Wyoming Department of Environmental Quality, Air Quality Division
Quality Assurance Project Plan for
Meteorological Ambient Air Monitoring Program

Summary of Revisions, Revision 2
Date: October 2023

Section	Page (s)	Revision made
All	1-56	Writing of QAPP T&B Systems 5.11.21
All	1-56	Final draft of QAPP 11.24.21
All	1-56	Updated all Organizational charts and tables 10/31/2023
14	38	Changed Precipitation to 5% instead of 10%
14	37-38	Added “Audit” to “Accuracy” changed frequency to “Semi-Annually” instead of “Annually” Table 8.
4	15	Updated Organization Chart
3	9	Updated Table 1 Distribution List
14	37	Added “Vertical Temperature” row to Table 8
Appendix B:	Table 1 & 2	Update Monitors Stations Detail (Table 1)& Site-Specific (Table 2).

Wyoming Department of Environmental Quality – Air Quality Division

Quality Assurance Project Plan for the Meteorological Ambient Air Monitoring Program

October, 2023
Revision 2.0

Section A. Project Management

1.0 Quality Assurance Project Plan Identification and Approval

Title: Wyoming Department of Environmental Quality, Air Quality Division (WDEQ-AQD) Quality Assurance Project Plan (QAPP) for the Meteorological Ambient Air Monitoring Program.

This QAPP for the Meteorological Ambient Air Quality Monitoring Program is hereby recommended for approval and commits from the Department to follow the elements described within.

Wyoming Department of Environmental Quality, Air Quality Division

Leif Oscar Paulson — 11/28/2023

Air Pollution Monitoring Program Supervisor, Leif Paulson — Date

Joseph Mazza — 11/28/2023

Quality Assurance Coordinator, Joseph Mazza — Date

Mark R. Gagen — 11/28/2023

Air Pollution Monitoring Program Manager, Mark R. Gagen — Date

2.0 Table of Contents

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Acknowledgment

Work on documents such as Quality Assurance Quality Plan (QAPP) requires the work and commitment of many dedicated people. This section will acknowledge those that have provided their time and effort to create this document.

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Acronyms

AGL	Above Ground Level
AMTIC	Ambient Monitoring Technology Information Center
APTI	Air Pollution Training Institute
AQD	Air Quality Division
APMP	Air Pollutant Monitoring Program
AQS	Air Quality System
ASQ	American Society for Quality
AWMA	Air & Waste Management Association
CFR	Code of Federal Regulations
DAS	Data Acquisition System
DQIs	Data Quality Indicators
DQOs	Data Quality Objectives
E-log	Electronic Logbook
EPA	U.S. Environmental Protection Agency
HVAC	Heating, Ventilation, and Air Conditioning
IMPACT	Inventory, Monitoring, Permitting, And Compliance Tracking system
IMS	Industrial Monitoring Stations
IP	Internet Protocol
IPA	Instrument Performance Audit
IR	Infrared
LIDAR	Light Detection and Radar
MQOs	Measurement Quality Objectives
NAAQS	National Ambient Air Quality Standards
NPAP	National Performance Audit Program
NIST	National Institute of Standards and Technology
NCore	National Core Air Measurement Network
OAQPS	Office of Air Quality Planning and Standards
PEs	Performance Evaluations
PEP	Performance Evaluation Program
PQAO	Primary Quality Assurance Organization
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
QMP	Quality Management Plan
SLAMS	State and Local Air Monitoring Stations
SLT	State/Local/Tribal
SOP	Standard Operating Procedure
SPMS	Special Purpose Monitoring Stations
WAAQS	Wyoming Ambient Air Quality Standards
WDEQ	Wyoming Department of Environmental Quality

3.0 Distribution List

The following individuals listed in **Table 1** have been provided a copy of this Quality Assurance Project Plan (QAPP).

Table 1. QAPP Distribution List

Wyoming Department of Environmental Quality – Air Quality Division	
Name	**Position**
Nancy Vehr	Administrator
Mark Gagen	Air Pollution Monitoring Program Manager
Leif Paulson	Air Pollution Monitoring Program Supervisor
Joe Mazza	Quality Assurance Coordinator
Jacob Berreth	CEMS/SLAMS Coordinator
Miriam Montana	Exceptional Events Analyst/Project Manager
Vacant	Data Manager
Lauren Deverse	Project Manager
Vacant	Project Manager
Vacant	Project Manager
Paul Bailey	Monitoring Specialist
Cortney Dekeyser	Monitoring Specialist
EPA Region VIII	
Name	**Position**
Aaron Worstell	EPA Region 8, Air Program Tech Unit
Adam Eisele	EPA Region 8, Air Permitting and Monitoring Branch Manager

4.0 Project/Task Organization

Since the early 1970s, the Air Pollutant Monitoring Program (APMP) has been committed to monitoring the air quality of Wyoming with the goal of protecting, conserving, and enhancing the quality of Wyoming's environment for the benefit of current and future generations. The APMP provides the WDEQ-AQD with valuable information that allows for determination of future policy considerations.

The WDEQ-AQD plans, operates, and maintains a number of different types of ambient monitoring stations, including National Core (NCore), State and Local Air Monitoring Stations (SLAMS), Special Purpose Monitoring Stations (SPMS), Interagency Monitoring of Protected Visual Environment (IMPROVE) monitoring stations, and Industrial Monitoring Stations (IMS).

The SLAMS are sited in populated areas to monitor public health and demonstrate compliance with the National Ambient Air Quality Standards (NAAQS) but may serve other purposes, such as:

- Providing air pollution data to the general public in a timely manner
- Supporting compliance with air quality standards and emissions strategy development
- Supporting air pollution research studies

The SPMS collectively have multiple objectives. These objectives include:

- Providing air pollution data to the general public in a timely manner
- Monitoring public health
- Investigating pollutant concentrations downwind of sources
- Determining background pollutant concentrations

Since 2011, the WDEQ-AQD has operated a fleet of mobile monitoring stations ("mobile stations") to investigate questions or concerns about air quality on a short-term basis (typically one year). Additionally, the WDEQ-AQD administers an NCore station as part of the national network to evaluate long-term trends in air quality. The IMS are independently operated stations that meet the requirements of their permits. Although WDEQ-AQD has oversight authority for the permit-required monitoring networks, the IMS operate as independent Primary Quality Assurance Organizations (PQAOs) under separate AQD and EPA approved QAPPs. IMPROVE monitoring stations are also independently operated, where AQD funds the operations and analysis through EPA Grants.

The WDEQ-AQD is committed to quality and the implementation of the procedures and practices found in this QAPP. Quality assurance (QA) is an integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and as expected. Quality control (QC) is the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer. The QC system includes the operational techniques and activities that are used to fulfill requirements for quality.

Quality control is largely implemented through the QAPP and the standard operating procedures (SOPs). Each instrument in the various monitoring programs has unique requirements, statutory standards, and support equipment that must be in place in order for the instrumentation to be operated according to the guidelines, rules, and policies that must be followed. This QAPP incorporates the unique qualities that are specific to meteorological monitoring for the WDEQ-AQD network.

Implementation of the WDEQ-AQD monitoring program requires an investment by the entire management team all the way to the Air Pollution Monitoring Program Manager. WDEQ-AQD management recognizes and accepts this responsibility to identify the QA requirements that will meet the needs and expectations of the monitoring program. Any worthwhile monitoring program focuses on preventing quality problems.

Since the WDEQ-AQD has an overarching Quality Management Plan (QMP) in place, this and all QAPPs will be mandated by the WDEQ-AQD QMP. The QMP describes the quality system in terms of the organizational structure, functional responsibilities of management and staff, lines of authority, and required interfaces for those planning, implementing, assessing, and reporting activities involving environmental data operations.

The following sub-sections describe the project participants and roles and responsibilities of each participant. **Figure 1**, which is in the last portion of this section, illustrates that management structure.

4.1 Air Pollution Monitoring Program Manager

The APMP Manager has overall responsibility for managing the WDEQ-AQD according to WDEQ policy. The direct responsibility for assuring data quality rests with line management. Ultimately, the APMP Manager is responsible for establishing QA policy and for resolving QA issues identified through the QA program.

Major QA related responsibilities of the APMP Manager include:

- Participating in the budget and planning processes.
- Assuring that the WDEQ-AQD develops and maintains a current and germane quality system.
- Assuring that the WDEQ-AQD develops and maintains current QAPPs.
- Assuring adherence to the QA documents by staff and, where appropriate, other extramural cooperators establishing policies to ensure that QA requirements are incorporated in all environmental data operations.
- Maintaining an active line of communication with the APMP Supervisor, QA Coordinator, and Project Managers conducting management systems reviews.

The WDEQ-AQD APMP Manager delegates the responsibility of QA development and implementation in accordance with WDEQ-AQD policies. Oversight of the WDEQ-AQD's QA program is delegated to the Quality Assurance Coordinator.

4.2 Air Pollution Monitoring Program Supervisor

The WDEQ-AQD APMP Supervisor is the delegated manager of the routine monitoring programs, which includes the QA/QC activities that are implemented as part of normal data collection activities. Responsibilities of the APMP Supervisor include:

- Communicating with EPA Project Officers and QA Personnel regarding sampling and quality assurance activities.
- Understanding EPA monitoring and QA regulations and guidance to ensure subordinates understand and follow the regulations and guidance.
- Understanding the WDEQ-AQD's QA policy and ensuring subordinates do as well.
- Understanding and ensuring adherence to the QAPP.
- Reviewing acquisition packages (contracts, grants, cooperative agreements, and interagency agreements) to determine the necessary QA requirements.
- Developing budgets and providing program costs necessary for EPA allocation activities.
- Ensuring that all personnel involved in environmental data collection have access to any training or QA information needed to be knowledgeable in QA requirements, protocols, and technology.
- Certifying to EPA that data are true, correct, and reported to EPA per Title 40 Code of Federal Regulations (CFR) Part 58.15[1].

4.3 Quality Assurance Coordinator

The QA Coordinator is the delegated manager of the WDEQ-AQD's QA Program. The QA Coordinator has direct access to the Administrator, APMP Manager, and APMP Supervisor on all matters pertaining to QA. The QA Coordinator's main responsibility is QA oversight and ensuring that all personnel understand the WDEQ-AQD's QA policy and all pertinent EPA QA policies and regulations specific to the APMP. The QA Coordinator provides technical support and reviews and approves QA products. Responsibilities include:

- Developing and interpreting WDEQ-AQD QA policy and revising it as necessary.
- Developing a QA Annual Report for the Administrator.
- Assisting Contractors and Project Managers in developing QA documentation and in providing answers to technical questions.
- Ensuring that all personnel involved in environmental data operations have access to any training or QA information needed to be knowledgeable in QA requirements, protocols, and technology.
- Ensuring that environmental data operations are covered by appropriate QA planning documentation (e.g., QAPPs, data quality objectives, etc.).
- Ensuring that reviews, assessments, performance evaluations, and audits are scheduled and completed and, if needed, conducting or participating in QA activities.
- Tracking the QA/QC status of all programs.
- Recommending required management-level corrective actions.
- Uploading QA/QC data to the EPA's Air Quality System (AQS), which is the National database for all air pollution and meteorological data.
- Serving as the program's QA liaison with EPA Regional QA Managers or QA Officers and the Regional Project Officer.

The QA Coordinator has the authority to carry out these responsibilities and to bring to the attention of the APMP Manager any issues associated with these responsibilities. The QA Coordinator either performs or delegates the responsibility of QA development and implementation.

4.4 Project Managers

Project Managers are responsible for project coordination; oversight of contractor activities; maintaining the official, approved QAPP; and QAPP distribution. Responsibilities include:

- Ensuring the day-to-day operation and upkeep of all monitors are maintained.
- Overseeing data processing, reporting, and assuring data collection are performed in a timely fashion.
- Understanding EPA monitoring, QA regulations and guidance, and ensuring Contractors, Monitoring Specialists and Site Operators understand and follow those standards.
- Understanding WDEQ-AQD QA policy and ensuring subordinates understand and follow the policy.
- Understanding and ensuring adherence to the QAPP as it relates to program support activities.
- Participating in the development of data quality requirements with the appropriate QA staff.
- Writing and modifying QAPPs and SOPs.
- Verifying that all required QA activities were performed and quality standards were met as required in the QAPP.

4.5 Monitoring Specialists

The field personnel, either WDEQ-AQD or contractor are responsible for carrying out required tasks and ensuring the data quality results of the tasks by adhering to the guidelines and protocols specified by the QAPP and SOPs for the field activities. Responsibilities include:

- Participating in the implementation of standards, as laid out in the QAPP.
- Keeping up-to-date in training and certification activities.
- Verifying that all required QA activities are performed and quality standards are met (as required by the QAPP).
- Following manufacturer specifications for any equipment used.
- Documenting deviations from established procedures and methods.
- Thoroughly document and keep all routine maintenance activities performed at the stations and all problems and report corrective actions to the Site Operator and Project Manager.
- Preparing and delivering reports to the Project Manager.
- Reviewing data and assessing and reporting on data quality.

4.6 Site Operators

The Site Operators visit the monitoring station once a month. The Site Operator's role is to do routine maintenance on the monitoring station and instrumentation. For the purpose of this meteorological QAPP, the WDEQ-AQD Monitoring Specialist can perform the duties of the Site Operator. Responsibilities include:

- Change in-line filters on the continuous instruments (monthly).
- Perform unexpected tasks such as running a manual calibration (if necessary after a repair).
- Replace electronic or pneumatic components at the direction of a Contractor or Project Manager.
- Reporting all problems and corrective actions to the Contractor or Project Manager.
- Thoroughly documents all activities performed at a station and reports activities and results to the Contractor and Project Manager.
- Assessing and reporting on data quality.

4.7 Data Manager

The Data Manager reports to the APMP Manager and is in charge of the WyVisNet website and the AirVision data management system, which runs WyVisNet. Responsibilities include:

- The Data Manager is in charge of uploading data to the EPA's Air Quality System (AQS), which is the National database for all air pollution and meteorological data
- Ensures data are moved to/from the IMPACT system and shared drives per our WDEQ Records Management Plan.
- Performs data queries within the central database in Cheyenne headquarters.
- Works with the vendors that supply and maintain the WyVisNet software system.
- Performs data analyses as described in Sections 22 and 23 of this QAPP.

Please note that an annual review of the QAPP will be performed and, if no changes are needed, the WDEQ-AQD will document that no changes were necessary. If changes are required, revised pages with the revisions will be inserted/changed, revisions will be tracked, and a new revision number will be assigned to the document.

Figure 1 on this page illustrates the organization structure for the WDEQ-AQD. For a list of project participants, please see Appendix B.

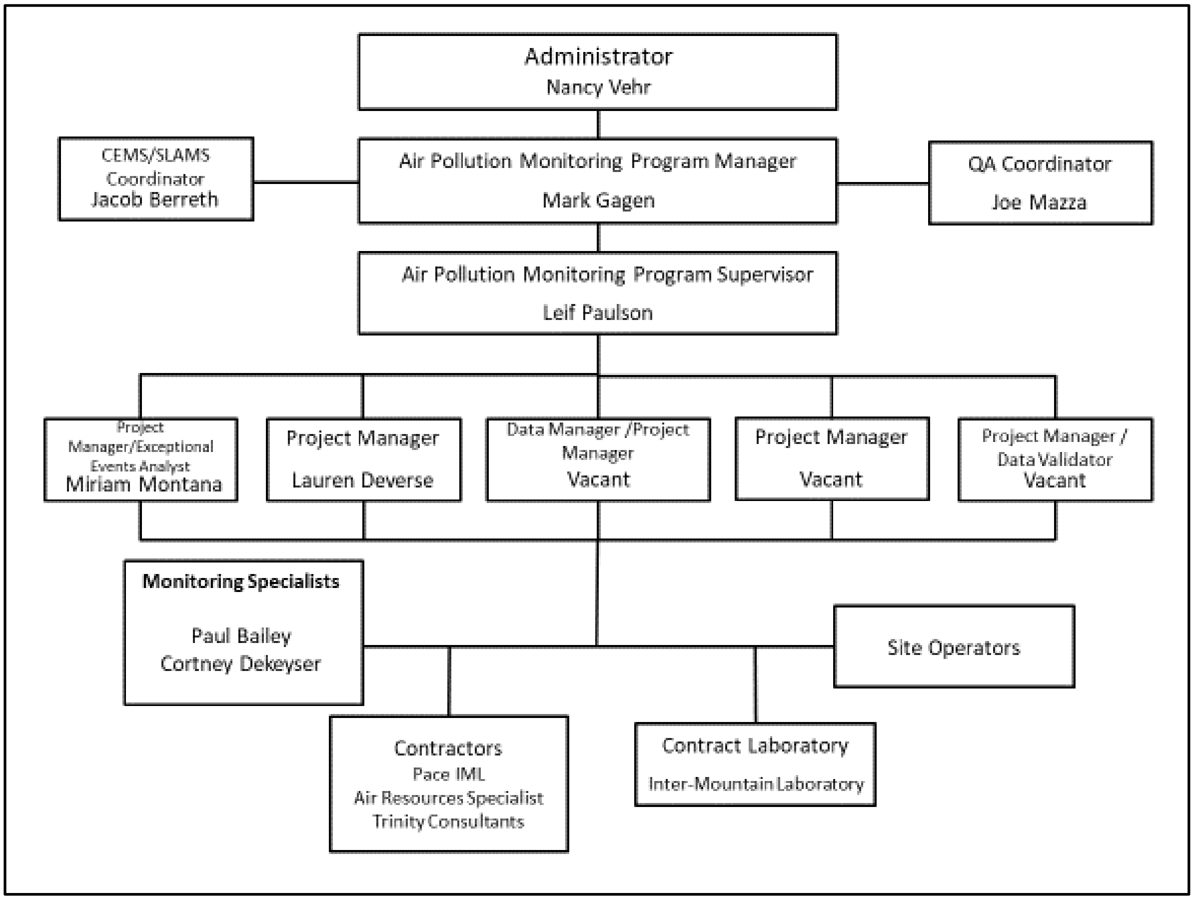

Figure 1. WDEQ-AQD Organization Chart

5.0 Problem Definition/Background

This QAPP pertains strictly to the collection and analysis of meteorological measurements within the WDEQ-AQD Network and details the methodologies to establish precise and accurate meteorology measurements at all stations within the WDEQ-AQD network, regardless of the type of monitoring that is performed.

The objective of the meteorology monitoring network is to provide the necessary information for developing a representative set of meteorological parameter data that supports the air quality data sets and be capable of delineating differences among geographical and climatological regions. The meteorological data are used to characterize and support trends in air quality and air quality standards' compliance, and may be used for national health assessments and model evaluations. The procedures outlined in this QAPP have been developed to meet the goals and objectives of the monitoring projects. Revisions to the QAPP are made, as necessary, to reflect changes to the regulations or goals of the monitoring project. As a minimum, the QAPP is reviewed annually and revisions are made as necessary.

