-hour</td> <td>PM_{2.5} (ug/m³)</td> <td>PM_{2.5} value ≥ -3 and < 0 adjusted to 0 PM_{2.5} value < -3 are flagged as invalid</td> </tr> <tr> <td>All gases</td> <td>Below zero values determined valid are adjusted to zero (values < -3 should be further investigated prior to setting to zero)</td> </tr> </tbody> </table>	Averaging Interval	Parameter	Validation Criteria	Sub Hourly	All parameters	All negative values determined valid shall remain negative prior to aggregation into hourly averages	1-hour	PM _{2.5} (ug/m ³)	PM _{2.5} value ≥ -3 and < 0 adjusted to 0 PM _{2.5} value < -3 are flagged as invalid	All gases	Below zero values determined valid are adjusted to zero (values < -3 should be further investigated prior to setting to zero)
Averaging Interval	Parameter	Validation Criteria										
Sub Hourly	All parameters	All negative values determined valid shall remain negative prior to aggregation into hourly averages										
1-hour	PM _{2.5} (ug/m ³)	PM _{2.5} value ≥ -3 and < 0 adjusted to 0 PM _{2.5} value < -3 are flagged as invalid										
	All gases	Below zero values determined valid are adjusted to zero (values < -3 should be further investigated prior to setting to zero)										
8												

Check #	Activity
	<p>Derived parameter relationships Some instruments do not directly measure a substance, rather the measurement is based on an established relationship. During validation, checks are made to ensure the relationship is preserved during the monitoring period.</p> <p>For example NO₂ is typically not a direct measurement of NO₂, rather it is calculated as the difference between NO_x and NO in the sample. If adjustments are made to NO, NO_x or NO₂ it may be necessary to apply these adjustments to all parameters to preserve the relationship. Since NO and NO_x are often not measured simultaneously a tolerance level of ±2 ppb difference is allowed for the summation of the three compounds.</p>

7.6 Level 2 - Final Validation

Level 2 validation, which is performed every 6 to 12 months, reviews the past 6 to 12 months' worth of hourly data. The objectives of the Level 2 validation are to:

- Verify zero inconsistencies between related data, measured at the station,
- Verify zero inconsistencies between regional data (if applicable), and;
- Provide contextualization of monitoring data to time and place.

All suspect data should be investigated. Investigation can include reviewing level 1 checks and supporting documentation to ensure any flags and adjustments are applied correctly. Additionally investigations may result in the identification of missed data that should be flagged and invalidated due to instrument malfunction or other issues. Recommended level 2 data validation activities are provided in the following table.

Table 7.6.1: Level 2 Validation Checklist

Check #	Activity
1	<p>Data summaries and statistics Plot data summaries and statistical analysis to assist in identifying outliers.</p>
2	<p>Meteorological data Review relevant meteorological data using wind rose and pollutant roses to assist in identifying anomalous data.</p>
3	<p>Data time series plots Plot multiple station parameters together if available to identify relationships/trends are as expected, for example O₃ and NO₂ are often inversely correlated. This may include plotting diurnal trends. For example in urban areas concentrations of NO₂ would be expected to correlate to times of peak traffic. O₃ typically exhibits a diurnal and seasonal trend</p>

Check #	Activity
4	<p>Independent Data Compare station data to data from nearby monitoring stations to assess the validity of suspect data. For example large pollutant events that would have regional air quality effects would likely be evident in the data from a number of monitoring stations.</p>

Data should be considered valid even if it is inconsistent with dependant (related) and intendant data or even if it is not representative of the time or place monitored, unless there is compelling evidence for its exclusion. Justifications for inclusion or exclusion of outlier or anomalous data validity should be documented in the validation log.

7.7 Level 3 - Independent Data Review

The level 3 independent data review is not meant to replicate or replace Level 1 or Level 2 reviews. The level 3 review should be undertaken by an individual independent from the field operator and previous validator. The reviewer should be a suitably qualified person whose knowledge of air pollutants and meteorological and basic site conditions will help ensure that the data is subjected to a robust and dependable level of review.

A level 3 review is generally performed annually on a full years-worth of data. The review focuses on the identification and assessment of trends that would most likely not be apparent in the shorter (e.g. monthly) data. In addition to trend analysis of data, the review should include comparisons to regional and other relevant datasets. Suspect data should be flagged and the previous reviewers and validators of that data should be notified. Appropriate investigations and modification should be undertaken and justifications noted and logged.