Currently, WDEQ-AQD measures meteorological parameters at 17 monitoring stations. Hourly meteorology readings from a monitor are collected to support the ambient air monitoring networks, both in support of the NAAQS pollutants and other monitoring data.

Below is **Figure 2**, which illustrates the current 2021 WDEQ-AQD Monitoring Stations. As can be seen from this map, the air monitoring network covers the entire State.

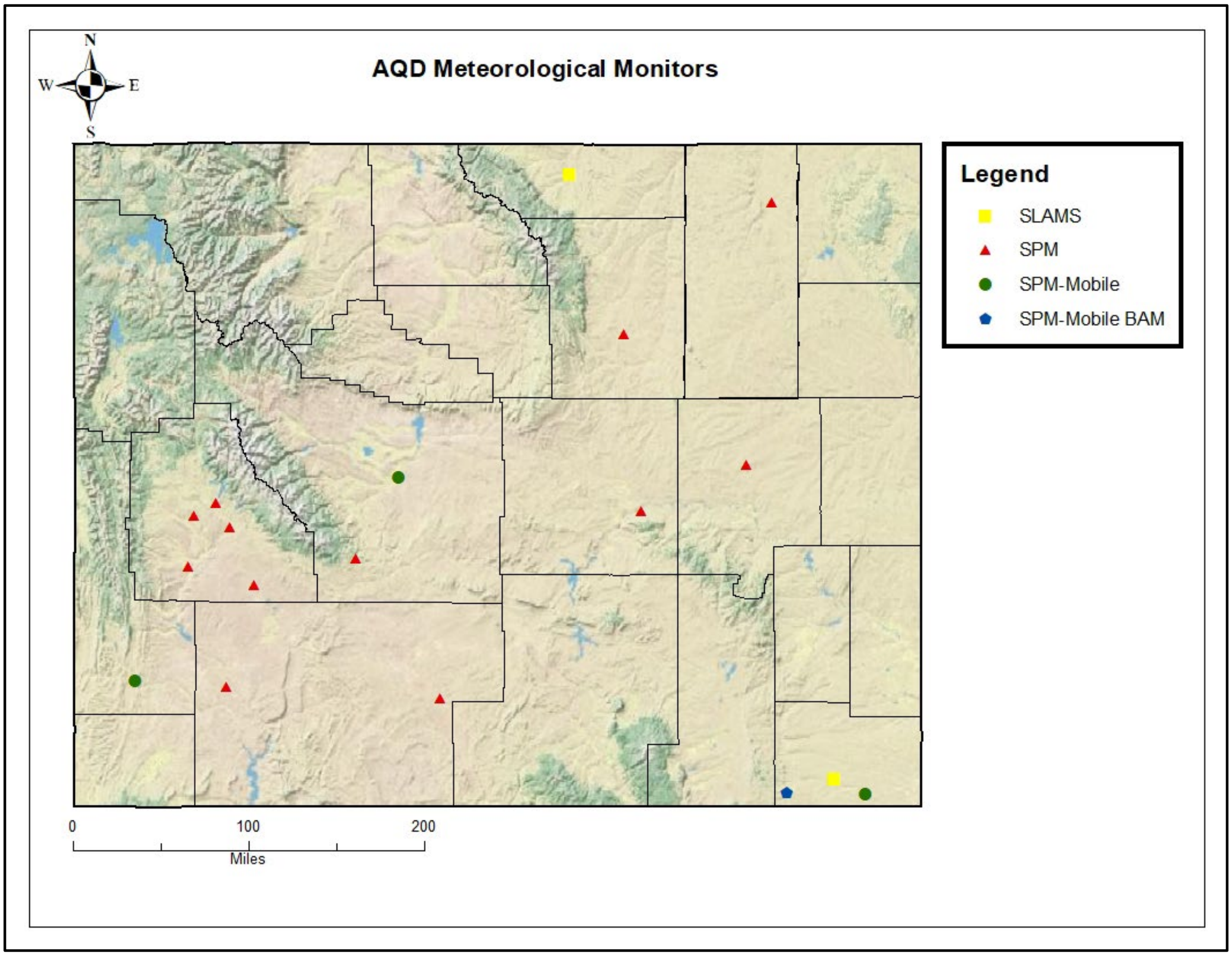

Figure 2. WDEQ-AQD Meteorological Site Locations, 2023

5.1 Supporting Documentation

The information collected for this monitoring program will meet the requirements as found in the following documents:

- Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Ambient Air Quality Monitoring Program, EPA-454/B-17-001, January 2017[2]
- Technical Assistance Document For Precursor Gas Measurements in the NCore Multi-Pollutant Monitoring Network, Version 4, EPA-454/R-05-003 September 2005[3]
- Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, EPA-454/B-08-002, March 2008[4]
- Technical Assistance Document for Sampling and Analysis of Ozone Precursors for the Photochemical Assessment Monitoring Stations Program, EPA-454/B-19-004, April 2019[5]

The guidance documents presented in the list above are to be followed for this monitoring program and are intended to ensure that data and technical information that are measured are of documented and appropriate quality and usability.

6.0 Project Task Description

6.1 Meteorology Measurements

Meteorological measurements encompass a variety of different types of measurements. For this QAPP and supporting documents meteorological measurements are:

- Wind speed, scalar or average
- Wind direction, scalar or average
- Vertical wind speed
- Ambient temperature
- Delta Temperature
- Relative humidity
- Barometric Pressure
- Upper Air Boundary Layer (Ceilometry)
- Solar Radiation, and
- Precipitation

In addition, there are several sets of data that are calculated from the wind speed and direction data, collected and stored. These are:

- Sigma Theta
- Wind speed vector
- Wind direction vector

The Sigma Theta and vector data are calculated by the Data Acquisition System (DAS) on one-second intervals, then averaged to 1-minute and hourly averages (at a minimum). For a description of how these parameters are calculated, please see the EPA's Handbook on Meteorological Measurements[4].

6.2 Sampling Frequency

Data from the meteorology instruments are sampled every second by the DAS. The DAS then stores the data in 1-minute and hourly increments (at a minimum). This data is then transmitted or reviewed by WDEQ-ADQ or Contractor staff on a defined interval to the central location in Cheyenne.

6.3 Project Schedule

Personnel working on this project are fully qualified, trained, and capable to perform their assigned duties. Work schedules include: daily data review, semi-annual meteorological equipment calibrations, quarterly data reports within 60 days of quarter completion, annual reports within 90 days of year completion, and maintenance and corrective action.

6.4 Project Reports

Table 2 presents the reports that will be produced as part of this project.

Table 2. Project Reports

Reports	Frequency	Content	Responsible Position
Quarterly Data Reports	Quarterly	Summarizes data following EPA guidelines, includes accuracy and precision	Contractor with review by Project Manager
Annual Data Report	Annually	Summarizes data following EPA guidelines	Contractor with review by Project Manager
Performance Audit Reports	Semi-annually	Summarizes audit results following EPA guidelines	WDEQ-AQD QA Coordinator or Contractor with review by Project Manager
Corrective Action Reports	As Needed	Summarizes corrective actions taken to return the monitoring station to compliant status	Contractor with review by Project Manager
Response to Corrective Action Reports	As Needed	Reports the results of the corrective actions taken	Contractor with review by Project Manager

7.0 Quality Objectives and Criteria for Measurement of Data

This section discusses the Data Quality Objectives (DQOs), the Measurement Quality Objectives (MQOs) and Data Quality Indicators (DQIs) that are mandatory for all monitoring programs.

Generally, the DQOs for any program are created by the stakeholders. The DQO process is a seven-step decision tree that allows the stakeholders of the WDEQ-AQD to define parameters for the program. The DQO process has been in existence for many years, first by the EPA and then utilized by the State, Local and Tribal governments that are required to collect data on behalf of the EPA. Since meteorological measurements only support NAAQS monitoring, there is no need to discuss NAAQS or WAAQS attainment.

As mentioned before, the DQO is a seven-step process that takes the form of a discussion of the important aspects of the program. It is encouraged and useful that the DQO process be performed from time to time to ensure that the objectives are clear and concise.

7.1 The DQO Process

On August 12, 2020, the WDEQ-AQD and its Contractor met to discuss the DQOs for the programs and define the objectives. **Table 3** below outlines the discussion and the outputs of the DQO process in each step.

In order for the DQOs to be fulfilled, MQOs are designed to evaluate and control various phases (sampling, preparation, and analysis) of the measurement process to ensure that total measurement uncertainty is within the range prescribed by the DQOs. MQOs can be defined in terms of the following DQIs: representativeness, detectability, completeness, and comparability.

Table 3. DQO Seven-Step Decision Tree Process

DQO Step	Output to Discussion by Decision Makers
Step 1. State the Problem	The State of Wyoming, being within the bounds of the United States, must adhere to the Clean Air Act Amendments. The Code of Federal Regulations 40 part 50 set the NAAQS and the State of Wyoming measures for the NAAQS pollutants. In addition, the State of Wyoming promulgated its own Wyoming Ambient Air Quality Standards (WAAQS), which are nearly identical to the NAAQS. The State of Wyoming must comply with these standards and thus measure in various locations to meet the requirements. In support of measuring for NAAQS compounds, meteorological parameters are monitored to understand the origins of the NAAQS compounds in question.
Step 2. Identify the Goal of the Study	Not only does the State of Wyoming have to measure for these NAAQS pollutants, but they must also adhere to the level of the standard (attainment vs. nonattainment as promulgated in 40 CFR Part 50). In order to understand the environment as a whole, meteorological data must be collected in support of the NAAQS pollutant data that are generally collected at the same location.
Step 3. Identify Information Input	The input information is the hourly meteorological data that are collected at the locations where NAAQS parameters are monitored (see Appendix B).
Step 4. Define the Boundaries of the Study	The boundary of the study is the entire State of Wyoming. This study only applies to the WDEQ-AQD Primary Quality Assessment Organization (PQAO).
Step 5. Develop the Analytical Approach	The WDEQ-AQD will collect meteorological data at all of the monitoring locations that are deemed necessary. At the end of the year, the WDEQ-AQD will review, analyze, and certify that the data collected within the WDEQ-AQD network are valid within the parameters laid out in this QAPP.
Step 6. Specify Performance Criteria	The performance criteria are described in this QAPP under the MQOs and thus the DQIs. If the data collected adhere to these performance criteria, then the data can be used to support the State’s declaration of nonattainment or attainment status. In addition, the meteorological data can be used to understand the nature of the sources of the pollutants and aid in their mitigation.
Step 7. Develop the Plan for Obtaining Data	Having developed these DQOs, the WDEQ-AQD has developed this meteorological QAPP and SOP for meteorological sensors to ensure that the QA and QC procedures are documented and followed by WDEQ-AQD staff and their Contractors.

7.2 Data Quality Indicators

The data quality indicators (DQIs) are a set of indicators which can be easily measured. The DQIs are either inherent in the instruments, i.e., detection limits, or indicate how the meteorological parameters are analyzed.

Here is a discussion of each DQI:

- **Accuracy** - is a measure of the overall agreement of a measurement to a known value and includes a combination of random error (precision) and systematic error (bias) components of sampling. This is performed using the independent meteorological performance audits.
- **Resolution** - The lowest value that the sensor can report. This should not be confused with minimum detectable limits (MDLs), which are defined below.
- **Detection Limit** - The lowest value that a sensor can determine to be different from zero by a single measurement at a stated level of probability.
- **Completeness** - describes the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal conditions. For meteorological measurements, generally this is data completeness of 90%.
- **Comparability** - generally falls under the auspice of equipment specifications and monitoring methods. For meteorology, there are no Federal reference or equivalent instruments.Therefore, instruments have been chosen that will meet the guidelines of EPA QA Handbook Volume IV[4] and the EPA Modeling Guidance[6]. Please refer to these two reference documents for further discussion.
- **Representativeness** - This DQI deals with whether or not the location of the meteorology sensor represents the type of monitoring that is necessary, i.e., are the station meteorology sited appropriately for the stations intended objective. Normally, sensors are mounted on 10 meter towers and placed according to their intended height.

The goals for acceptable DQIs for detailed in **Table 4** on this page.

Table 4. Meteorological Sensors DQIs

Parameter	Accuracy	Sensor Resolution	Minimum Detectable Limits
Wind Speed	±0.25 m/s ≤5 m/s ±5% >5m/s not to exceed 2.5 m/s	0.01 m/s	0.1 m/s
Wind Direction	±5 degrees	0.01 degree	1.0 degree
Ambient Temperature	±1.0°C	0.01°C	0.1°C
Vertical temp. difference	±0.1°C	0.01°C	0.01°C
Relative Humidity	±10%	0.1%	0.5%
Solar	±10 W/m^2 below 200 W/m^2 and 5% above 200 W/m	1.0 W/m^2	10 W/m^2
Barometric Pressure	±3 mb	0.001 mb	0.05 mb
Precipitation	±10% of input volume	±0.01 in	0.01 in
Boundary Layer	±1% or 5 meters	5 meters	5 meters

7.3 Representativeness of the Meteorology Measurements

Site selection and probe placement followed guidelines in the following US EPA documents to assure that measurements are representative of meteorological and air quality monitoring conditions near the monitoring stations:

- Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, EPA-454/B-08-002, March 2008[4]
- EPA's Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R- 99-005, February 2000[6]

The placement of meteorological sensors must consider local interferences, distance to structures, trees, buildings and height of probe above ground. The network was set up in accordance with EPA-defined ambient air quality and meteorological siting criteria, which is detailed in EPA's Meteorology Handbook Volume IV[4], Section 1.0, Tower Guidance and Siting. Please refer to this reference document for further discussion.

8.0 Special Training/Certifications

Personnel assigned to the APMP will meet the educational, work experience, responsibility, and training requirements for their positions. Records on personnel qualifications and training will be maintained in personnel files and will be accessible for review during audit activities.

Adequate education and training are integral to any monitoring program that strives for reliable and comparable data. It is recommended that WDEQ-AQD maintain some requirements for personnel qualifications (combination of education and experience). Training is aimed at increasing the effectiveness of employees and their organization.

As part of a quality assurance program the procedures should include information on:

- Personnel qualifications (general and position-specific)
- Training requirements (based on position)
- Frequency of training

Appropriate training should be available to employees supporting the APMP and commensurate with their duties. Such training may consist of classroom lectures, workshops, web-based courses, teleconferences, vendor-provided and on-the-job training. Training should also include appropriate reading materials, such as the CFR, EPA guidance documents, and the monitoring organization's QAPPs and SOPs, to name a few.

EPA encourages monitoring organizations to maintain documentation that details the training provided to all monitoring staff, along with documentation that illustrates the successful completion of the training requirements. Along with suggested training, the EPA encourages regional planning organizations and monitoring organizations to develop training programs that require some level of certification. Over the years, a number of courses have been developed for personnel involved with ambient air monitoring and quality assurance aspects.

Formal QA/QC training is offered through the following organizations:

- Air Knowledge Training Program https://airknowledge.gov/
- Air & Waste Management Association (AWMA) http://www.awma.org/
- American Society for Quality (ASQ) https://asq.org
- EPA Quality Staff (QS) http://www.epa.gov/quality/
- EPA Regional Offices https://www.epa.gov/aboutepa/regional-and-geographic-offices
- EPA Ambient Monitoring Technology Information Center (AMTIC) Technology Transfer Network https://www.epa.gov/amtic

WDEQ-AQD should consider adding manufacturer-provided training to the equipment purchase cost. Persons having experience in the subject matter described in the courses would select courses according to their appropriate experience level. Courses not included in the core sequence would be selected according to individual responsibilities, preferences, and available resources.

9.0 Documents and Records

The WDEQ-AQD is committed to fully documenting all activities related to data collection, analysis, validation, and reporting. **Table 5** contains a list of the records maintained by the APMP. These records can be electronic, bound in notebooks, and/or forms that are used for specific applications. Electronic records will be stored on main office storage drives and archived by the Contractors and ultimately, the WDEQ-AQD office servers. All project files are backed up daily. In addition, weekly network backup occurs. The weekly backup network files are stored onto external hard drives which are stored off-site. The WDEQ-AQD has several of these backup hard drives and copies of the field logbook are archived in the WDEQ-AQD Cheyenne office for 5 years.

Table 5. Documentation and Reports

Documentation Type	Frequency	Report Submission	Archive	Retention Period
Monitoring Data	Daily Downloads	Contractors	WDEQ-AQD and Contractor's Server (with backup)	5 years
QAPP and SOPs	Annually or more frequently, as needed	QA Coordinator	WDEQ-AQD	5 years
Copies of Field Logbooks	After each site visit	Site Operators and Contractors	WDEQ-AQD and Contractors	5 years
Quarterly Reports	Quarterly	Contractors	WDEQ-AQD and Contractors	5 years
Annual Data Report	Annually	Contractors	WDEQ-AQD and Contractors	5 years
Performance Audit Summaries	Semi-Annually	QA Coordinator or Contractor	WDEQ-AQD	5 years

All monitoring data, reports and program documentation will be retained by WDEQ-AQD for a minimum of five (5) years. The WDEQ-AQD will review and approve updates or changes to the QAPP plan given updates or changes to the Records Management Plan.

Section B. Data Generation and Acquisition

10.0 Network Description

This section describes the project design and implementation of the meteorological monitoring network. For the list of current locations and a description of the Meteorological Monitoring Network, please see Section 1.0 of Appendix B, Instrument Locations.

11.0 Sampling Method

The meteorology network maintained by the WDEQ-AQD is placed nearby monitoring shelters across the State. The sensors used to measure metrological parameters are described in Volume II of EPA's Quality Assurance Handbook for Measurement Systems[4]. Meteorology is measured by sensors placed in ambient air from several levels of a 10 meter tower. In addition, some of the sensors, such as the solar radiation or precipitation gauge, can be mounted on the hand rails around the roof of the shelter.

11.1 Meteorology Sensors

For a list of the current instruments utilized throughout the monitoring network, please see Appendix B, Section 2.0, and Types of Instruments. This discussion gives a brief overview on how these sensors operate.

- **Horizontal Wind Speed:** Horizontal wind speed sensors commonly utilize a cup or propeller assembly turning on either a vertical or horizontal axis. The aerodynamic shape of the cups converts the wind pressure into torque. This will turn a shaft that is supported by low friction, precision bearings. The shaft rate of rotation is converted to wind speed by the use of a transducer. Ideally, there is a relationship between the rate of rotation and wind speed, above the starting threshold. Please note that because no bearings are frictionless, there is a finite amount of wind, albeit very low, which is needed to start the anemometer to begin to move. This amount of wind is known as the starting threshold. A performance audit on this sensor provides physical verification that: 1) the sensor's starting threshold has not changed or is below the manufacturer's stated starting threshold, and 2) the transducer is properly converting cup rate of rotation (rpm) to wind speed.
- **Vertical Wind Speed:** The vertical wind speed (VWS) sensor employs a helicoid four blade propeller. A miniature tachometer/generator produces an analog DC voltage proportional to the axial wind component. When propeller rotation reverses, signal polarity reverses. This produces a plus (+) or minus (-) direction of rotation.
- **Horizontal Wind Direction**: Wind direction sensors indicate the direction from which the wind is blowing. The wind direction is expressed as an azimuth angle on a 360° circle where 0° or 360° indicates North (usually True North) and 180° indicates South. Wind direction sensors use a tail assembly positioned on a vertical shaft to detect wind direction. Wind applies a force to the tail assembly of the sensor forcing the assembly to turn into the wind seeking a position of minimum force. The shaft of the sensor rests on low friction precision grade bearings and is connected to a low torque potentiometer. The potentiometer yields a voltage output proportional to the wind direction. The starting threshold of the sensor is controlled by the relationship of shape, size, and distance from the axis of rotation of the tall assembly to the vertical shaft, bearings, and potentiometer torque requirements.
- **Ambient Temperature**: For air quality applications, ambient temperature is measured with a temperature probe. The probe can be a thermistor, resistance temperature detector (RTD), or thermocouple. The probe to be audited should be located in a radiation shield that protects it from the effects of solar heating and wind variations.
- **Delta Temperature:** Also known as delta T (ΔT), for air quality applications, delta temperature is measured with two temperature probes at different heights. The utility of this is to ascertain whether air is rising or falling. This information can go into dispersion models used to track the movement of vertical movement of air.

- **Relative humidity (RH):** RH is the ratio of the existing amount of water vapor in the air at a given temperature to the maximum amount that could exist at that temperature. This value is usually expressed in percent relative humidity (%RH). Percent relative humidity is a variable parameter which is affected by atmospheric conditions during its measurement. Capacitive sensors measure RH utilizing a strip of metal between an electrical current. The metal strip electrical capacity (i.e., voltage) changes linearly with the RH.
- **Barometric pressure (BP)**: BP measurements can be used in modeling and can be used to correct an ambient measurement to standard conditions (298°K and 760 millimeters of mercury). BP sensors use pressure transducers which transform the sensor response into a pressure-related electrical signal.
- **Solar Radiation:** Solar radiation is related to atmospheric stability and is commonly described in units of energy flux: Watts/meter^2 (W/m^2). A pyranometer is used to measure sun and sky radiation on a horizontal surface. Most pyranometers incorporate a thermopile sensor; however, a silicon photovoltaic cell can also be used. The net radiometer measures the difference between downward (solar) and upward (terrestrial) radiation.
- **Precipitation**: Precipitation is defined as: "the total amount of precipitation which reaches the ground in a stated period is expressed as the depth to which it would cover a horizontal projection of the earth's surface if there were no loss by evaporation or run-off and if any part of the precipitation falling as snow or ice were melted." Precipitation gauges work on the principle of a tipping bucket gauge. A funnel directs precipitation to a small inlet that directs water over two equal compartments, or buckets, that tilt in sequence with each representing a known quantity of rainfall. The motion of the buckets causes an electrical switch to close and the number of tips are counted.
- **Ceilometer**: A ceilometer employs pulsed diode laser Light Detection and Ranging (LIDAR) technology, where short, powerful laser pulses are sent out in a vertical or near-vertical direction. The reflection of light, backscatter, caused by haze, fog, mist, precipitation, and/or clouds, is measured as the laser pulses traverse the sky. The resulting backscatter intensity profile and the mixing height is measured using the characteristics of the backscattered profile. The time delay between the launch of the laser pulse and the detection of the backscatter signal provides the measure of the layer heights. The operating principle of a ceilometer is based on the measurement of the time needed for a short pulse of light to traverse the atmosphere from the transmitter emitted from the ceilometer to the top of the backscattering layer and back to the receiver of the ceilometer.

11.2 Support Monitoring Equipment

This section summarizes the meteorology support equipment being used at the WDEQ-AQD meteorology network. The SOP for meteorological sensors details the calibration and operation of the equipment.

11.3 Data Acquisition System (DAS)

Instantaneous data from the meteorological instruments are transferred once per second to the DAS usually by a serial cable. The DAS is a self-contained box with the ability to measure and control electronics, communicate with on-site computers or remote systems. Data is generally stored in a table format. Please note that the DAS stores 1-minute and hourly data (at a minimum). The one-second data is not stored.

11.4 Telecommunications

Telecommunication services are used for high-speed remote communication to all onsite equipment including the DAS. Additionally, each instrument onsite is configured with a unique IP address for remote maintenance and control purposes. The gateway has all of the firewall protection and routing protocols necessary for protection, isolation, and security.

11.5 Meteorological Tower

The WDEQ-AQD utilizes free-standing towers that are tilted down in order to have easy access to the sensors at the top of the tower. In most cases, to accommodate wind speed/wind direction sensors, the towers must be able to reach a height of 10 meters. Some instruments, such as RH, ambient temperature and ΔT are mounted at 2 meters above the ground. **Figure 3** illustrates the configuration of the monitoring equipment and the placement of this equipment at a typical monitoring site.

Figure 3. A Typical Meteorological 10 meter Tower

11.6 Standard Operating Procedures

A SOP for meteorological sensors has been developed to provide instructions to the Site Operators regarding routine operation of the meteorology equipment. The SOP for meteorological sensors discusses equipment inspection and acceptance testing, visual inspections, preventive maintenance, and calibration procedures. The SOP for meteorological sensors is an independent document that is a companion to this QAPP.

The identification, cause, and corrective action for conditions adverse to quality will be documented on the Corrective Action Report form (see the SOP). Follow-up action will be taken by the Contractor and Project Manager to verify the corrective action was taken.

12.0 Sample Handling and Custody

All meteorological data is generated by the individual sensors based on the environmental conditions around the monitoring station. The sensors send a digital or analog signal to the DAS that records, averages and stores the data in the DAS. There are no sample handling requirements for the meteorological data.

13.0 Analytical Method

All modern meteorological sensors measure the atmosphere by using its physical characteristics; e.g. for wind direction, the movement of the wind pushes the tail of the wind vane, therefore, when the wind forces are equal on both sides of the vane, the front of the vane points in the direction of the wind. An electronic potentiometer measures this direction and sends a signal to the DAS, which is recorded.

Section 11.1 of this QAPP describes how these instruments operate. For more detailed information, please refer to the operating manual of each of the instruments that are listed in Appendix B, List of Instruments.

14.0 Quality Control Requirements

This section describes the routine quality control procedures used for the meteorology monitoring program. All procedures have been specifically designed to provide the appropriate quality control and ensure that valid data recovery meets or exceeds the WDEQ-AQD data recovery requirements of 90 percent per quarter for meteorology monitoring.

The meteorological measurements follow the quality control guidelines as stated in the following documents:

- Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, EPA-454/B-08-002, March 2008[4]
- EPA's Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005, February 2000[6]

14.1 Instrument/Equipment Calibration and Frequency

Table 6 illustrates the QC procedures and their frequency for meteorology instruments.

Table 6. Meteorology Sensor QC Procedures

Procedure	Frequency	Requirement
Visual Inspection of Equipment	Each site visit; typically, once a month	As needed, see below
Remote interrogation of monitoring station and inspection of data	Daily	QC Checks for data screening. Section 14.2
Calibration	Every six months or whenever maintenance or replacement occurs.	See brief description in Section 14.3 and detailed description in SOP
Equipment Maintenance	As needed or as the operating manual recommends	Section 15
Data Validation	Daily and monthly	Section 22 and 23

Normally, the Site Operator visits the shelter at least once per month to check that the analyzers and meteorological instruments are operational and recording concentrations typical for the environment. At this time, the Site Operator will step outside and look at the meteorological sensors to make sure they are operational. Here are a few items the site operator will look for:

- Is the propeller or cups moving?
- Does the wind direction appear to be correct relative to the cross arm direction?
- Is it raining, or was there precipitation last night? Check the DAS.
- Does the temperature appear to be normal with how it feels outside, either cold or hot?
- Do the vents in the temperature/RH housing appear clear?
- Is the window on the ceilometer clean?

If any of these items do not appear to be correct, it may be necessary to perform an up-close inspection and/or calibration.

14.2 Remote Interrogation of Monitoring Station and Inspection of Data

The DAS at the monitoring stations will be interrogated daily via an internet connection to download and process the data. Abnormal data values or problems will be reported as soon as possible to the Contractor, who will initiate corrective action and determine if a special site visit is required.

Computerized inspection and visual inspection of these data will be performed daily using an outlier program. Values that fall outside of prescribed limits will be evaluated by the Contractor and Project Manager and corrections to data will be documented.

14.3 Instrument/Equipment Calibration and Frequency

The following paragraphs are brief descriptions of the calibration of the meteorological instruments. Detailed procedures are found in the SOP for meteorological sensors.

Wind Direction: The cross arm orientation will be checked using a professional compass. The wind vane will be aligned with the cross arm and set to true north. True north is distinguished from magnetic north by reading a magnetic compass and applying a correction factor for the magnetic declination. The declination will be determined from a declination calculation computer program. If the overall wind direction error (orientation plus linearity) exceeds ±5 degrees from true North, the sensor will be re-calibrated. The wind direction sensor starting threshold will be checked using a torque gauge. The torque gauge is placed on the sensor shaft and the torque is measured. If the sensor starting threshold is greater than 0.5 meters per second (m/s), the bearings will be replaced and the sensor will be re-calibrated. The wind direction linearity will be checked using a direction template. The sensor response will be checked at a minimum at 30-degree increments in both clockwise and counterclockwise rotations and compared with the DAS readings. If the indicated wind direction linearity plus orientation error exceeds ±5 degrees, the sensor will be repaired and recalibrated.

Wind Speed: Wind speed response checks will be performed using a synchronous motor. Sensor readings taken from the DAS will be compared to calibration values obtained from transfer functions provided in the sensor manufacturer's specifications. If the wind speed error exceeds ±0.25 m/s when ≤5 m/s or±5% when > 5 m/s not to exceed ±2.5 m/s, then the instrument will be recalibrated. The horizontal wind speed sensor starting threshold will be checked using a torque gauge or a torque disc. The torque device is placed on the sensor shaft and the torque is measured. If the measured torque exceeds the manufacturer's tolerance specifications the for wind speed sensor starting threshold of 0.5 m/s, then the bearings will be replaced and the instrument will be recalibrated.

Vertical Wind Speed: The VWS speed response checks will be performed using a synchronous motor similar to the horizontal wind speed instruments. The VWS Sensor readings taken from the DAS will be compared to calibration values obtained from transfer functions provided in the sensor manufacturer's specifications. Note that the readings must be taken in both directions; upward and downward (clockwise and counter-clockwise). With the propeller removed, record the zero point. Next, a selectable speed anemometer drive is connected to the sensor shaft to simulate wind speeds through the operational range of the system. The DAS responses are then compared to the calculated actual values and the differences compared to the calibration criteria. The VWS values should not exceed +/- 0.20 m/s.

Temperature: Temperature sensor calibration will be verified by direct comparison of sensor outputs to a collocated calibrated reference standard thermometer encompassing the measurement range expected at that particular site. If the sensor output is more than 0.5 degrees Centigrade (°C) different from the reference, the sensor will be repaired and re-calibrated. Sensors at different levels will be checked simultaneously in the same medium so that the delta temperature (ΔT) function can be verified. If the vertical temperature difference differs by more than 0.1°C for 10-2 meters, the sensors will be repaired/replaced and recalibrated.

Relative Humidity: The relative humidity sensor calibration will be verified by comparison of station sensor outputs with a relative humidity reference sensor collocated at ambient conditions. If the site sensor output differs by more than ±7 percent relative humidity from the reference, the sensor will be repaired/replaced and recalibrated.

Solar Radiation: The solar radiation pyranometer outputs will be verified by the collocation of a calibrated pyranometer adjacent to the system sensor. Readings from the reference pyranometer will be compared directly to the site's pyranometer readings recorded on the DAS. If the sensor output differs by more than ±10 W/m^2 below 200 W/m^2 or 5% above 200 W/m^2 from the reference, the sensor will be recalibrated.

Barometric Pressure: The barometric pressure sensor calibration will be verified by collocation of a certified reference barometer and comparing the reference output with sensor outputs recorded on the data acquisition system. If the site sensor output differs from the reference by more than ±3 mb, the sensor will be recalibrated.

Precipitation: Precipitation sensor output will be verified using a standard graduated burette or dripper bottle to add water to the gauge simulating rainfall. If using a graduated burette, the volume of water required to produce ten tips will be recorded for each of three runs. This volume will be divided by the area of the gauge opening to determine the calculated amount of simulated rainfall. This amount will be compared with amounts reported by the station DAS. If using a dripper bottle, the volume of water will be used to calculate the expected DAS value based on the site gauge. If the sensor differs by more than ±10% from the reference input, the sensor will be recalibrated. During calibration verification, the Site Operator will confirm that both sides of the tip bucket have similar sensitivity and provide similar balance results.

Ceilometer: The altitude reporting of the ceilometers will be verified by aiming the ceilometer at a hard target a known distance away. This "hard target" calibration should be performed by pointing the ceilometer at an object that reflects the light source a known distance. The nominal distance is recommended to be 300 meters from the ceilometer. A hard target could be a wall at ground level, a vehicle, or other large profile object of known distance (the ceilometer would be angled down, the beam aimed roughly parallel to the ground).

14.4 Calibration Reference Standard Certification

All equipment used to calibrate the meteorological instruments must be National Institute of Standards and Technology (NIST) traceable. Each of these equipment must be sent back to the manufacturer or tested against a primary standard in order to be used to calibrate the field instruments. Please see the SOP for meteorological sensors for more details on the calibration reference standards.

Table 7. Meteorological Calibration Equipment

Parameter	Type of Standard
Wind Direction	Compass Vane torque gauge Linearity reference
Wind Speed	Anemometer Drive Torque Disc
Temperature, Delta Temperature	Electronic Thermometer
Relative Humidity	Digital Humidity Sensor
Solar Radiation	Solar Radiation Sensor
Precipitation	Burette or graduated cylinder or dripper bottle
Barometric Pressure	Digital Barometer

Table 8. Calibration and Accuracy Criteria for Meteorological Sensors[4,6]

Measurement	Verification/Calibration			Accuracy/Audit		
	Type	Acceptance Criteria	Frequency	Type	Acceptance Criteria	Frequency
Ambient Temperature	3 pt. Water Bath with NIST- traceable thermistor or thermometer	±0.5 °C	Semi- Annually	3 pt. Water Bath With NIST-traceable thermistor or thermometer	±0.5 °C	Semi- Annually
Vertical Temp. Diff.	3 pt. Water Bath with NIST- traceable thermistor or thermometer	±0.1 °C	Semi- Annually	3 pt. Water Bath With NIST-traceable thermistor or thermometer	±0.1 °C	Semi- Annually
Relative Humidity	NIST-traceable Psychrometer or standards solution	±7% RH	Semi-Annually	NIST-traceable Psychrometer or standards solution	±7% RH	Semi- Annually
Wind Speed	NIST-traceable Synchronous Motor, CTS method	±0.25m/s ≤5m/s; 5%>2m/s not to exceed 2.5m/s	Semi- Annually	NIST-traceable Synchronous Motor	±0.25m/s ≤5m/s; 5%>2m/s not to exceed 2.5m/s	Semi- Annually
Vertical Wind Speed	NIST-traceable Synchronous Motor, CTS method	±0.20 m/s	Semi- Annually	NIST-traceable Synchronous Motor	±0.20 m/s	Semi- Annually
Wind Direction	GPS	±5 degrees; includes orientation error	Semi- Annually	GPS	±5 degrees; includes orientation error	Semi- Annually
Solar Radiation	NIST-traceable Pyranometer	below 200 w/m^2: 10 w/m^2 above200 w/m^2: ±5%	Semi- Annually	NIST-traceable Pyranometer	below 200 w/m^2: 10 w/m^2 above200 w/m^2: ±5%	Semi- Annually
Barometric Pressure	NIST-traceable Aneroid Barometer	±3 mb	Semi- Annually	NIST-traceable Aneroid Barometer	±3 mb	Semi- Annually

Measurement	Verification/Calibration			Accuracy/Audit		
	Type	**Acceptance Criteria**	**Frequency**	**Type**	**Acceptance Criteria**	**Frequency**
Precipitation	Burette and graduated cylinder Dripper bottle	±1% of input volume	Semi- Annually	Burette and graduated cylinder Dripper bottle	±10% of input volume	Semi- Annually
Ceilometer	Aim at hard object	± 5 meters of know distance or ± 1%, whichever is greater	Semi- Annually	Radiosonde	±5 meters or ±1% of known height of temperature inversion, whichever is greater	Semi- Annually

15.0 Equipment Maintenance

The manufacturer's recommendations for maintenance will be followed. Sensor instruction manuals are available at the site for the reference of preventive and remedial maintenance procedures. Preventive and corrective maintenance will be documented on the calibration forms completed immediately after any maintenance. **Table 9** in section 16.0 detail equipment maintenance.

16.0 Instrument Equipment Testing, and Inspection

16.1 Acceptance Testing of Instrumentation and Equipment Integration

Prior to installation, all equipment will be visually inspected to ensure there is no physical damage. Acceptance testing of sensors will be performed to verify that the sensors meet the suggested regulatory performance criteria set by the manufacturer.

To ensure that the sensors and analyzers are operating properly, periodic performance audits are conducted by the WDEQ-AQD semi-annually for meteorological parameters.

During each site visit, entries will be made in the site or electronic logbook (E-log) documenting all site activities conducted. These entries will include the date of the visit, the reason for the visit, and the maintenance or calibration activities, if performed. If changes are made to the equipment or configuration of the system, these changes will also be entered in the site logbook. If the Site Operator encounters a problem that cannot be rectified, he/she will contact the Contractor, who will be responsible for resolving the issue. The Contractor will initiate a plan for corrective action and will employ whatever resources are required to rectify the situation.

Entries will be made when: (1) any meteorological instrument data output appears to not match the atmospheric conditions (2) there is a visible problem with the meteorological sensor. For instance, if one of the propeller blades or anemometer cups are missing, this will be logged into the logbook and corrective action will ensue.

16.2 Site and Equipment Maintenance

The manufacturer's recommendations for maintenance of the meteorological sensors will be followed. Instrument instruction manuals are available for reference of preventative and remedial maintenance procedures. Preventive and corrective maintenance will be documented on calibration forms completed immediately after any maintenance. See **Table 9** for activity and frequency.