7.8 Post Validation

Despite the best efforts of station operators, reviewers and independent validators, errors and omissions may still exist in the validated data.

Charts, time series, and annual statistics (minimum and maximum) should be reviewed annually, as a minimum. If errors and omissions are identified or suspected the data review periods may be re-evaluated. If changes are required the edited data should undergo re-submittal and re-validation.

8 Data Collection and Validation – Non-Continuous/Sampler

Air monitoring measurements by non-continuous or sampler collection methods typically involve a specific method of sample collection which typically require subsequent laboratory analysis to complete the measurement. This process includes methods such as passive sampling, low flow rate sampling and high volume sampling. The data validation function for these sampling methods is performed by the laboratory, and is therefore not covered in detail in this document. However there are some important data validation aspects that must be considered and addressed at the sample collection stage. In addition to the information provided in the following two subsections, detailed information on sample collection is provided in method-specific SOPs located in the appendices section of this Manual.

8.1 Preparatory Considerations

Prior to the data collection stage, a laboratory will typically be involved in the preparation/preconditioning of the sample media such as filters, cartridges or passive sampler cartridges. As a best practice, sample media should be used within 30 days of conditioning by the laboratory. The appropriate sample media should be selected in consideration of the monitoring objectives and the subsequent laboratory analysis required. For example, if metals analysis of a filter is required then this may require a different sample media to be used. Samples are transported to the sampling location, installed, left for the sampling period and then retrieved and transported back to the laboratory for analysis.

During the data collection period, the following information should be recorded as a minimum:

- Monitoring location/ID
- Date/time of sample installation and retrieval
- Sample ID
- Sample media ID
- Sample type (field blank, travel blank, duplicate/s)
- Complete chain of custody and any other documentation required by the laboratory
- Other operational parameters specific to a sample collection method (see method specific SOP within the appendices for more information)
- Information on sample validity, for example:
 - Sample media damage
 - Note if sample tempering is suspected
 - Sampler equipment errors/malfunctions
 - Unusual weather conditions

- Potential interference during sampling (e.g. vegetation clearing activities occurred during the sampling period)

During the data collection period, appropriate laboratory blanks should be used. A minimum of one blank sample media should be used for every media shipment. The blank should be returned to the laboratory with the same batch of sample media it was received with. It is recommended that the number of blanks required be determined in consultation with the analysing laboratory.

Sample media should be retrieved and shipped to the laboratory as soon as practical following the sampling period. Some sampling methods provide recommended retrieval times (e.g.: within 5 days) and maximum handling times depending on the required laboratory analysis.

8.2 High Volume Sampling

Detailed data collection information for high volume samplers is provided in SOP-08 located in the appendices section of this Manual. This section of the Manual provides additional information on the use of high volume sampling to collect data to assess chronic hazards associated with the presence of trace metals in particulate matter.

8.2.1 Background

Requirements of the High Volume sampling method include:

- The analysis of 5 blank filters prior to the use/implementation of new filter types.
- A trip blank must be provided for every 5 samples collected.
- High Volume samplers must draw a sample over a full 7 day period per filter, and the 7 day sampling intervals must be contiguous (one interval following immediately after another) over the course of a full year.
- The sampling site must meet Ministry standards for particulate sampling.
- Analytical reports must include QA/QC data and information for all reported parameters.

These requirements maximize the amount of information obtained from the sampling equipment and laboratory methodologies. Information produced by this method facilitates a calculation of chronic exposure hazards with the greatest accuracy and reliability without significantly increasing the costs of sample collection and analysis.

An assessment of the chronic impact of trace metals involves calculating the average metal concentration found in a sequence of samples. The high volume sampling method involves drawing particulate onto a filter. Laboratory analysis of the sample will determine the

combination of metals in the sample and metals in the filter.

In calculating an averaged ambient metal concentration, the averaged metal content of the filters must be subtracted from the averaged total (sample and filter) of the metal measured. The greatest source of uncertainty in calculating ambient metals concentrations is generally due to the variability in the metal composition of the filter.