Table 9. Equipment Maintenance Activities

Maintenance Activity	Frequency
Wind Speed and Direction	
Check bearing for drag	Every calibration or audit
Check cups, propeller or vane for integrity	Every visit
Temperature and Delta Temperature, Relative Humidity	
Verify inlets or Gill screen is clear	Monthly
Inspect wires for integrity	Monthly
Solar Radiation	
Inspect wires for integrity	Monthly
Check window for dust or debris	Monthly
Barometric Pressure	
Inspect wires for integrity	Monthly
Verify inlets is clear	Monthly
Ceilometer	
Inspect wires for integrity	Monthly
Check window of instrument is clear of debris	Annually
Check door gasket for integrity	Annually

17.0 Inspection/Acceptance of Supplies and Consumables

17.1 Spare Parts

Spare parts for the meteorological instruments will be stored in the monitoring shelter and will be used as needed. These spare parts include, but are not limited to wind speed and direction bearings, cups and vanes.

17.2 Inspection/Acceptance of Supplies and Consumables

Spare parts will be purchased only from the instrumentation manufacturer by the Project Managers or Contractors. Parts will be inspected by the Project Managers, Contractors or Site Operators for shipping damage upon receipt. Spare parts will be kept in the monitoring shelter for use when needed. The use of spare parts will be documented on calibration forms.

18.0 Non-Direct Measurements

The meteorological data collected from the WDEQ-AQD meteorological monitoring program are utilized to support the gaseous instruments as described in Section 7.0 of this QAPP. There are no NAAQS and WAAQS non-attainment decisions that will be made for meteorological data. The data will be used to perform dispersion modeling, and/or utilized to validate or verify ambient air pollution data.

19.0 Data Management

The proper management of all data is critical to assuring the quality and usability of the monitoring results. As such, procedures have been implemented to ensure robust data acquisition, validation, reduction, reporting, and storage of electronic data. Meteorological data will be recorded and stored on the site DAS. Ceilometer data is not stored on the DAS, it is stored on an independent computer that has software that can collect, store and interpret the mixing height layer (MLH) data. Data will be retrieved from the monitoring site daily via internet connection. The monitoring site can be called from any computer having the correct software and the IP address.

All electronic calculations and statistical analyses will be performed using standard software that can be easily verified. All project documentation, records, data, and reports will be stored for at least five (5) years following project completion. The data are stored at the WDEQ-AQD network servers once it is reported to AQS and will be archived at a separate location.

Meteorological data will be reviewed routinely by the Contractor and Project Managers. These data will be subjected to several levels of QC, validation and QA. Validated data are compiled into the final database for further analysis and report preparation. The final database is processed and stored on a personal computer and then archived on various storage media and maintained in duplicate in more than one location for protection. For more details, please see Sections 21 and 22.

19.1 Data Retrieval

Data is retrieved from the site by connecting to the DAS via remote telemetry. The MLH are also retrieved via remote telemetry separately. In the past, WDEQ-AQD did not house the raw data. The data were housed and validated data by the Contractors. Recently, the WDEQ-AQD changed over to the AirVision platform also known as WyVisNet. This is a WDEQ-AQD housed data storage system that will be accessible to both Contractors and WDEQ-AQD staff. For the SLAMs stations (PM), the WDEQ-AQD data will be housed in the AirVision system and the WDEQ-AQD staff will perform validation on the data. For our SPM/gaseous stations, the Contractors will be the primary data repository.

19.2 Raw Data

Raw data are records, notes, memoranda, worksheets or exact copies and are the result of original observations and activities of the monitoring project. Raw data include data from the DAS and data entered directly into a system.

19.3 Data Transfer

The sensors produce digital and analog voltages that are collected by a DAS and averaged for a particular time period. The data are stored on a network and are validated quarterly. The hourly air quality data are uploaded to WyVisNet every 15 minutes.

19.4 DAS Data Review

Data review is performed by the Contractor. The review of the data includes reviewing the calibration information, maintenance logs, hourly data, flags, and recording any information that might be vital to proper review of the data. Information used in the review may be used to invalidate data.

It is recommended that the Contractor follow a checklist when reviewing. This list should provide a reminder for the reviewer to verify missing data periods, percent data recovery, or data table calculations, to name a few. Data review also includes documentation of suspect data or invalidations that occurred.

19.5 Data Validation

Data validation ensures that data processing operations have been carried out correctly and that the field operations have been performed properly and in accordance with written procedures. Once data validation has identified problems, the data can be corrected, flagged or invalidated and corrective actions can be taken when necessary. In the event of a failed audit or out-of-range calibration, the Contractor or Project Manager will be responsible for checking or invalidating data. Data validation procedures are described in detail in Section 22.

19.6 Data Transmittal

Data transmission occurs when data are transferred from one location to another or from one person or group to another. An example of data transfer is the electronic transfer of data over a telephone or computer network. WDEQ-AQD requires that data be prepared in AQS format on a quarterly basis and stored in zip files with a specific name format that incorporates the reported year and quarter.

The Data Manager will report all ambient air quality data and information as specified by the AQS Users Guide and coded in the AQS format. Such data will be fully validated and will be submitted directly to the AQS via electronic transmission.

19.7 Data Processing

Data processing includes the aggregating and summarizing of results so they can be easily understood and interpreted in various ways. EPA regulations require certain summary data be computed and reported on a regular basis such as precision, accuracy, bias, etc.

19.8 Data Analyses

Data summary and analysis requirements, as presented in the QA Handbook Volume IV[2] will be followed for this program. Please see Section 10 of the QA Handbook for more details on how analyses for meteorological data are performed.

19.9 Data Flagging

Data will be flagged if a numeric result was available but it has been qualified in some respect related to the validity of the result. Null data codes will be generated for invalid data as they are entered into the AQS database.

An exceptional event, as defined in 40 CFR §50.1 (j)[7] is one that affects air quality, is not reasonably controllable or preventable, and is caused by human activity that is unlikely to recur at a particular location or a natural event. Additional requirements in 40 CFR §50.14(1)[8] (2) and (b) (1) identify that a state must demonstrate a “clean and casual relationship between the measured exceedances or violation of such standard and the event” and that “an exceptional event caused a specific air pollution concentration in excess of one or more national ambient air quality standards.” Thus, WDEQ-AQD and the Contractors will flag data related to an exceptional event at the request of the WDEQ-AQD. Electronic copies of the data will be stored at the WDEQ-AQD office in Cheyenne, Wyoming.

19.10 Data Submittal to the Air Quality System

Each quarter, WDEQ-AQD files of observed data that are ready for AQS upload (“RD” transaction) are prepared and submitted to WDEQ-AQD’s IMPACT system. These files are prepared from validated hourly data and conform to the AQS coding guidelines found on the AQS website[9]. Missing data will carry the null code that best describes the reason for each missing data point. The most common reasons for missing data include calibration, maintenance, audit, and power outage.

Data may also be marked with a qualifier code to denote suspect data if necessary. Data in the AQS files may be reported in standard or alternative units which are defined by AQS. For details on WDEQ-AQD AQS coding, please see Appendix B, Ancillary Information, and Section 3.0.

Section C. Assessment and Oversight

20.0 Assessment and Response Actions

The WDEQ-AQD QA Coordinator will perform the semi-annual performance audits on the meteorological sensors. Audit procedures and techniques followed by the WDEQ-AQD are established by EPA and can be found in EPA's QA Handbook, Volume IV[4].

Performance audits are attended by a Contractor representative and the QA Coordinator. Audit summaries are available on WDEQ-AQD's IMPACT system.

EPA QA Handbook established the audit levels for the meteorological instruments. Please see **Table 8** in Section 14 of this QAPP for details on the annual accuracy requirements.

21.1 Data Quality Audits

Data review is conducted daily utilizing electronic and visual scanning to identify outliers and determine whether data are reasonable and representative. The systems audit includes a confirmation of the integrity of transmitted data from sensor outputs to data reporting.

21.2 Corrective Actions

All deficiencies identified during routine data surveillance, performance audits and/or site surveillances will be documented and reported to the Project Manager and Contractor no later than one working day of discovery and, depending on the nature of the deficiency, corrective action will be made no later than seven (7) business days of the notification. Corrective actions to deficiencies will be addressed and documented in the station logbook and on a corrective action report. Follow-up action shall be taken to verify implementation of the corrective action. A corrective action report form will be filled out and identify the problem or deficiency, the proposed corrective action, and the results of the corrective action. An example of a corrective action report is presented in Appendix A of the SOP for meteorological sensors. WDEQ-AQD has the authority to issue stop work orders to contractors, if necessary.

21.3 QAPP Revisions

If revisions to the QAPPs are needed, any modifications will be performed or approved by the WDEQ-AQD. QAPP reviews will be performed annually by WDEQ-AQD.

21.0 Reports to Management

A summary of the reports to be generated is presented in **Table 10**. The QA Coordinator or his/her designate will generate reports to management.

Table 10. Reports to Management

Reports	Frequency	Content	Responsible Individual	Distribution
Quarterly Reports	Quarterly	Summarize data for Quarterly Summaries	Contractor	See Section 3 Distribution List
Annual Report	Annually	Summarize data for Annual Reports	Contractor	See Section 3 Distribution List
Corrective Action Reports	As Needed	Summarizes Corrective Actions Taken to return the Monitoring Station into compliant status	Contractor	See Section 3 Distribution List
Response to Corrective Action Reports	As Needed	Reports the results of the Corrective Actions Taken	Contractor	See Section 3 Distribution List

Quarterly reports will be submitted to the WDEQ-AQD within 60 days of the end of the monitoring quarter. The annual report will be submitted to the WDEQ-AQD within 90 days of the end of the monitoring year. Corrective action reports are submitted as needed within seven (7) business days of identifying a deficiency and in the quarterly report.

Section D. Data Validation and Usability

22.0 Data Review, Validation, and Verification Requirements

The data validation criteria are based on US EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volumes II and IV[2,4]. The data validation criteria are detailed in **Table 8** and are based on the EPA QA handbook IV templates.

The Project Managers, Contractors and Site Operator are responsible for verifying proper operation of the monitoring equipment under their control. The Contractors will review the incoming data to the standards discussed in this document. During each quarter, the data will be reviewed again by a Project Manager to ensure that the data are complete, accurate, and representative and that erroneous data have been removed in preparation for the final data report.

The Contractor will routinely check for irregularities during the daily data review. Data review includes evaluation of the raw data, maintenance records, calibration and audit data. Any abnormalities in the data will be flagged and noted on the appropriate checklists. Any suspect data will be brought to the attention of the Project Manager as soon as possible. All other documentation pertaining to the project (i.e. station logs, field notes, calibration and audit sheets) will be reviewed to ensure that erroneous data are identified and removed, as necessary from the final data set.

Calibration procedures for the meteorological equipment are presented in Section 14.3 of this QAPP and the SOP for meteorological sensors. The sensor's accuracy will be determined using the data presented in **Tables 4 and 8**. Meteorological data will be considered valid when the system response indicated calibration responses and accuracy goals are being achieved.

22.1 Data Acceptance Limits for Meteorological Data

Performance audits will be conducted to verify calibration and maintenance of the sensors are correct. Audit results will be used to invalidate periods of data when the sensor is not operating within specifications as discussed in **Table 8** of this QAPP

Meteorological data will be valid and acceptable if the following conditions apply:

- The instruments are calibrated or audited and meet the requirements in **Table 8**.
- The review of the data meets the requirements of the data validation process. See Section 23 for details on data validation.

23.0 Data Validation and Verification Methods

Meteorological data are stored on DAS loggers as one minute and hourly averages (at a minimum) computed from one-second values. Data validation will be performed on the hourly average data. An hourly average will be computed when at least nine five-minute averages are available for the hour.

The Project Managers and Contractors are responsible for verifying the data by reviewing the calibration records, audit results, and field notes from the Site Operator prior to formal acceptance of these data. The Project Managers will use the validation criteria (**Tables 4 and 8**) to ensure that the reported data meets the appropriate DQIs.

23.1 Level 0 Data Validation

Level 0 data validation is essentially raw data obtained directly from the data acquisition systems in the field. These data have not received any adjustments for known biases or problems that may have been identified during preventive maintenance checks or audits. Level 0 data validation is accomplished by:

- Collecting data via modem
- Initially screening the daily data for anomalies

Stacked parameter plots will be generated which consist of every data point downloaded since the last site interrogation and reviewed by a Contractor for consistency and possible problems. This redundancy assures that problems that might go unnoticed by the software will always be caught by the reviewer.

To aid in data validation, a password-protected project web-site will be hosted which will be updated daily. This will differ from Contractor to Contractor. The site should contain 24-hour meteorological chart graphics, daily minimum, maximums, and averages, quality assurance reports and wind roses. Historical data should also be accessible**. Figures 4 and 5** present examples of these graphics. By using this approach, data collection percentages are greatly enhanced and data management personnel can quickly note and resolve any potential instrumentation problems.

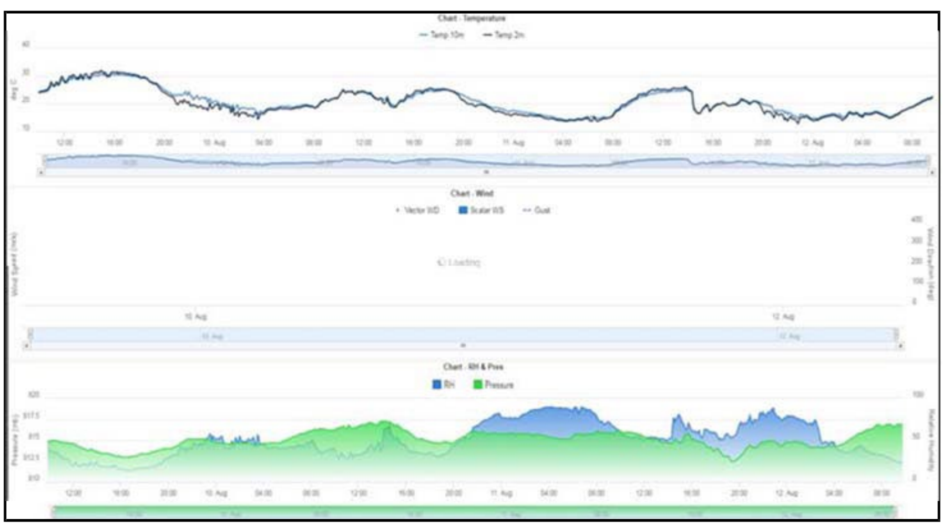

Figure 4. Real Time Meteorological Data Display

Figure 5. Real-Time Air Quality Display

23.2 Quality Control Checks for Data Validation

Once data are downloaded via modem, they will be subjected to a series of QC checks by a software package. The software package performs extensive quality control checks of the data, generates a data summary report which lists means, maximums, minimums, time of occurrence, data values which fall outside of prescribed ranges, periods of constant values, and periods of rapid value changes.

These criteria may be adjusted as data are collected to more accurately encompass site-specific conditions.

For the meteorological parameters, additional data review will be initiated by the following:

- When values approach the upper end of the operating ranges
- When values remain at the lower end of the operating range or go below the lower operating range.

The QC software is used to generate flags or warnings that the parameter value is outside of a normally acceptable range. The outlier program does not invalidate data or erase file records on the basis of these outlier tests. Raw data files are never modified and are archived. It will be left to the Contractor to review the results of the outlier program in conjunction with the data parameter plots and initiate corrective actions if warranted (site visit or data invalidation).

23.3 Level 1 Data Validation

After the QC software is run, visual inspection of the data is performed to identify suspect data values that warrant further investigation. These values will be flagged.

Per EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Ambient Air Quality Monitoring Program[2], EPA recommends the use of flags or result qualifiers to identify potential problems with data (or a sample). According to EPA, a flag is an indicator of the fact and the reason that a data value (a) did not produce a numeric result, (b) produced a numeric result but it is qualified in some respect relating to the type or validity of the result, or (c) produced a numeric result but for administrative reasons is not to be reported outside the organization.

Thus, quality control flags and codes, consisting of a letter and value will be assigned to each datum to indicate its quality. Multiple flags will be applied to each invalid data point such as data invalid due to calibration. **Table 11** presents the data flags and codes that will be applied to the data. AQS qualifier codes can be found at; https://aqs.epa.gov/aqsweb/documents/codetables/qualifiers.html.

Table 11. Data Flags

Flag	Code	Description
V	0	Valid
C	1	Corrected or Estimated
S	7	Suspect: data appears to be a data spike or outside normal data range
I	8	Invalid data
M	9999	Missing data: measurement not taken
BJ	9963	Operator Error
AC	9969	Construction in Area
AL	9978	Voided by Operator
AM	9979	Miscellaneous Void
AN	9980	Instrument Malfunction
AP	9982	Vandalism
AQ	9983	Collection Failure
AS	9985	Poor QA Results
AT	9986	Calibration
AV	9988	Power Failure
AW	9989	Wildlife Damage
AZ	9992	QC Audit
BA	9993	Maintenance
BB	9994	Unable to Reach Site
BC	9995	Multi-Point Calibration

To assist in data validation, a copy of the site logbook and E-log will be examined to confirm periods when instrumentation may have been off-line due to power outages, maintenance or repair, audits, or other quality assurance activities. Significant events will be checked against the graphs for consistency. Especially high values will be checked to be sure that audit or calibration data were not inadvertently included. Suspect data will be reported but flagged as suspect. Missing data will be left missing.

It is important to maintain detailed, accurate records of changes to the data. The justification for all data invalidations will be permanently documented. Suspect data will also be documented.

23.4 Minimum Acceptable Data Recovery Percentage

To be considered valid, each hour of meteorological data must consist of at least 45 minutes (75% of a valid hour) of valid data. The data recovery goal for the data will be at least 90% per quarter.

23.5 Data Report QA Checklist

As part of the data validation process to prepare data for reports, report table content versus data files, missing data, off-line periods, percent data recovery and mathematical calculations are routinely verified.

24.0 Reconciliation with User Requirements

The objective of the meteorological network is to collect data that will provide the necessary information for the WDEQ-AQD to assess whether the DQOs are being met. The meteorological data will be used to characterize and monitor trends in air quality, National and State air quality standards' compliance, and may be used for national health assessments, model evaluations, and comparison with other meteorological data. Following the procedures described in this QAPP and the SOP for meteorological sensors will ensure that the DQOs are met and the data will be representative of air quality conditions and be of acceptable quality for precision, bias and completeness.

References

1. Wyoming Department of Environmental Quality- Air Quality Division 2020 Network Assessment. http://deq.wyoming.gov/media/attachments/Air%20Quality/Monitoring/Wyo%20Network%20Assessments/2020_Network_Assessment_FINAL.pdf

2. QA Handbook for Air Pollution Measurement Systems: Volume II: Ambient Air Quality Monitoring Program, January 2017, https://www.epa.gov/amtic/ambient-air-monitoring-quality-assurance#documents

3. Technical Assistance Document For Precursor Gas Measurements in the NCore Multi-Pollutant Monitoring Network, Version 4, EPA-454/R-05-003 September 2005

4. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, EPA-454/B-08-002, March 2008

5. Technical Assistance Document for Sampling and Analysis of Ozone Precursors for the Photochemical Assessment Monitoring Stations Program, EPA-454/B-19-004, April 2019

6. EPA's Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R- 99-005, February 2000

7. Code of Federal Regulations Title 40 Part 50.1 (j). https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr50_main_02.tpl

8. Code of Federal Regulation Title 40 Part 50.14(1). https://www.govinfo.gov/content/pkg/CFR-2011-title40-vol2/pdf/CFR-2011-title40-vol2-sec50-14.pdf

9. AQS Users Guide. https://www.epa.gov/aqs/aqs-manuals-and-guides

APPENDIX A: Standard Operating Procedures

A-1 Standard Operating Procedure for Meteorological Sensors

A-2 Standard Operating Procedure for Meteorological Sensor Audits

Wyoming
Department of Environmental Quality –
Air Quality Division

Standard Operating Procedure for Meteorological Sensor Audits

October 2023

Revision 2.0

1.0 Scope and Applicability

This SOP applies to the quality assurance activities involving the performance evaluations of meteorological sensors within the WDEQ-AQD air quality monitoring network. Meteorological audits are required 2 times per year per WDEQ-AQD QAPP and as recommended by the Quality Assurance Handbook, Vol. IV. This SOP details the procedures WDEQ-AQD will take to perform the audits in the field. Occasionally, the WDEQ-AQD may contract out the audits. If this is the case, the Contractor may have their own SOP to follow.

Meteorological measurements encompass a variety of different types of instrumentation and techniques. For this SOP and supporting documents, meteorological sensors include:

- Wind speed
- Wind direction
- Vertical wind speed
- Ambient temperature
- Delta Temperature
- Relative humidity
- Barometric Pressure
- Solar Radiation
- Precipitation

1.1 Introduction

Audits are performed with independent equipment and personnel from data generation. For WDEQ-AQD, the QA Coordinator or designated Contractor will travel to the site location with independent equipment to perform the audit. The audit is performed by using a certified meteorological equipment.

It is a requirement for meteorological sensors to be audited twice a year.

2.0 Summary of Method

This method is for use for auditing WDEQ-AQD meteorological sensors. The parameters to be audited include wind speed, wind direction, vertical wind speed, ambient temperature at 2 meters and 10 meters, delta temperature, relative humidity, solar radiation, barometric pressure, station temperature, and precipitation. These parameters will be audited twice a year.

2.1 Definitions

The following terms that are used throughout this document are defined here:

- **NIST:** This acronym refers to the National Institute of Standards and Technology. This is a laboratory in Washington D.C. that creates standards for instruments and materials for government and non-governmental entities and also cooperates with other countries to create international standards. This is performed so that a value of one thing in data collected anywhere in the world or U.S. is comparable to the same information collected somewhere else.
- **NIST Traceability:** This term refers to a "transfer" of a standard or technique that allows the known standardization of one material or instrument to another. For example with sulfur dioxide, this is done by using sulfur dioxide gas that has been tested by a NIST traceable instrument and then placed into a compressed gas aluminum cylinder. In addition, the flow rates of the mass flow calibration (MFC) unit is also calibrated using NIST traceable flow devices, so that the operator in the field will know the level of gas that is being delivered within a known level of confidence. All gaseous analyzers within the WDEQ-AQD network are NIST traceable.
- **Horizontal Wind Speed:** Horizontal wind speed sensors commonly utilize a cup or propeller assembly turning on either a vertical or horizontal axis. The aerodynamic shape of the cups converts the wind pressure into torque. This will turn a shaft which is supported by low friction, precision bearings. The shaft rate of rotation is converted to wind speed by the use of a transducer. Ideally, there is a linear relation between rate of rotation and wind speed, above the starting threshold. Please note that because no bearings are frictionless, there is a finite amount of wind, albeit very low, which is needed to start the anemometer to begin to move. This amount of wind is known as the starting threshold. An audit on this sensor provides physical verification that: 1) the sensor's starting threshold has not changed, or is below the instrument manufacturer's stated starting threshold and 2) the transducer is properly converting cup rate of rotation (rpm) to wind speed. For sonic anemometer systems are based on the principle that wind changes the transit time of a sound pulse across a fixed distance. Sonic systems can be designed in two dimensions for horizontal wind speed and direction as a replacement for the cup and vane or propeller units, or in three dimensions for both horizontal and vertical wind measurements. The measurement principle is based on the disturbance of the winds between the ultrasonic emitter and the receiver. The emitter sends out an ultrasonic pulse that is received by the sensor. As the wind perturbs this pulse wave, the sensor can detect the difference between calm winds and winds moving between the sensor and emitter. This disturbance is proportional to the wind speed and direction. Note that there are no mechanical components to sonic anemometers; therefore, there is no starting threshold.
- **Vertical Wind Speed**: The vertical wind speed sensor employs a helicoid four blade propeller. A miniature tachometer/generator produces an analog DC voltage proportional to the axial wind component. When propeller rotation reverses, signal polarity reverses. This produces a plus (+) or minus (-) direction of rotation. Performance audits verify starting threshold as stated in the previous paragraph, rpm to wind speed conversion, and proper signal polarity reversal. Ideally, there is a linear relation between rate of rotation and wind speed, above the starting threshold. Please note that because no bearings are frictionless. A calibration on this sensor provides physical verification that: 1) the sensor's starting threshold has not changed, or is below the instrument manufacturer's stated starting threshold and 2) the transducer is properly converting propeller rpms to wind speed.

- **Horizontal Wind Direction**: Wind direction sensors indicate the direction from which the wind is blowing. The wind direction is expressed as an azimuth angle on a 360° circle where 0° or 360° indicates North (usually True North) and 180° indicates South. Wind direction sensors use a tail assembly positioned on a vertical shaft to detect wind direction. Wind applies a force to the tail assembly of the sensor forcing the assembly to turn into the wind seeking a position of minimum force. The shaft of the sensor rests on low friction precision grade bearings and is connected to a low torque potentiometer. The potentiometer yields a voltage output proportional to the wind direction. The starting threshold of the sensor is controlled by the relationship of shape, size, and distance from the axis of rotation of the tall assembly to the vertical shaft, bearings, and potentiometer torque requirements. Sonic anemometers can detect wind direction as well due to the design of the systems. As the sensor is producing ultrasonic pulses from the emitters, it can estimate not only speed but direction as well.
- **Ambient Temperature**: For air quality applications, ambient temperature is measured with a temperature probe. The probes can be thermistor, resistance temperature detector (RTD), or thermocouple. The probe to be audited should be located in a radiation shield which protects it from the effects of solar heating and wind variations.
- **Delta Temperature:** Also known as delta T (ΔT), for air quality applications, delta temperature is measured with two temperature probes at different heights. The utility of this is to ascertain whether air is rising or falling. This information can go into dispersion models used to track movement of vertical movement of air.
- **Relative humidity:** RH is the ratio of the existing amount of water vapor in the air at a given temperature to the maximum amount that could exist at that temperature. This value is usually expressed in percent relative humidity (%RH), which is a variable parameter which is affected by atmospheric conditions during its measurement. Capacitive sensors sense RH utilizing a strip of metal between an electrical current. The metal strip electrical capacity (i.e., voltage) changes linearly with the RH.
- **Barometric pressure**: BP measurements can be used in modeling and can be used to correct an ambient measurement to standard conditions (298^{o}K and 760 millimeters of mercury). BP sensors use pressure transducers which transform the sensor response into a pressure-related electrical.
- **Solar Radiation:** Solar radiation is related to atmospheric stability and is commonly described in units of energy flux: Watts/meter2 (W/m^2). A pyranometer measures sun and sky radiation on a horizontal surface. Most pyranometers incorporate a thermopile sensor; however, a silicon photovoltaic cell can also be used. The net radiometer measures the difference between downward (solar) and upward (terrestrial) radiation.
- **Precipitation**: Precipitation is defined as, "the total amount of precipitation which reaches the ground in a stated period is expressed as the depth to which it would cover a horizontal projection of the earth's surface if there were no loss by evaporation or run-off and if any part of the precipitation falling as snow or ice were melted". Precipitation gauges work on the principle of a tipping bucket gauge. A funnel directs precipitation to a small inlet that directs water over two equal compartments, or buckets, that tilt in sequence with each representing a known quantity of rainfall. The motion of the buckets causes an electrical switch to close and the numbers of tips are counted.

3.0 Health and Safety Warnings

The following health and safety warning must be followed in order for safe operation of the instrument.

- Many meteorological instruments are mounted on booms on towers that can range between 10, 20 or even 30 meters in height. **It is strongly recommended never climb towers unless you are trained to climb.** Falling off of a tower even a few meters from the ground can cause injury or even death. All instruments on the towers must be lowered in order to safely perform audits, calibrations or maintenance.
- Most meteorological instruments operate on low direct current (DC) voltage. Usually, this voltage is also low in amperes (amps). However, some instruments have heaters that may have 110 volts alternating current (AC) that can shock or even cause death in some circumstances. It is important that each station technician know and understand whether or not the system they are working is powered by DC or AC current. In addition, if an instrument has two-lead wire, this means there is no ground on the instrument. Be careful not to ground the instruments if performing troubleshooting as this can damage electronic components.
- If working with any glass devices, such as burettes or flasks, use caution to not break them.
- Avoid electrical contact with jewelry. Remove rings, watches, bracelets, and necklaces to prevent electrical burns.

4.0 Cautions

- Always obtain the orientation of the instrument boom before you lower the tower. This can be done using a GPS device that shows position and direction.
- It is recommended that a winch and cable system be installed to lower the tower.
- Some meteorological towers can be very heavy. It is recommended that two or three people be available to lower towers on a tripod base. Do not drop the tower. This can damage the instruments on the top boom or bend the tower.
- Always guy the meteorological tower. High, consistent or gusty winds can damage or even knock over a tower that is not guyed.

4.1 Interferences

Do not place solar radiation sensors in location where a shadow may cross over its sensor. This will cause false reading and the data will need to be invalidated.

5.0 Personnel Qualifications

It is the responsibility of WDEQ-AQD or the Contractor to train their auditing staff on instrument operation and maintenance. It is a requirement of the WDEQ-AQD to train their staff and keep records of all training that is performed. Although meteorological instruments are self-contained, there is a level of knowledge of electronics and know-how involved in the operation and maintenance of the instrument. The instrument manual is the best training tool for this.

6.0 Equipment

The following supplies are required for the operation of this instrument:

- Wind speed R.M. Young Selectable Speed Anemometer Drive and R.M. Young torque disk
- Wind direction: Bruton compass to determine the alignment of the sensor. R.M. Young Vane Angle Bench Stand.
- Ambient temperature: NIST traceable thermometer, potable water, ice, heating element and thermally isolating container.
- Delta Temperature: NIST traceable thermometer, potable water, ice, heating element and thermally isolating container.
- Relative Humidity: NIST traceable temperature/RH sensor, a data logger, aspiration shield.
- Barometric Pressure: NIST traceable altimeter
- Solar Radiation: NIST traceable solar radiation pyranometer
- Precipitation: 1000 mL drip bottle and water

6.1 Inspection/Acceptance of Supplies and Consumables

Spare parts will be purchased only from the instrumentation manufacturer by the QA Coordinator. Parts will be inspected by the QA Coordinator for shipping damage upon receipt. Spare parts will be kept in the WDEQ-AQD workshop for use when needed. Wind speed anemometer drives, altimeter, relative humidity probe, and thermometers will be sent off for annual certification. Solar sensors will be sent off every two years for certification.

7.0 Quality Assurance Procedures

Audits are required to be performed at a minimum of twice a year per WDEQ-AQD's Meteorological QAPP.

The audits are performed by challenging the sensor with known parameters or by collocation. The procedure for each sensor is listed in this section. On all audit forms, record the site sensor information including the make/model/serial number. For the audit forms, it is necessary to select the site type on the Site Verification/Audit Standards Form. This will populate the acceptance criteria for each parameter. All SPM stations will be PSD site and Cheyenne NCore will be an NCore site.

7.1 Solar Sensor Audit

1. Collocated at least one audit solar sensor with the site sensor. This can be done by placing the audit sensor directly next to the site sensor, relocating the site sensor next to the audit sensor, or placing the audit sensor(s) within reasonable distance to the site sensor. The positioning of sensor(s) should minimize the effect of any local interference or obstructions.
2. Make sure the audit sensor(s) is level and clean.
3. Connect the audit sensor(s) to the audit data logger.
4. Inspect the site sensor to check if it is clean and level. Note on audit form.
5. Record hourly averages for the site and the audit sensor(s). Record on audit form.

7.2 Relative Humidity Audit

1. Note if site has an active or passive aspiration shield.
   a. If site has a passive aspiration shield, attach audit aspiration shield and insert RH probe as close as possible to the site sensor.
   b. If site has an active aspiration shield, try to collocate the sensors as best as possible, under similar conditions.
2. Connect the audit RH probe to the audit data logger.
3. Record hourly averages for the site and the audit sensor(s). Record on audit form.

7.3 Barometric Pressure Audit

1. Hold audit standard as close to site sensor. Record the audit barometric pressure value.
2. On the site DAS, record the site barometric pressure value. Convert this to mmHg if necessary.

7.4 Precipitation Gauge Audit

1. Make notation in station logs and/or flag the precipitation channel in the on-site data logger indicating performance audit.
2. Check starting value for the precipitation channel. If greater than 0.0 note the starting precipitation value.
3. Fill drip bottle to 1000 mL.
4. Take large screen out of the precipitation gauge, if it is in the gauge.
5. Let bottle drip until empty.
6. Check the appropriate box for the make/model of the precipitation gauge on the audit form. Enter the DAS value in mm when all water has been introduced to the gauge. Convert value from inches to mm if necessary.

7.5 Wind Direction Audit

1. Sensor Alignment
    a. Make notation in station logs and/or flag the wind direction channel in the on-site data logger indicating performance audit.
    b. Determine the magnetic declination of magnetic north from true north using one of the following methods:
        i. Approved Solar Azimuth applications on your smart phone
        ii. National Geomagnetism Program from the USGS web site (http://geomag.usgs.gov/models)
        iii. National Geographic Data Center web site (http://www.ngdc.noaa.gov/seg/geomag/ magfield.shtml)
        iv. U.S. Navy Observatory web site (http://aa.Usno.navy.mil/data/docs/AltAz.html)
    c. Set up tripod and affix compass or transit at the same location where alignment checks will be performed (care should be taken to ensure the location is free of nearby interferences such as buried wires or pipes, buildings, cell phones, belt buckles, or other ferrous materials).
    d. Adjust the compass or transit to match the azimuth or declination determined.
    e. Rotate compass or transit to align the crosshairs through the cross-arm or alignment rod of the wind direction sensor.
    f. Enter alignment results in the audit form.
2. Sensor Linearity
    a. Use the appropriate linearity test assembly for the sensor under audit.
        i. RM Young sensors generally use either RM Young Model 18112 or 18212
        ii. Climatronics sensors use a 8-position Wilson Machining disc
    b. Cycle the test assembly through nine 45° increments.
    c. Enter results in audit form.
3. Starting Threshold/Torque
    a. While sensor is on the linearity template and level on the ground, release the tail such that it is freely moving. Install the torque disc on the sensor shaft.
    b. Note the weight size and distance from center when the shaft first turns (torque).
    c. NOTE: this test is extremely difficult when windy.

7.6 Wind Speed Audit

1. Wind Speed
    a. Make notation in station logs and/or flag the wind speed channel in the on-site data logger indicating performance audit.
    b. On the audit form, select the manufacturer and model of the sensor and measured units. This will populate the motor speed targets.
    c. Remove the propeller for the site monitor and attach the variable speed anemometer to the sensor shaft input.
    d. Set the anemometer drive to the slowest motor speed from the audit form and allow to stabilize.
    e. Record the results from the DAS in the audit form.
    f. Repeat with the other motor speeds listed on the audit form.
2. Starting Threshold/Torque
    a. Install the torque disc on the sensor shaft.
    b. Hold the sensor such that the shaft is parallel to the ground.
    c. Note the weight size and distance from center when the shaft first turns (torque).
    d. Enter the value in the audit form.
3. Vertical Wind Speed
    a. Follow the same process above using a low speed wind anemometer.
    b. Motor speeds will be tested clockwise and counter clockwise.

7.7 Ambient Temperature and Delta Temperature Audit

1. Make notation in station logs and/or flag the temperature channels and delta temperture channel in the on-site data logger indicating performance audit.
2. Prepare three different water baths in an insulated thermos: ice bath, ambient bath (~15-25 °C) and a high range bath (~40-50 °C). Measure these temperatures with a NIST-traceable digital thermometer.
3. Remove the temperature probe(s) from the aspirator(s) and check the fans for proper operation and flow.
4. Place the probe(s) in the first water bath along with an audit standard. Be sure not to submerge the sensitive components of the sensors.
5. Agitate the water bath until the values indicated on the DAS and audit standard stabilize.
6. Record measurements on the audit form.
7. Repeat for the other 2 water baths.
8. If there are multiple probes, verify the channels and check that the delta temperature is being calculated correctly.

7.8 Station Temperature Audit

1. Using an audit standard, collocate with the station temperature probe. Once audit standard is stable, record the temperature and the station temperature from the DAS on the audit form.

8.0 References

1. Environmental Protection Agency, 2000, Meteorological Montoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005 (February 2000).
2. Environmental Protection Agency, 2008, Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements (Version 2.0), EPA-454/B-08-002 (March 2008).

APPENDIX A
Meteorological Audit Forms

DEQ

Site Information
Audit Verification Standards

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

		Deg	Min	Sec		Decimal
Latitude	North				--CALCULATE->	
Longitude	West					

			Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference						
AT/RH Sensor Reference						
Barometric Pressure Reference						
Wind Speed Reference (high rpm)						
Wind Speed Reference (low rpm)						
Wind Speed Torque Gauge						
Wind Direction Alignment Reference						
Wind Direction Linearity Reference						
Wind Direction Torque Gauge						
Solar Radiation Reference						
Multiplier		W/m2 / mV				
Solar Radiation Reference						
Multiplier		W/m2 / mV				
UV Radiation Reference						
Multiplier		W/m2 / mV				
Precipitation Reference						
Volume		mL				

Notes:	

Temperature / Delta-Temperature System Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference				

Manufacturer	
Model	
Serial Number	

List sensors according to height on tower, from highest to lowest.