8.2.2 Quality Control

Because metals are often present in concentrations which border on the threshold of detection:

- ✓ A proper understanding of the uncertainties and statistical distribution of the amounts of metals in the analyzed sample (filter plus collected particulate) is required, as is;
- ✓ A proper understanding of the uncertainties and statistical distribution of the amounts of metals in blank filters.

Under no circumstance should data be censored at a detection limit as this destroys the statistical profile.

Analytical reports provided from laboratories must include quality control information. Quality control information is used to separate bias and precision from overall uncertainties so that averaged quantities can be accorded an appropriate uncertainty. This also allows for the incorporation of information obtained from a variety of analytic sources (laboratories) and methodologies, into a statistical analysis, adjusting for bias and precision as required.

To mitigate the costs associated with quality control, samples can be processed in batches. However, to build a base of quality control information, a given batch should not contain more than 5 samples.

As quality control reference samples, containing known concentrations of metals, which match those found in a typical field sample become available, at least one reference sample must be included with every sample batch analyzed.

Because of the volume of information, all data from the laboratory analysis must be available electronically in a form that can be easily incorporated into Ministry databases. Laboratories that seek to provide analytical services must receive approval from the Ministry for data delivery formats prior to submission.

8.2.3 Analysis of Blank Filters

A statistical base of information must be generated for every filter type used in the collection of

ambient metals samples. This can be accomplished whenever a new filter type is introduced by having the lab provide an analysis of the metallic composition of 5 filters prior to circulation and use. At present, only the Pallflex Teflon TX40HI20WW has been approved for metals analysis sampling. Other filter types must receive approval from the Ministry before being used.

The contamination associated with the field analysis can be determined by analyzing trip blanks. A trip blank is a blank filter that is delivered to the field site, placed on the high volume sampler, removed immediately without activating the sampler, and then repackaged and shipped to the lab for analysis. To develop a base of information, trip blanks must accompany every 5 samples collected in the field. This will allow tracking of contamination and variations between filter batches.

Should a significant trend be noted in the trip blanks it may be necessary to re-analyze a sequence of blanks (not trip blanks). This step is taken to ensure that the filter composition has not shifted. If, after this step, it is determined that the composition of the filter has not changed, the sampling methodology should be re-examined to ensure that contamination is being minimized.

8.2.4 Sampling

The uncertainty introduced by the metal composition of a filter can be reduced if the amount of sample per filter is increased. This can be accomplished by running the high volume sampler for a period exceeding 24 hours per filter.

Sampling period durations are limited by the build-up of particulate matter on the filter. At a certain concentration the particulate matter will block the air flow pathways through the filter which results in an alteration of its screening properties. The suppliers of filters generally do not provide or specify maximum load limits.

A rough estimate of acceptable loading can be obtained using maximum loading limits of historic/past measurements in British Columbia. For TSP, the maximum load was 1.3 grams (ambient concentration of 787 ug/m^3 collected over 24 hours). For PM_{10} the maximum load was 0.7 g (ambient concentration of 419 ug/m^3 collected over 24 hours). No failure of equipment was noted for such loadings over the 24 hour sampling period.

Actual loading limits will depend on the density and size of particulate collected. As a guide however, filters should generally not become overloaded when operated for 7 days in an environment where the ambient concentration rarely exceeds 100 ug/m^3 . The 7 day sampling duration is provided as an initial guideline to coincide with a normal work week schedule. Additionally the 7 day sampling duration is long enough that the relative uncertainty associated

with the metallic composition of the Teflon filters (Pallflex EMFAB TX40HI20WW) is less than levels set by current ambient objectives.

The duration of the sampling period can be extended beyond 7 days if it is demonstrated that this will not overload the HiVol sampler. The number of days can be reduced if filters of greater metallic purity (less trace metal composition, or more uniform metallic composition) are used. At present only the Pallflex Teflon TX40HI20WW has been approved for metals analysis sampling, and as such the sampling period must not be reduced without prior consultation with the Ministry.

For quality assurance, the flow rate of the high volume sampler must be measured at the beginning and end of the sampling interval, although an instrument model that continuously monitors and records the flow rate throughout the sampling period is preferred. Flow rate information must be available for incorporation into Ministry databases.

Sampling must be conducted over contiguous intervals (the next sample started as soon as the previous sample is finished) so that statistical artifacts associated with high, or low concentration episodes can be minimized.