Temp. Deltas	
10m	2m

Sensor(s) verified against their data channel(s)?
☐ Yes ☐ No ☐ N/A
Temperature Difference = Upper - Lower?
☐ Yes ☐ No ☐ N/A

Audit Criteria (<=)	
Ambient Temperature Difference (^{o}C)	
Vertical Temperature Difference (^{o}C)	

	☐ Yes	☐ No	☐ N/A
	☐ Yes	☐ No	☐ N/A

Bath Temp (^{o}C)									
Max ABS Difference									

Notes:	

Relative Humidity Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
RH Sensor Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Relative Humidity Difference (%)	

	Relative Humidity (%)			
Hour	STD	DAS	Difference	
	Average			

Aspirator fan functional?	☐ Yes ☐ No ☐ N/A

Notes:	

Station Temperature Sensor Audit

Site Name		Auditor		Date	
Site Type				Time Of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference				

Audit Criteria (<=)	
Temperature Difference (°C)	

	Temperature		
Reference (°C)	DAS (°C)	Difference	

Notes:	

Wind Speed Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Wind Speed Reference				
Wind Speed Torque Gauge				

Manufacturer and Model	
Sensor Serial #	
Cups Serial #	

Audit Criteria (<=)	
Wind Speed Difference (m/s)	
Wind Speed Difference (%)	

Select Units	m/s

		Wind Speed			
Motor Speed (rpm)	Target Speed	DAS	Difference		
			N/A	N/A	N/A

Starting Threshold	Torque
Torque<= #N/A g-cm	

Heater sleeve functional?	☐ Yes ☐ No ☐ N/A

Notes:	

Barometric Pressure Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Barometric Pressure Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Pressure Difference (mmHg)	

	Barometric Pressure		
Reference (mmHg)	DAS (mmHg)	Difference	

Notes:	

Wind Direction Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Direction Alignment Ref.				
Direction Linearity Ref.				
Direction Torque Gauge				

Manufacturer & Model	-
Sensor Serial #	
Vane Serial #	

Local Magnetic Declination (degrees)	
Method	

Mag. Dec. from NOAA (deg/min/sec)				

http://www.ngdc.noaa.gov/geomag-web/#declination

Audit Criteria (<=)	
Cross-arm Alignment Error (degrees)	
Total Align. Diff (degrees)	
Sensor Linearity (degrees)	

Reference Alignment Error (degrees)		

Sensor Alignment				
Reference	Degrees	DAS	Difference	
From the North	0			
From the South	180			
From the East	90			
From the West	270			
Total Alignment MAX ABS Diff				

Sensor Linearity			
Point	DAS	Difference	
1		N/A	
2			
3			
4			
5			
6			
7			
8			
1			
MAX Difference			

Starting Threshold	Torque
Torque <= g-cm	

Heater sleeve functional? ☐ Yes ☐ No ☐ N/A

Notes:

Vertical Wind Speed Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Wind Speed Reference				
Wind Speed Torque Gauge				

Manufacturer and Model	-
Sensor Serial #	
Cups Serial #	

Audit Criteria (<=)	
Wind Speed Difference (m/s)	

Use recommended 1.25 multiplier?	Yes

Select Units	m/s

Motor Speed (rpm)	Target Speed (m/s)	Vertical Wind Speed		
		DAS (m/s)	Difference	
			N/A	N/A

CW = +

CCW = -

Starting Threshold	Torque	
Torque <= g/cm		

Notes:	

Solar Radiation Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date	Multipler
Solar Radiation Reference					

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Difference from CTS (%)	

	Solar Radiation		
Hour	CTS (W/m^2)	DAS (W/m^2)	Difference
	Mean ABS % Diff.		

Sensor found clean?	☐ Yes ☐ No

Sensor found level?	☐ Yes ☐ No

Notes:

Precipitation Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Precipitation Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Difference from Input Volume (%)	#N/A

	Reference Chart			Input Volume (mL)		
	Manufacturer	Model	Diameter(in)	mm/tip	mL/tip	DAS target
	Met One	385	12	0.254	18.53	#VALUE!
	RM Young	52202	6.2825	0.100	2.00	#VALUE!
	Climatronics	100097-1-G0-H0	8	0.254	8.24	#VALUE!
	Climatronics	100508	9.66	0.100	4.73	#VALUE!

Precipitation				
Reference (mL)	Target (mm)	DAS (mm)	Difference	
	#N/A			

Heater functional?	☐ Yes ☐ No ☐ N/A

Notes:	

Air Resource SPECIALISTS

STATION TEMPERATURE SENSOR VERIFICATION & CALIBRATION

ABBR.					
CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
Temperature Reference				

CALIBRATION ACCEPTANCE CRITERIA (<=)	
Temperature Difference (ºC)	#N/A

AS FOUND	Temperature		
Reference (ºC)	DAS (ºC)	Difference	

AS LEFT	Temperature		
Reference (ºC)	DAS (ºC)	Difference	

NOTES:

Air Resource SPECIALISTS

SOLAR RADIATION SENSOR VERIFICATION & CALIBRATION

ABBR.	

CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE	MULTIPLIER
Solar Radiation Reference					

AS FOUND

Manufacturer			
Model			
Serial Number			
Translator			
Logger Type		High Input (V)	
ESC		Low Input (V)	
		High Output	
		Low Output	

AS LEFT

Manufacturer			
Model			
Serial Number			
Translator			
Logger Type		High Input (V)	
ESC		Low Input (V)	
		High Output	
		Low Output	

CALIBRATION ACCEPTANCE CRITERIA (<=)	
Difference from CTS (%)	#N/A

DATA ACCEPTANCE CRITERIA (<=)	
Difference from CTS (%)	#N/A

AS FOUND	Solar Radiation				V
Hour	CTS (W/m^2)	DAS (W/m^2)	Difference		
	MEAN ABS % DIFF				

	DAS (W/m^2)
DARK RESPONSE	

Sensor found clean?	☐ Yes ☐ No
Sensor found level?	☐ Yes ☐ No

AS LEFT	Solar Radiation				V
Hour	CTS (W/m^2)	DAS (W/m^2)	Difference		
	MEAN ABS % DIFF				

	DAS (W/m^2)
DARK RESPONSE	

NOTES:	

Air Resource SPECIALISTS

PRECIPITATION SENSOR VERIFICATION & CALIBRATION

ABBR.	

CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
Precipitation Reference				

AS FOUND

Manufacturer	
Model	
Serial Number	

AS LEFT

Manufacturer	
Model	
Serial Number	

CALIBRATION ACCEPTANCE CRITERIA (<=)	
Difference from Input Volume (%)	#N/A

DATA ACCEPTANCE CRITERIA (<=)	
Difference from Input Volume (%)	#N/A

	Reference Chart			Input Volume (mL)		0
	Manufacturer	Model	Diameter (in.)	mm/tip	mL/tip	DAS target
X	Climatronics	100097-1-G0-H0	8	0.254	8.24	0.00
	Climatronics	100508	9.66	0.100	4.73	0.00
	Met One	370	8	0.254	8.24	0.00
	Met One	385	12	0.254	18.53	0.00
	RM Young	52202	6.2825	0.100	2.00	0.00
	Texas Electronics	TR-525I-HT	6.06	0.254	4.73	0.00

Conversions			
Value	Units	Value	Units
1.000	inch	25.400	mm
25.40	mm	1.000	inch

AS FOUND		Precipitation		
Reference (mL)	Target (mm)	DAS (mm)	Difference	
0	0.00			

Heater functional?	☐ Yes ☐ No ☐ N/A
Sensor found level?	☐ Yes ☐ No
Sensor found clean?	☐ Yes ☐ No

POST-maintenance check must be conducted after ANY maintenance performed on the precipitation gauge

AS LEFT		Precipitation		
Reference (mL)	Target (mm)	DAS (mm)	Difference	
0				

NOTES:	

Air Resource SPECIALISTS

RELATIVE HUMIDITY SENSOR VERIFICATION & CALIBRATION

ABBR.					
CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
RH SENSOR REFERENCE				

AS FOUND

Manufacturer	
Model	
Serial Number	

AS LEFT

Manufacturer	
Model	
Serial Number	

DATA ACCEPTANCE CRITERIA (<=)	
Relative Humidity Difference (%)	#N/A

AS FOUND	Relative Humidity (%)				V
Hour	STD	DAS	Difference		
	Average				

AS LEFT	Relative Humidity (%)				V
Hour	STD	DAS	Difference		
	Average				

Aspirator fan functional? ☐ Yes ☐ No ☐ N/A

NOTES:

BAROMETRIC PRESSURE SENSOR VERIFICATION & CALIBRATION

ABBR.	

CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
Barometric Pressure Reference				

AS FOUND

Manufacturer	
Model	
Serial Number	

AS LEFT

Manufacturer	
Model	
Serial Number	

DATA ACCEPTANCE CRITERIA (<=)	
Pressure Difference (mmHg)	#N/A

AS FOUND	Barometric Pressure		
Reference (mmHg)	DAS (mmHg)	Difference	

AS LEFT	Barometric Pressure		
Reference (mmHg)	DAS (mmHg)	Difference	

Common Pressure Conversions					
Value	Units	mmHg	mmHg	Value	units
1.000	atm	760.00	760.00	1.000	atm
29.92	inHg	760.00		29.92	inHg
1013.2	mb	760.00		1013.2	mb
1013.2	hPa	760.00		1013.2	hPa
14.70	psi	760.00		14.70	psi

NOTES:

WIND SPEED SENSOR VERIFICATION & CALIBRATION

ABBR.	

CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
Wind Speed Reference				
Wind Speed Torque Gauge				

AS FOUND	
Manufacturer and Model	RM Young - 05305 / 08254 PSD
Sensor Serial #	
Cups Serial #	

AS LEFT	
Manufacturer and Model	-
Sensor Serial #	
Cups Serial #	

DATA ACCEPTANCE CRITERIA (<=)		
Wind Speed Difference (m/s)	#N/A	##
Wind Speed Difference (%)	#N/A	##

Select UNITS	m/s

AS FOUND

Motor Speed (rpm)	Target Speed	Wind Speed DAS	Difference		
0	0.000		N/A	N/A	N/A
600	3.072				
1200	6.144				
4000	20.480				
7000	35.840				
9000	46.080				

Starting Threshold	TORQUE
Torque <= 0.3 g-cm	

Heater sleeve functional? ☐ Yes ☐ No ☐ N/A

AS LEFT

Motor Speed (rpm)	Target Speed	Wind Speed DAS	Difference		
			N/A	N/A	N/A

Starting Threshold	TORQUE
Torque <= g-cm	

NOTES:

Air Resource SPECIALISTS

WIND DIRECTION SENSOR VERIFICATION & CALIBRATION

ABBR.					
CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
Direction Alignment Reference			[redacted]	
Direction Linearity Reference				
Direction Torque Gauge				

AS FOUND	
Manufacturer & Model	-
Sensor Serial #	
Vane Serial #	

AS LEFT	
Manufacturer & Model	-
Sensor Serial #	
Vane Serial #	

Local Magnetic Declination (degrees)	
Method	

Mag. Dec. from NOAA (deg/min/sec)				0.00

http://www.ngdc.noaa.gov/geomag-web/#declination

Landmarks	Degrees
From the North	0
From the South	180
From the East	90
From the West	270

ACCEPTANCE CRITERIA (<=)	
Cross-arm Alignment Error (degrees) (CAL)	#N/A
Total Align. Diff (degrees) (DATA)	#N/A
Sensor Linearity (degrees) (CAL)	#N/A

Is the Reference Alignment intended to be N-S? YES

Is the Reference Alignment intended to be N-S? YES

AS FOUND

Reference Alignment (degrees)		#N/A

SENSOR ALIGNMENT

N-S Reference	Degree	DAS	Difference
From the North	0		
From the South	180		
From the East	90		
From the West	270		
Total Alignment MAX ABS Diff			

OR

SENSOR ALIGNMENT

Landmark	Degree	DAS	Difference
From the North	0		
From the South	180		
From the East	90		
From the West	270		
Total Alignment MAX ABS Diff			

OR

SENSOR ALIGNMENT

X Reference	Degree	DAS	Difference
	0		
	180		
	90		
	270		
Total Alignment MAX ABS Diff			

SENSOR LINEARITY

Point	DAS	Difference
1		N/A
2		
3		
4		
5		
6		
7		
8		
1		
MAX Difference		

Starting Threshold	TORQUE
Torque <= g-cm	

AS LEFT

Reference Alignment (degrees)		#N/A

SENSOR ALIGNMENT

N-S Reference	Degree	DAS	Difference
From the North	0		
From the South	180		
From the East	90		
From the West	270		
Total Alignment MAX ABS Diff			

OR

SENSOR ALIGNMENT

Landmark	Degree	DAS	Difference
From the North	0		
From the South	180		
From the East	90		
From the West	270		
Total Alignment MAX ABS Diff			

OR

SENSOR ALIGNMENT

X Reference	Degree	DAS	Difference
Align with Ref (N)	0		
Align with Ref (S)	180		
Perp with Ref (E)	90		
Perp with Ref (W)	270		
Total Alignment MAX ABS Diff			

SENSOR LINEARITY

Point	DAS	Difference
1		N/A
2		
3		
4		
5		
6		
7		
8		
1		
MAX Difference		

Starting Threshold	TORQUE
Torque <= g-cm	

Heater sleeve functional? ☐ Yes ☐ No ☐ N/A

NOTES:

Air Resource SPECIALISTS

AMBIENT TEMPERATURE SENSOR* VERIFICATION & CALIBRATION

*Non-Immersible

ABBR.	

CLIENT		FIELD SPECIALIST		DATE	
SITE NAME				DATE OF LAST VISIT	

	MANUFACTURER	MODEL	SERIAL NUMBER	EXPIRATION DATE
AT SENSOR REFERENCE				

AS FOUND

Manufacturer	
Model	
Serial Number	

AS LEFT

Manufacturer	
Model	
Serial Number	

DATA ACCEPTANCE CRITERIA (<=)	
Ambient Temperature Difference (ºC)	#N/A

AS FOUND	Temperature (ºC)				V
Hour	STD	DAS	Difference		
	Average				

AS LEFT	Temperature (ºC)				V
Hour	STD	DAS	Difference		
	Average				

Aspirator fan functional? ☐ Yes ☐ No ☐ N/A

NOTES:

Wyoming
Department of Environmental Quality –
Air Quality Division

Standard Operating Procedure for
Meteorological Sensor Audits

October 2023
Revision 2.0

1.0 Scope and Applicability

This SOP applies to the quality assurance activities involving the performance evaluations of meteorological sensors within the WDEQ-AQD air quality monitoring network. Meteorological audits are required 2 times per year per WDEQ-AQD QAPP and as recommended by the Quality Assurance Handbook, Vol. IV. This SOP details the procedures WDEQ-AQD will take to perform the audits in the field. Occasionally, the WDEQ-AQD may contract out the audits. If this is the case, the Contractor may have their own SOP to follow.

Meteorological measurements encompass a variety of different types of instrumentation and techniques. For this SOP and supporting documents, meteorological sensors include:

- Wind speed
- Wind direction
- Vertical wind speed
- Ambient temperature
- Delta Temperature
- Relative humidity
- Barometric Pressure
- Solar Radiation
- Precipitation

1.1 Introduction

Audits are performed with independent equipment and personnel from data generation. For WDEQ-AQD, the QA Coordinator or designated Contractor will travel to the site location with independent equipment to perform the audit. The audit is performed by using certified meteorological equipment.

It is a requirement for meteorological sensors to be audited twice a year.

2.0 Summary of Method

This method is for use for auditing WDEQ-AQD meteorological sensors. The parameters to be audited include wind speed, wind direction, vertical wind speed, ambient temperature at 2 meters and 10 meters, delta temperature, relative humidity, solar radiation, barometric pressure, station temperature, and precipitation. These parameters will be audited twice a year.

2.1 Definitions

The following terms that are used throughout this document are defined here:

- **NIST:** This acronym refers to the National Institute of Standards and Technology. This is a laboratory in Washington D.C. that creates standards for instruments and materials for government and non-governmental entities and also cooperates with other countries to create international standards. This is performed so that a value of one thing in data collected anywhere in the world or U.S. is comparable to the same information collected somewhere else.
- **NIST Traceability:** This term refers to a “transfer” of a standard or technique that allows the known standardization of one material or instrument to another. For example with sulfur dioxide, this is done by using sulfur dioxide gas that has been tested by a NIST traceable instrument and then

placed into a compressed gas aluminum cylinder. In addition, the flow rates of the mass flow calibration (MFC) unit is also calibrated using NIST traceable flow devices, so that the operator in the field will know the level of gas that is being delivered within a known level of confidence. All gaseous analyzers within the WDEQ-AQD network are NIST traceable.

- **Horizontal Wind Speed:** Horizontal wind speed sensors commonly utilize a cup or propeller assembly turning on either a vertical or horizontal axis. The aerodynamic shape of the cups converts the wind pressure into torque. This will turn a shaft which is supported by low friction, precision bearings. The shaft rate of rotation is converted to wind speed by the use of a transducer. Ideally, there is a linear relation between rate of rotation and wind speed, above the starting threshold. Please note that because no bearings are frictionless, there is a finite amount of wind, albeit very low, which is needed to start the anemometer to begin to move. This amount of wind is known as the starting threshold. An audit on this sensor provides physical verification that: 1) the sensor's starting threshold has not changed, or is below the instrument manufacturer's stated starting threshold and 2) the transducer is properly converting cup rate of rotation (rpm) to wind speed. For sonic anemometer systems are based on the principle that wind changes the transit time of a sound pulse across a fixed distance. Sonic systems can be designed in two dimensions for horizontal wind speed and direction as a replacement for the cup and vane or propeller units, or in three dimensions for both horizontal and vertical wind measurements. The measurement principle is based on the disturbance of the winds between the ultrasonic emitter and the receiver. The emitter sends out an ultrasonic pulse that is received by the sensor. As the wind perturbs this pulse wave, the sensor can detect the difference between calm winds and winds moving between the sensor and emitter. This disturbance is proportional to the wind speed and direction. Note that there are no mechanical components to sonic anemometers; therefore, there is no starting threshold.
- **Vertical Wind Speed**: The vertical wind speed sensor employs a helicoid four blade propeller. A miniature tachometer/generator produces an analog DC voltage proportional to the axial wind component. When propeller rotation reverses, signal polarity reverses. This produces a plus (+) or minus (-) direction of rotation. Performance audits verify starting threshold as stated in the previous paragraph, rpm to wind speed conversion, and proper signal polarity reversal. Ideally, there is a linear relation between rate of rotation and wind speed, above the starting threshold. Please note that because no bearings are frictionless. A calibration on this sensor provides physical verification that: 1) the sensor's starting threshold has not changed, or is below the instrument manufacturer's stated starting threshold and 2) the transducer is properly converting propeller rpms to wind speed.
- **Horizontal Wind Direction**: Wind direction sensors indicate the direction from which the wind is blowing. The wind direction is expressed as an azimuth angle on a 360° circle where 0° or 360° indicates North (usually True North) and 180° indicates South. Wind direction sensors use a tail assembly positioned on a vertical shaft to detect wind direction. Wind applies a force to the tail assembly of the sensor forcing the assembly to turn into the wind seeking a position of minimum force. The shaft of the sensor rests on low friction precision grade bearings and is connected to a low torque potentiometer. The potentiometer yields a voltage output proportional to the wind direction. The starting threshold of the sensor is controlled by the relationship of shape, size, and distance from the axis of rotation of the tall assembly to the vertical shaft, bearings, and potentiometer torque requirements. Sonic anemometers can detect wind direction as well due to the design of the systems. As the sensor is producing ultrasonic pulses from the emitters, it can estimate not only speed but direction as well.
- **Ambient Temperature**: For air quality applications, ambient temperature is measured with a temperature probe. The probes can be thermistor, resistance temperature detector (RTD), or thermocouple. The probe to be audited should be located in a radiation shield which protects it from the effects of solar heating and wind variations.

- **Delta Temperature:** Also known as delta T (ΔT), for air quality applications, delta temperature is measured with two temperature probes at different heights. The utility of this is to ascertain whether air is rising or falling. This information can go into dispersion models used to track movement of vertical movement of air.
- **Relative humidity:** RH is the ratio of the existing amount of water vapor in the air at a given temperature to the maximum amount that could exist at that temperature. This value is usually expressed in percent relative humidity (%RH), which is a variable parameter which is affected by atmospheric conditions during its measurement. Capacitive sensors sense RH utilizing a strip of metal between an electrical current. The metal strip electrical capacity (i.e., voltage) changes linearly with the RH.
- **Barometric pressure**: BP measurements can be used in modeling and can be used to correct an ambient measurement to standard conditions (298^{o}K and 760 millimeters of mercury). BP sensors use pressure transducers which transform the sensor response into a pressure-related electrical.
- **Solar Radiation:** Solar radiation is related to atmospheric stability and is commonly described in units of energy flux: Watts/meter2 (W/m^2). A pyranometer measures sun and sky radiation on a horizontal surface. Most pyranometers incorporate a thermopile sensor; however, a silicon photovoltaic cell can also be used. The net radiometer measures the difference between downward (solar) and upward (terrestrial) radiation.
- **Precipitation**: Precipitation is defined as, "the total amount of precipitation which reaches the ground in a stated period is expressed as the depth to which it would cover a horizontal projection of the earth's surface if there were no loss by evaporation or run-off and if any part of the precipitation falling as snow or ice were melted". Precipitation gauges work on the principle of a tipping bucket gauge. A funnel directs precipitation to a small inlet that directs water over two equal compartments, or buckets, that tilt in sequence with each representing a known quantity of rainfall. The motion of the buckets causes an electrical switch to close and the numbers of tips are counted.

3.0 Health and Safety Warnings

The following health and safety warning must be followed in order for safe operation of the instrument.

- Many meteorological instruments are mounted on booms on towers that can range between 10, 20 or even 30 meters in height. **It is strongly recommended never climb towers unless you are trained to climb.** Falling off of a tower even a few meters from the ground can cause injury or even death. All instruments on the towers must be lowered in order to safely perform audits, calibrations or maintenance.
- Most meteorological instruments operate on low direct current (DC) voltage. Usually, this voltage is also low in amperes (amps). However, some instruments have heaters that may have 110 volts alternating current (AC) that can shock or even cause death in some circumstances. It is important that each station technician know and understand whether or not the system they are working is powered by DC or AC current. In addition, if an instrument has two-lead wire, this means there is no ground on the instrument. Be careful not to ground the instruments if performing troubleshooting as this can damage electronic components.
- If working with any glass devices, such as burettes or flasks, use caution to not break them.
- Avoid electrical contact with jewelry. Remove rings, watches, bracelets, and necklaces to prevent electrical burns.

4.0 Cautions

- Always obtain the orientation of the instrument boom before you lower the tower. This can be done using a GPS device that shows position and direction.
- It is recommended that a winch and cable system be installed to lower the tower.
- Some meteorological towers can be very heavy. It is recommended that two or three people be available to lower towers on a tripod base. Do not drop the tower. This can damage the instruments on the top boom or bend the tower.
- Always guy the meteorological tower. High, consistent or gusty winds can damage or even knock over a tower that is not guyed.

4.1 Interferences

Do not place solar radiation sensors in location where a shadow may cross over its sensor. This will cause false reading and the data will need to be invalidated.

5.0 Personnel Qualifications

It is the responsibility of WDEQ-AQD or the Contractor to train their auditing staff on instrument operation and maintenance. It is a requirement of the WDEQ-AQD to train their staff and keep records of all training that is performed. Although meteorological instruments are self-contained, there is a level of knowledge of electronics and know-how involved in the operation and maintenance of the instrument. The instrument manual is the best training tool for this.

6.0 Equipment

The following supplies are required for the operation of this instrument:

- Wind speed R.M. Young Selectable Speed Anemometer Drive and R.M. Young torque disk
- Wind direction: Bruton compass to determine the alignment of the sensor. R.M. Young Vane Angle Bench Stand.
- Ambient temperature: NIST traceable thermometer, potable water, ice, heating element and thermally isolating container.
- Delta Temperature: NIST traceable thermometer, potable water, ice, heating element and thermally isolating container.
- Relative Humidity: NIST traceable temperature/RH sensor, a data logger, aspiration shield.
- Barometric Pressure: NIST traceable altimeter
- Solar Radiation: NIST traceable solar radiation pyranometer
- Precipitation: 1000 mL drip bottle and water

6.1 Inspection/Acceptance of Supplies and Consumables

Spare parts will be purchased only from the instrumentation manufacturer by the QA Coordinator. Parts will be inspected by the QA Coordinator for shipping damage upon receipt. Spare parts will be kept in the WDEQ-AQD workshop for use when needed. Wind speed anemometer drives, altimeter, relative humidity probe, and thermometers will be sent off for annual certification. Solar sensors will be sent off every two years for certification.

7.0 Quality Assurance Procedures

Audits are required to be performed at a minimum of twice a year per WDEQ-AQD's Meteorological QAPP.

The audits are performed by challenging the sensor with known parameters or by collocation. The procedure for each sensor is listed in this section. On all audit forms, record the site sensor information including the make/model/serial number. For the audit forms, it is necessary to select the site type on the Site Verification/Audit Standards Form. This will populate the acceptance criteria for each parameter. All SPM stations will be PSD site and Cheyenne NCore will be an NCore site.

7.1 Solar Sensor Audit

1. Collocated at least one audit solar sensor with the site sensor. This can be done by placing the audit sensor directly next to the site sensor, relocating the site sensor next to the audit sensor, or placing the audit sensor(s) within reasonable distance to the site sensor. The positioning of sensor(s) should minimize the effect of any local interference or obstructions.
2. Make sure the audit sensor(s) is level and clean.
3. Connect the audit sensor(s) to the audit data logger.
4. Inspect the site sensor to check if it is clean and level. Note on audit form.
5. Record hourly averages for the site and the audit sensor(s). Record on audit form.

7.2 Relative Humidity Audit

1. Note if site has an active or passive aspiration shield.
   a. If site has a passive aspiration shield, attach audit aspiration shield and insert RH probe as close as possible to the site sensor.
   b. If site has an active aspiration shield, try to collocate the sensors as best as possible, under similar conditions.
2. Connect the audit RH probe to the audit data logger.
3. Record hourly averages for the site and the audit sensor(s). Record on audit form.

7.3 Barometric Pressure Audit

1. Hold audit standard as close to site sensor. Record the audit barometric pressure value.
2. On the site DAS, record the site barometric pressure value. Convert this to mmHg if necessary.

7.4 Precipitation Gauge Audit

1. Make notation in station logs and/or flag the precipitation channel in the on-site data logger indicating performance audit.
2. Check starting value for the precipitation channel. If greater than 0.0 note the starting precipitation value.
3. Fill drip bottle to 1000 mL.
4. Take large screen out of the precipitation gauge, if it is in the gauge.
5. Let bottle drip until empty.
6. Check the appropriate box for the make/model of the precipitation gauge on the audit form. Enter the DAS value in mm when all water has been introduced to the gauge. Convert value from inches to mm if necessary.

7.5 Wind Direction Audit

1. Sensor Alignment
    a. Make notation in station logs and/or flag the wind direction channel in the on-site data logger indicating performance audit.
    b. Determine the magnetic declination of magnetic north from true north using one of the following methods:
        i. Approved Solar Azimuth applications on your smart phone
        ii. National Geomagnetism Program from the USGS web site (http://geomag.usgs.gov/models)
        iii. National Geographic Data Center web site (http://www.ngdc.noaa.gov/seg/geomag/ magfield.shtml)
        iv. U.S. Navy Observatory web site (http://aa.Usno.navy.mil/data/docs/AltAz.html)
    c. Set up tripod and affix compass or transit at the same location where alignment checks will be performed (care should be taken to ensure the location is free of nearby interferences such as buried wires or pipes, buildings, cell phones, belt buckles, or other ferrous materials).
    d. Adjust the compass or transit to match the azimuth or declination determined.
    e. Rotate compass or transit to align the crosshairs through the cross-arm or alignment rod of the wind direction sensor.
    f. Enter alignment results in the audit form.
2. Sensor Linearity
    a. Use the appropriate linearity test assembly for the sensor under audit.
        i. RM Young sensors generally use either RM Young Model 18112 or 18212
        ii. Climatronics sensors use a 8-position Wilson Machining disc
    b. Cycle the test assembly through nine 45° increments.
    c. Enter results in audit form.
3. Starting Threshold/Torque
    a. While sensor is on the linearity template and level on the ground, release the tail such that it is freely moving. Install the torque disc on the sensor shaft.
    b. Note the weight size and distance from center when the shaft first turns (torque).
    c. NOTE: this test is extremely difficult when windy.

7.6 Wind Speed Audit

1. Wind Speed
    a. Make notation in station logs and/or flag the wind speed channel in the on-site data logger indicating performance audit.
    b. On the audit form, select the manufacturer and model of the sensor and measured units. This will populate the motor speed targets.
    c. Remove the propeller for the site monitor and attach the variable speed anemometer to the sensor shaft input.
    d. Set the anemometer drive to the slowest motor speed from the audit form and allow to stabilize.
    e. Record the results from the DAS in the audit form.
    f. Repeat with the other motor speeds listed on the audit form.
2. Starting Threshold/Torque
    a. Install the torque disc on the sensor shaft.
    b. Hold the sensor such that the shaft is parallel to the ground.
    c. Note the weight size and distance from center when the shaft first turns (torque).
    d. Enter the value in the audit form.
3. Vertical Wind Speed
    a. Follow the same process above using a low speed wind anemometer.
    b. Motor speeds will be tested clockwise and counter clockwise.

7.7 Ambient Temperature and Delta Temperature Audit

1. Make notation in station logs and/or flag the temperature channels and delta temperture channel in the on-site data logger indicating performance audit.
2. Prepare three different water baths in an insulated thermos: ice bath, ambient bath (~15-25 °C) and a high range bath (~40-50 °C). Measure these temperatures with a NIST-traceable digital thermometer.
3. Remove the temperature probe(s) from the aspirator(s) and check the fans for proper operation and flow.
4. Place the probe(s) in the first water bath along with an audit standard. Be sure not to submerge the sensitive components of the sensors. Agitate the water bath until the values indicated on the DAS and audit standard stabilize.
5. Record measurements on the audit form.
6. Repeat for the other 2 water baths.
7. If there are multiple probes, verify the channels and check that the delta temperature is being calculated correctly.

7.8 Station Temperature Audit

1. Using an audit standard, collocate with the station temperature probe. Once audit standard is stable, record the temperature and the station temperature from the DAS on the audit form.

8.0 References

1. Environmental Protection Agency, 2000, Meteorological Montoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005 (February 2000).
2. Environmental Protection Agency, 2008, Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements (Version 2.0), EPA-454/B-08-002 (March 2008).

APPENDIX A
Meteorological Audit Forms

Site Information
Audit Verification Standards

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

		Deg	Min	Sec		Decimal
Latitude	North				--CALCULATE->	
Longitude	West					

			Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference						
AT/RH Sensor Reference						
Barometric Pressure Reference						
Wind Speed Reference (high rpm)						
Wind Speed Reference (low rpm)						
Wind Speed Torque Gauge						
Wind Direction Alignment Reference						
Wind Direction Linearity Reference						
Wind Direction Torque Gauge						
Solar Radiation Reference						
Multiplier		W/m2 / mV				
Solar Radiation Reference						
Multiplier		W/m2 / mV				
UV Radiation Reference						
Multiplier		W/m2 / mV				
Precipitation Reference						
Volume		mL				

Notes:	

Temperature / Delta-Temperature System Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference				

Manufacturer	
Model	
Serial Number	

List sensors according to height on tower, from highest to lowest.

Temp. Deltas	
10m	2m

Sensor(s) verified against their data channel(s)?
☐ Yes ☐ No ☐ N/A
Temperature Difference = Upper - Lower?
☐ Yes ☐ No ☐ N/A

Audit Criteria (<=)	
Ambient Temperature Difference (^{o}C)	
Vertical Temperature Difference (^{o}C)	

	☐ Yes	☐ No	☐ N/A
	☐ Yes	☐ No	☐ N/A

Bath Temp (^{o}C)								
Max ABS Difference								

Notes:	

Relative Humidity Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
RH Sensor Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Relative Humidity Difference (%)	

	Relative Humidity (%)			
Hour	STD	DAS	Difference	
	Average			

Aspirator fan functional?	☐ Yes ☐ No ☐ N/A

Notes:	

DEQ

Station Temperature Sensor Audit

Site Name		Auditor		Date	
Site Type				Time Of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Temperature Reference				

Audit Criteria (<=)	
Temperature Difference (°C)	

	Temperature		
Reference (°C)	DAS (°C)	Difference	

Notes:	

Wind Speed Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Wind Speed Reference				
Wind Speed Torque Gauge				

Manufacturer and Model	
Sensor Serial #	
Cups Serial #	

Audit Criteria (<=)	
Wind Speed Difference (m/s)	
Wind Speed Difference (%)	

Select Units	m/s

		Wind Speed			
Motor Speed (rpm)	Target Speed	DAS	Difference		
			N/A	N/A	N/A

Starting Threshold	Torque
Torque<= #N/A g-cm	

Heater sleeve functional?	☐ Yes ☐ No ☐ N/A

Notes:	

Barometric Pressure Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Barometric Pressure Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Pressure Difference (mmHg)	

	Barometric Pressure		
Reference (mmHg)	DAS (mmHg)	Difference	

Notes:	

Wind Direction Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Direction Alignment Ref.				
Direction Linearity Ref.				
Direction Torque Gauge				

Manufacturer & Model	-
Sensor Serial #	
Vane Serial #	

Local Magnetic Declination (degrees)	
Method	

Mag. Dec. from NOAA (deg/min/sec)				

http://www.ngdc.noaa.gov/geomag-web/#declination

Audit Criteria (<=)	
Cross-arm Alignment Error (degrees)	
Total Align. Diff (degrees)	
Sensor Linearity (degrees)	

Reference Alignment Error (degrees)		

Sensor Alignment				
Reference	Degrees	DAS	Difference	
From the North	0			
From the South	180			
From the East	90			
From the West	270			
Total Alignment MAX ABS Diff				

Sensor Linearity			
Point	DAS	Difference	
1		N/A	
2			
3			
4			
5			
6			
7			
8			
1			
MAX Difference			

Starting Threshold	Torque
Torque <= g-cm	

Heater sleeve functional? ☐ Yes ☐ No ☐ N/A

Notes:

Vertical Wind Speed Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Wind Speed Reference				
Wind Speed Torque Gauge				

Manufacturer and Model	-
Sensor Serial #	
Cups Serial #	

Audit Criteria (<=)	
Wind Speed Difference (m/s)	

Use recommended 1.25 multiplier?	Yes

Select Units	m/s

Motor Speed (rpm)	Target Speed (m/s)	Vertical Wind Speed		
		DAS (m/s)	Difference	
			N/A	N/A

CW = +

CCW = -

Starting Threshold	Torque	
Torque <= g/cm		

Notes:	

Solar Radiation Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date	Multipler
Solar Radiation Reference					

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Difference from CTS (%)	

	Solar Radiation			
Hour	CTS (W/m^2)	DAS (W/m^2)	Difference	
	Mean ABS % Diff.			

Sensor found clean?	☐ Yes ☐ No

Sensor found level?	☐ Yes ☐ No

Notes:	

Precipitation Sensor Audit

Site Name		Auditor		Date	
Site Type				Time of Audit (MST)	

	Manufacturer	Model	Serial Number	Expiration Date
Precipitation Reference				

Manufacturer	
Model	
Serial Number	

Audit Criteria (<=)	
Difference from Input Volume (%)	#N/A

	Reference Chart			Input Volume (mL)		
	Manufacturer	Model	Diameter(in)	mm/tip	mL/tip	DAS target
	Met One	385	12	0.254	18.53	#VALUE!
	RM Young	52202	6.2825	0.100	2.00	#VALUE!
	Climatronics	100097-1-G0-H0	8	0.254	8.24	#VALUE!
	Climatronics	100508	9.66	0.100	4.73	#VALUE!

Precipitation				
Reference (mL)	Target (mm)	DAS (mm)	Difference	
	#N/A			

Heater functional?	☐ Yes	☐ No	☐ N/A

Notes:	

APPENDIX B: Ancillary Information

Wyoming Department of Environmental Quality – Air Quality Division

Appendix B – Ancillary Information for Meteorological Monitoring

October, 2023
Revision 2

1.0 Instrument Locations

This table is based on the current WDEQ-AQD Ambient Air Monitoring Stations and Operations. For Historic locations, see **Figure 1** in the QAPP.