Equipment downtime is tolerable as long as samples are collected over at least 85% of the time for each calendar month.

9 Training

Personnel who operate ambient air monitoring stations within the provincial jurisdiction of British Columbia as well as persons conducting maintenance on those stations and the instrumentation deployed at the stations must be appropriately trained to carry out those tasks. In addition to mentoring and on-the-job training, formal training is available through several agencies such as the Air and Waste Management Association (AWMA), the US EPA's Air Pollution Training Institute (APTI), and NAPS. Training should be ongoing through refresher courses and continual improvement so opportunities to take advantage of technological developments and to better understand the specific operational characteristics and requirements of each monitoring station can occur. Training records must be maintained and available for review.

In addition to training required for monitoring station operation and maintenance, personnel must have formal training as required to conduct activities included in the British Columbia Occupational Health and Safety Regulation (OHSR).

Training in the following areas should be taken where warranted:

- First Aid
- Workplace Hazardous Material Information System (WHMIS)
- Transportation of Dangerous Goods
- Working at Height and Ladder Safety, and
- Safe Driving Techniques

10 Documentation and Record Keeping

Ambient air monitoring stations must maintain records that are relevant to the operation of the station, the maintenance and deployment of instrumentation and issues and incidents with the potential to affect the validity of the data and the station must be produced. Accurate and organized record keeping will help identify substantial issues before they arise, identify potential trends and demonstrate the proficiency of a stations operation.

In particular ambient air monitoring stations must keep the following records:

- Station Start-Up Record,
- Training Records,
- Inspection and Maintenance Records,
- Verification and Calibration Records,
- Non-Conformance and Corrective Action Records,
- Level 0 Data Verification Log, and,
- Audit Evaluations

11 Audits

The objective of an audit is to ensure that the data generated by ambient air monitoring stations is produced at an acceptable level of quality and in a consistent manner across all regions of the province. In this way the monitoring results from each station are comparable to one another and reliable in use for their intended monitoring objectives. The B.C. ENV's detailed audit processes are described in the *Standard Auditing Procedure for Continuous Emission Monitors and Ambient Air Monitoring Instruments* (B.C. ENV 2009).

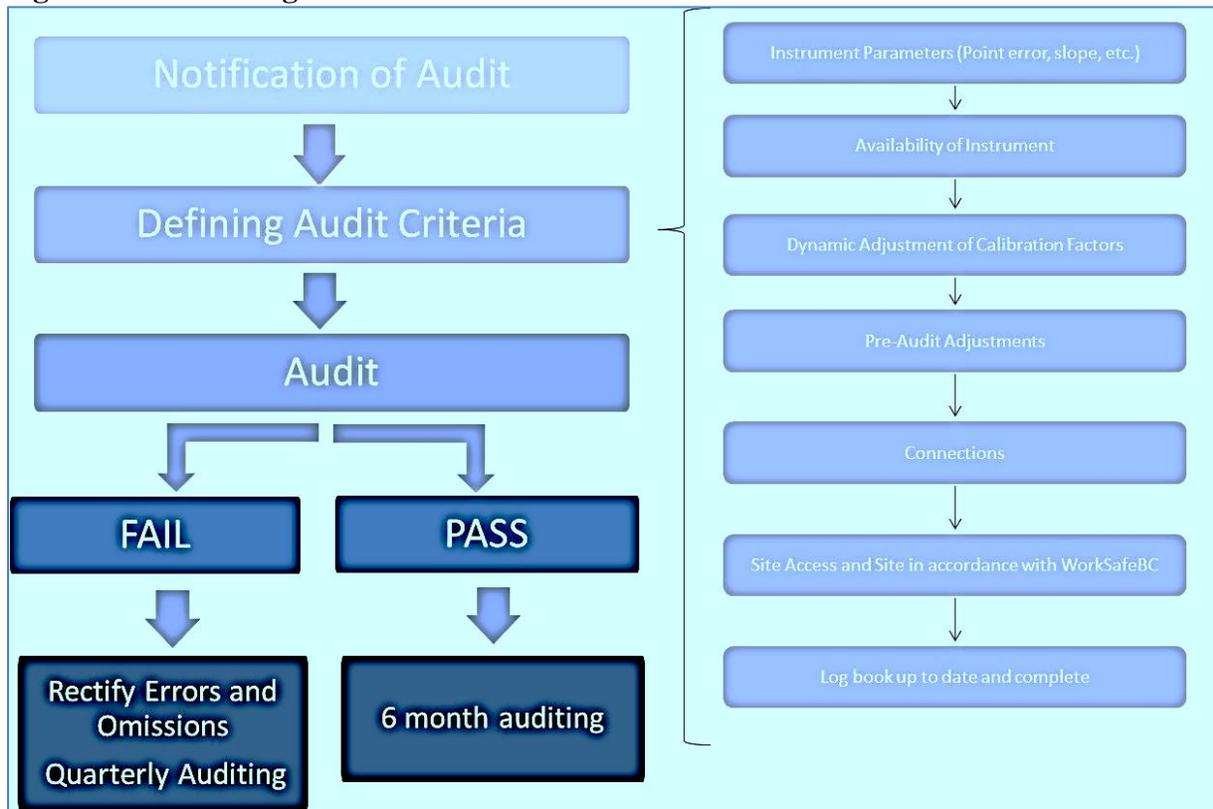
The B.C. Ministry of Environment and Climate Change Strategy conducts audits on all of the ambient air monitoring stations within their jurisdiction. Generally, an audit consists of:

- Audit notice
- Audit process
 - Instrument performance verification
 - Calibrator verification
 - Housing inspection
 - Site accessibility

- Post-audit corrective actions

A flow chart of the audit process is provided in Figure 11.1 below.

Figure 11.1: Auditing Procedure



11.1 Audit Process

Ambient air monitoring station operators can expect to receive an audit notice from the B.C. ENV one to two weeks prior to an audit event. The notice will provide an overview of the audits intent and activities. The station operator will work with the B.C. ENV auditor in the completion of the audit. General audit criteria are listed below.

A. Instrument criteria

- Instrument performance verification (point errors, slope, time to reach stability point, etc.)
- Point and multi-point verification checks
 - Point error
 - Slope
 - Intercept

- Correlation coefficient
- Stability
- Time to reach audit point
- Sample inlet cleanliness
- Time/date
- Flow rates
- Leak check
- Other parameters
- Calibration gas verification
- Calibration system
- Review of meteorological parameters
 - Temperature
 - Pressure
 - Relative humidity
- Instrument availability
- Dynamic adjustment of calibration factors
- Analyzer adjustments prior to audit
- Connections (leak and flow checks)
- Instrument access compliance with WorkSafeBC Occupational Health and Safety Regulation requirements

B. Station log book criteria

- Kept current
- Date and times for all service activity
- Relevant data for all calibration and maintenance (description of maintenance activities)

11.2 Audit Results

At the end of the audit process the station will be assigned a pass or fail in accordance with the criteria listed in the *Standard Auditing Procedure*. Stations that pass their audit will continue to be audited bi-annually. Stations that fail an audit must investigate the failure, identify the root cause of the failure and together with the B.C. ENV, develop and implement corrective actions to ensure the failure does not reoccur. The station operator must ensure that the corrective actions are implemented in order to restore the ambient air monitoring station to an acceptable state.

If the root cause of an audit failure is unclear, and or the two parties disagree on the root cause and proposed corrective action plan, then a third party reviewer will examine the audit record and work with the two parties to resolve the issue and determine what the corrective action should be. Ambient air monitoring stations will be audited on a quarterly basis until the station has passed two consecutive audits.

11.3 Audit Follow-Up

Within one month of an audits completion the B.C. ENV auditor will provide the station operator with an audit report. Audit reports will provide the following information:

- Audit date and site name
- Audit team members
- Monitoring organization participants
- A brief statement describing the purpose of the audit
- A brief description of the audit process
- Audit findings

The audit event must be recorded in the station's log along with any follow up maintenance or work that has been undertaken as a result of the audit.

DRAFT

12 References

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13 Revision History

June 01, 2018	This 'Part' (Part B1 – Ambient Air Monitoring) initial publication.
October 10, 2013:	This section republished without change. Appendix 10.3 - Sample Container, Preservation, and Hold Times for Air (Vapours) included.
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November 1996:	Initial publication.