Table 1. Monitoring Station Details

Station Name	AQS ID	Latitude Longitude	AQD Project Manager	Project Manager Contractor	Site Operator
Big Piney	56-035-0700	42.48640 -110.09890	Mark Gagen	Casey Lenhart Trinity Consultants	Charles Prior/Staff Polk
Boulder	56-035-0099	42.71900 -109.75300	Mark Gagen	Casey Lenhart Trinity Consultants	Meghann Smith
Casper Gaseous	56-025-0100	42.82231 -106.36501	Leif Paulson	Casey Lenhart Trinity Consultants	Kurt Rissler
Cheyenne NCore	56-021-0100	41.18235 -104.77842	Mark Gagen	Casey Lenhart Trinity Consultants	Paul Bailey/Leif Paulson
Converse County	56-009-0010	43.10108 -105.49896	Lauren Deverse	Casey Lenhart Trinity Consultants	Paul Bailey
Daniel South	56-035-0100	42.79070 -110.05510	Leif Paulson	Emily Wiechman Air Resource Specialists	Staff Polk
Johnson County	56-019-0004	43.87483 -106.50974	Lauren Deverse	Casey Lenhart Trinity Consultants	Paul Bailey
Juel Spring	56-035-1002	42.37350 -109.56050	Leif Paulson	Casey Lenhart Trinity Consultants	Contact MSI
Kemmerer Mobile	56-023-0004	41.783083 -110.53788	Leif Paulson	Emily Wiechman Air Resource Specialists	Lauren Deverse
Laramie County Mobile	56-021-0004	41.32417 -105.61489	Leif Paulson	Emily Wiechman Air Resource Specialists	Lauren Deverse
Moxa Arch	56-037-0300	41.75056 -109.78833	Mark Gagen	Casey Lenhart Trinity Consultants	Contact MSI
Pinedale Gaseous	56-035-0101	42.86982 -109.87076	Leif Paulson	Casey Lenhart Trinity Consultants	Meghann Smith
Riverton Mobile	56-013-0004	43.02421 -108.36370	Leif Paulson	Emily Wiechman Air Resource Specialists	Travis Guthrie
South Pass	56-013-0099	42.53000 -108.72000	Jacob Berreth	Emily Wiechman Air Resource Specialists	Marty Hamilton
Thunder Basin	56-005-0123	44.65220 -105.29030	Miriam Montana	Casey Lenhart Trinity Consultants	Paul Bailey
Wamsutter	56-037-0200	41.67771 -108.02415	Jacob Berreth	Emily Wiechman Air Resource Specialists	Lauren Deverse

2.0 Type of Instruments

Ambient Temperature Probe Description

The RM Young Platinum RTD Model 41342VC ambient temperature sensors at the 2-and 10-meter level utilize precision, extended range thermistors to measure ambient air temperature. The temperature sensors will be operated in a motor-aspirated radiation shield. With a factory calibration, the sensor has an absolute accuracy of ±0.1°C.

Table 2a. Site-Specific 10m Temperature/ Relative Humidity Probe Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	RM Young	41342	TS017953	-50 to 50°C	Semi-Annual	62201/ 62101
Boulder	RM Young	41342	12929	-50 to 50°C	Annual Annual	62101 62101
Casper Gaseous	RM Young	41342-VC	033887	-50 to 50°C	Semi-Annual	62201/ 62101
Cheyenne NCore	RM Young	41342VC	026554	-50 to 50°C	Semi-Annual	62201/ 62101
Converse County	RM Young	41342	25540	-50 to 50°C	Semi-Annual	62201/ 62101
Daniel South	RM Young	41342VC	34248	-50 to 50°C	Semi-Annual	62201/ 62101
Johnson County	RM Young	41342-VC	031115	-50 to 50°C	Semi-Annual	62201/ 62101
Juel Spring	RM Young	41342	131379	-50 to 50°C	Semi-Annual	62201/ 62101
Kemmerer Mobile	RM Young	41342	018279	-50 to 50°C	Semi-Annual	62201/
Laramie County Mobile	RM Young	41342	018278	-50 to 50°C	Semi-Annual	62201/
Moxa Arch	RM Young	41342	0331870	-50 to 50°C	Semi-Annual	62201/ 62101
Pinedale Gaseous	Campbell Scientific	CS107	S0330692	-50 to 50°C	Semi-Annual	62201/ 62101
Riverton Mobile	RM Young	41342	N/A	-50 to 50°C	Semi-	62201/
South Pass	RM Young	41342VC	17438	-50 to 50°C	Annual Annual	62101 62101
Thunder Basin	RM Young	41342VC	032857	-50 to 50°C	Semi-Annual	62201/ 62101
Wamsutter	RM Young	41342VC	034183	-50 to 50°C	Semi-	62201/

Table 2b. Site-Specific 2m Temperature/ Relative Humidity Probe Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	RM Young	41342	TS017954	-50 to 50°C	Semi- Annual	62201/ 62101
Boulder	RM Young	41342	23501	-50 to 50°C	Semi- Annual	62201/ 62101
Casper Gaseous	RM Young	41342-VC	033886	-50 to 50°C	Semi- Annual	62201/ 62101
Cheyenne NCore	RM Young	41342VC	026553	-50 to 50°C	Semi- Annual	62201/ 62101
Converse County	RM Young	41342	25539	-50 to 50°C	Semi- Annual	62201/ 62101
Daniel South	RM Young	41342VC	34247	-50 to 50°C	Semi- Annual	62201/ 62101
Johnson County	RM Young	41342-VC	031114	-50 to 50°C	Semi- Annual	62201/ 62101
Juel Spring	RM Young	41342	034092	-50 to 50°C	Semi- Annual	62201/ 62101
Moxa Arch	RM Young	41342	32855	-50 to 50°C	Semi- Annual	62201/ 62101
South Pass	RM Young	41342VC	17437	-50 to 50°C	Semi- Annual	62201/ 62101
Thunder Basin	RM Young	41342VC	032856	-50 to 50°C	Semi- Annual	62201/ 62101
Wamsutter	RM Young	41342VC	034182	-50 to 50°C	Semi- Annual	62201/ 62101

Barometric Pressure Sensors

The Vaisala Model PTB101B Barometer uses Vaisala's silicon capacitive sensor to measure barometric pressure over a 600 to 1060 millibar range.

The RM Young Model 61302V barometric pressure sensor is a versatile electronic barometer featuring high accuracy, low power, a wide operating temperature range, and calibrated voltage output. The Model 61302V measures barometric pressure over a 500 to 1100 hPa range with an accuracy of 0.3 hPa (-40 to +60°C).

Table 2c. Site-Specific Barometric Pressure Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	Vaisala	PTB110	F1220017	500-1100 mb	Semi- Annual	64101
Boulder	Vaisala	PTB101B	23430002	600-1060 mb	Semi- Annual	64101
Casper Gaseous	Vaisala	PTB110	H1620005	500-1100 mb	Semi- Annual	64101
Cheyenne NCore	RM Young	61302V	BPA1581	500-1100 mb	Semi- Annual	64101
Converse County	Vaisala	PTB110	K2830011	500-1100 mb	Semi- Annual	64101
Daniel South	Vaisala	PTB101B	A045015	500-1100 mb	Semi- Annual	64101
Juel Spring	Vaisala	PTB101B	W0550033	500-1100 mb	Semi- Annual	64101
Kemmerer Mobile	RM Young	61302	BPA1871	500-1100 mb	Semi- Annual	64101
Laramie County Mobile	RM Young	61302V	BPA1871	500-1100 mb	Semi- Annual	64101
Moxa Arch	RM Young	61302V	BPA1339	500-1100 mb	Semi- Annual	64101
Riverton Mobile	RM Young	61302V	BPA2038	500-1100 mb	Semi- Annual	64101
South Pass	RM Young	61202V	BP03904	500-1100 mb	Semi- Annual	64101
Thunder Basin	Vaisala	PTB110	P4650216	500-1100 mb v	Semi- Annual	64101
Wamsutter	Vaisala	61202V	BP03352	500-1100 mb	Semi- Annual	64101

Precipitation Gauge Descriptions

The Met One Model 385, heated tipping bucket rain gauge has a 12-inch diameter collection funnel and a resolution of 0.01inch per tip. The accuracy of the gauge is ±0.5% at 0.5 inches per hour or ±1.0% at 1 to 3 inches per hour.

The Climatronics Model 100097-1-GO, heated tipping bucket rain gauge has an 8-inch diameter collection funnel and a resolution of 0.01 inch per tip. The accuracy of the gauge is ±0.5% at 0.5 inch per hour or ±1.0% at 1 to 3 inches per hour.

Table 2d. Site-Specific Precipitation Gauge Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	Met One	385	N9390	inches	Semi-Annual	65102
Boulder	Met One	TR-525	911620622	inches	Semi-Annual	65102
Casper Gaseous	Met One	375	M10896	inches	Semi-Annual	65102
Casper Gaseous	Met One	100097-1-GO	NA	inches	Semi-Annual	65102
Cheyenne NCore	Climatronics	385	R13401	inches	Semi-Annual	65102
Converse County	Met One	385	D7229	inches	Semi-Annual	65102
Daniel South	Met One	385	D3757	inches	Semi-Annual	65102
Hiawatha	Met One	52202	TB07454	inches	Semi-Annual	65102
James Town Mobile	RM Young	52202	TB07428	inches	Semi-Annual	65102
Juel Spring	Met One	TR-525	83516-0520	inches	Semi-Annual	65102
Moxa Arch	Texas Electronics	52202	TB07455	inches	Semi-Annual	65102
Paradise Road Mobile		260-2500E	C1836	inches	Semi-Annual	65102
Riverton Mobile	RM Young	52202	TB04376	inches	Semi-Annual	65102
Sheridan Police Station SLAMS	NovaLynx	375	M1373	inches	Semi-Annual	65102
South Pass	RM Young	Pyranometer	PY50734	inches	Semi-Annual	65102
Thunder Basin	Climatronics	375	M1373	inches	Semi-Annual	65102
Wamsutter	LICOR	Pyranometer	PY50734	inches	Semi-Annual	65102

Solar Radiation Sensor Descriptions

A Licor Model LI200X measures solar radiation with a silicon photovoltaic detector mounted in a cosine-corrected head. The LI200X is calibrated for the daylight spectrum (400 to 1100 nm).

A Kipp & Zonen CMP6 measures solar radiation with a high quality blackened thermopile protected by a dome. The blackened thermopile provides a flat spectral response for the full solar spectrum range. The CMP6 has a light spectrum waveband of 285 to 2800 nm with a maximum irradiance of 2000 W/m2.

Table 2f. Site-Specific Solar Radiation Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	Hukseflux	LP02	41038	W/m^2	Semi-Annual	63301
Boulder	LICOR	LI200x-10	PY49045	W/m^2	Semi-Annual	63301
Casper Gaseous	Hukseflux	SR05-D1A3	12428	W/m^2	Semi-Annual	63301
Cheyenne NCore	Kipp & Zonen	CMP6	123312	W/m^2	Semi-Annual	63301
Cheyenne NCore	LICOR	200X	PY66330	W/m^2	Semi-Annual	63301
Converse County	Hukseflux	LP02	45383	W/m^2	Semi-Annual	63301
Daniel South	Apogee	CS301	67535	W/m^2	Semi-Annual	63301
Kemmerer Mobile	Apogee	CS301	75565	W/m^2	Semi-Annual	63301
Juel Spring	LICOR	Pyranometer	PY48166	W/m^2	Semi-Annual	63301
Moxa Arch	LICOR	LI 200X	PY64239	W/m^2	Semi-Annual	63301
Laramie County Mobile	Apogee	CS301	73178	W/m^2	Semi-Annual	63301
Riverton Mobile	Apogee	CS301	72142	W/m^2	Semi-Annual	63301
South Pass	LICOR	Pyranometer	PY53166	W/m^2	Semi-Annual	63301
Thunder Basin	LICOR	Pyranometer	PY68982	W/m^2	Semi-Annual	63301
Wamsutter	Apogee	CS301	74425	W/m^2	Semi-Annual	63301
Wamsutter	LICOR	LI 200X	PY83359	W/m^2	Semi-Annual	63301

UV Radiation Sensor Descriptions

The Eppley Total Ultraviolet Radiometer (TUVR) is a rugged, relatively simple detector for the measurement of solar UV radiation. Ease of operation combined with performance accuracy comparable with pyranometers intended for recording the total short-wave radiation (0.295 to 0.385 µm) make this instrument an attractive instrument for UV measurement.

This instrument utilizes a hermetically sealed selenium barrier-layer cell which is protected by a quartz window. It is operated at low light levels and under conditions of minimum electrical current drain to ensure a high degree of performance stability over lengthy periods of exposure.

Table 2i. Site-Specific UV Radiation Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Boulder	Eppley	TUVR (Radiation In)	34635	W/m^2	Semi-Annual	63302
Boulder	Eppley	TUVR (Radiation In)	34636	W/m^2	Semi-Annual	63302

Specific Scalar Wind Direction Sensor Description

The RM Young Model 05305 Wind Monitor measures horizontal wind speed and direction. Developed for air quality applications, it is accurate, sensitive, and corrosion-resistant. The main housing, nose cone, propeller, and other internal parts are injection molded U.V. stabilized plastic. The tail section is lightweight expanded polystyrene. Both the propeller and vertical shafts use stainless steel precision grade ball bearings. Bearings have shields to help exclude contamination and moisture. Propeller rotation produces an AC sine wave signal with a frequency proportional to wind speed. This AC signal is induced in a stationary coil by a six-pole magnet mounted on the propeller shaft. Three complete sine wave cycles are produced for each propeller revolution.

The Climatronics F460 Wind Speed Sensor, P/N 100075, is designed to provide low starting threshold, wide dynamic response and high accuracy over a wide range of wind speeds and a variety of environmental conditions. The sensor, installed at the 10-meter level, consists of a three-cup anemometer. An LED photo chopper device provides a frequency output directly proportional to the wind speed. The starting threshold is 0.5 m/s.

Table 2g. Site-Specific Scalar Wind Direction Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Big Piney	RM Young	Wind Monitor AQ	100333	0-50 m/s	Semi- Annual	61104
Boulder	RM Young	Wind Monitor AQ	169000	0-50 m/s	Semi- Annual	61104
Casper Gaseous	RM Young	05305	103454	0-50 m/s	Semi- Annual	61104
Cheyenne NCore	RM Young	05305-AQ	76869	0-50 m/s	Semi- Annual	61104
Converse County	RM Young	05305-5	196830	0-50 m/s	Semi- Annual	61104
Daniel South	RM Young	05305	12784	0-50 m/s	Semi- Annual	61104
Johnson County	MetOne	020C	D11918	0-50 m/s	Semi- Annual	61104
Juel Spring	RM Young	05305	76871	0-50 m/s	Semi- Annual	61104
Kemmerer Mobile	Model RM Young	05305 / 08254	178251	0-50 m/s	Semi- Annual	61104
Laramie County Mobile	RM Young	05305	178251	0-50 m/s	Semi- Annual	61104
Moxa Arch	Climatronics	100076	3968	0-56 m/s	Semi- Annual	61104
Pinedale	RM Young	05305	191283	0-56 m/s	Semi- Annual	61104

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Riverton Mobile	RM Young	05305	174799	0-50 m/s	Semi- Annual	61104
South Pass	RM Young	05305	103455	0-56 m/s	Semi- Annual	61104
Sheridan Police Station SLAMS	RM Young	05305	87592	0-50 m/s	Semi- Annual	61104
Thunder Basin	RM Young	05305	115152	0-50 m/s	Semi- Annual	61104
Wamsutter	RM Young	05305	166513	0-50 m/s	Semi- Annual	61104

Table 2h. Site-Specific Vector Wind Speed Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Units/ Range of Measure	Audit Frequency	EPA Method Code*
Boulder	RM Young	5305 AQ	169000	0-56 m/s	Semi- Annual	61101
Cheyenne NCore	RM Young	05305-AQ	76869	0-50 m/s	Semi- Annual	61101
Kemmerer Mobile	RM Young	05305 / 08254	178251	0-50 m/s	Semi- Annual	61101
Laramie County Mobile	RM Young	05305/0825405 305	178251	0-50 m/s	Semi- Annual	61101
Moxa Arch	Climatronics	100075	N/A	0-50 m/s	Semi- Annual	61101
Riverton Mobile	RM Young	05305/08254	174799/78548	0-50 m/s	Semi- Annual	61101
South Pass	RM Young	05305/08254	115152	0-50 m/s	Semi- Annual	61101
Wamsutter	RM Young	05305 / 08254	166513	0-56 m/s	Semi- Annual	61101

Wind Direction Sensor Description

The wind direction sensor consists of a counter-balanced, lightweight vane and a precision low torque, highly reliable potentiometer that yields a voltage output proportional to the wind direction. Once properly oriented on the cross-arm, the wind direction sensor can be removed without requiring reorientation. The vane starting threshold is 0.22 m/s and has an accuracy of ±2 degrees.

Table 2i. Site-Specific Vector Wind Direction Sensor Details

Station Name	Instrument Make	Instrument Model	Serial Number	Calibrated Range (ppb)	Audit Frequency	EPA Method Code*
Big Piney	RM Young	Wind Monitor AQ	100333	0-56 m/s	Semi- Annual	61103
Boulder	RM Young	05305-AQ	169000	0-50 m/s	Semi- Annual	61103
Casper Gaseous	RM Young	05305	103454	0-50 m/s	Semi- Annual	61103
Cheyenne NCore	RM Young	05305-AQ	76869	0-50 m/s	Semi- Annual	61103
Converse County	RM Young	05305-5	196830	0-50 m/s	Semi- Annual	61103
Johnson County	MetOne	020C	D11918	0-50 m/s	Semi- Annual	61103
Juel Spring	RM Young	05305	76871	0-50 m/s	Semi- Annual	61103
Moxa Arch	Climatronics	100076	3968	0-56 m/s	Semi- Annual	61103
Riverton Mobile	RM Young	05305	66606	0-50 m/s	Semi- Annual	61103
South Pass	RM Young	05305	115152	0-50 m/s	Semi- Annual	61103
Wamsutter	RM Young	05305	1665131726/3110	0-56 m/s	Semi- Annual	61103

3.0 AQS Coding

AQS numbers are assigned for each monitoring station and parameters. **Table 3** illustrates the AQS code used for the WDEQ-AQD program. A sample of the AQS raw data is presented below. Please note all data submitted to AQS is pipe-delimited.

```
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|5.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|5.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|8.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|9.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|3.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|9.0||||||||||||||||
RD|I|56|021|0100|44201|1|1|007|087|20181001|00:00|0.0||||||||||||||||
```

The column order is defined as follows in **Table 3**:

Table 3. Example Transaction Codes for AQS

Fields	Example
Transaction Type	RD (Raw Data Type)
Action Indicator	I (Insert)
State Code	56 (Wyoming)
County Code	021 (Laramie)
Site ID	0100 (NCORE)
Parameter Code	44201
POC	1
Duration Code	1 (Hourly)
Reported Unit Code	007 (parts per million)
Method Code	See Table 2*
Date	YYYYMMDD
Sample Time	HH: MM (hour- beginning)
Reported Sample Value	
Qualifier Code - Null Data	AN
Monitor Protocol ID	(N/A)
Qualifier Code	Up to ten (10) permitted