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CASTNET
2019 Annual Report

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List of Acronyms and Abbreviations

% diff	percent difference
A/D	analog to digital converter
AQS	Air Quality System
ARS	Air Resource Specialists, Inc.
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
BLM-WSO	Bureau of Land Management-Wyoming State Office
CASTNET	Clean Air Status and Trends Network
CFR	Code of Federal Regulation
CMAQ	Community Multi-scale Air Quality
DAS	data acquisition system
DC	direct current
DEP	Department of Environmental Protection
deg	degree
DQO	data quality objectives
DVM	digital voltmeter
ECCC	Environment and Climate Change Canada
EEMS	Environmental, Engineering & Measurement Services, Inc.
EPA	U.S. Environmental Protection Agency
ESC	Environmental Systems Corporation
FSAD	Field Site Audit Database
g-cm	gram centimeter
GPS	goblal positioning system
k	kilo (1000)
km	kilometer
lpm	liters per minute
MLM	Multilayer Model
m/s	meters per second
mv	millivolt
NADP	National Atmospheric Deposition Program
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPAP	National Performance Audit Program
NPS	National Park Service
OAQPS	Office of Air Quality Planning and Standards
PE	Performance Evaluation
ppb	parts per billion
ppm	parts per million

PSD	Prevention of Significant Deterioration
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RH	relative humidity
RTD	Resistance Temperature Detector
SJRWMD	Saint John's Water Management District
SLAMS	State or Local Air Monitoring Stations
SOP	standard operating procedure
SRP	standard reference photometer
SSRF	Site Status Report Forms
STP	standard temperature and pressure
TEI	Thermo Environmental Instruments
TTP	Through The Probe
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USNO	United States Naval Observatory
V	volts
VDC	volts direct current
Wood	Wood Environment and Infrastructure Solutions
WRR	World Radiation Reference

1.0 Introduction

The Clean Air Status and Trends Network (CASTNET) is a national air monitoring program established in 1988 by the US EPA. Nearly all CASTNET sites measure weekly concentrations of acidic gases and particles to provide accountability for EPA's emission reduction programs. Most sites measure ground-level ozone as well as supplemental measurements such as meteorology and/or other trace gas concentrations.

Ambient concentrations are used to estimate deposition rates of the various pollutants with the objective of determining relationships between emissions, air quality, deposition, and ecological effects. In conjunction with other national monitoring networks, CASTNET data are used to determine the effectiveness of national emissions control programs and to assess temporal trends and spatial deposition patterns in atmospheric pollutants. CASTNET data are also used for long-range transport model evaluations and critical loads research.

Historically, CASTNET pollutant flux measurements have been reported as the aggregate product of weekly measured concentrations and model-estimated deposition velocities. The Multi-layer Model (MLM) was used to derive deposition velocity estimates from on-site meteorological parameters, land use types, and site characteristics. In 2011, EPA discontinued meteorological measurements at most EPA-sponsored CASTNET sites.

Currently, CASTNET pollutant flux estimates are calculated as the aggregate product of weekly measured chemical concentrations and gridded model-estimated deposition velocities. Total deposition is assessed using the NADP's Total Deposition Hybrid Method (TDEP; EPA, 2015c; Schwede and Lear, 2014), which combines data from established ambient monitoring networks and chemical-transport models. To estimate dry deposition, ambient measurement data from CASTNET were merged with dry deposition rates and flux output from the Community Multiscale Air Quality (CMAQ) modeling system. The dry deposition surface is then merged with wet deposition grids from NADP and the Parameter-elevation Regressions on Independent Slopes Model (PRISM) to estimate total deposition.

Since 2011 nearly all CASTNET ozone monitors have adhered to the requirements for State or Local Air Monitoring Stations (SLAMS) as specified by the EPA in 40 CFR Part 58. As such, the ozone data collected must meet the requirements in 40 CFR Part 58 Appendix A, which defines the quality assurance (QA) requirements for gaseous pollutant ambient air monitoring. The audits performed by EEMS under this contract fulfill the requirement for annual performance evaluation (PE) audits of pollutant monitors in the network. The QA requirements can be found at: https://www3.epa.gov/ttn/amtic/files/ambient/pm25/qa/APP_D%20validation%20template%20version%2003_2017_for%20AMTIC%20Rev_1.pdf

Currently 86 sites at 84 distinct locations measure ground-level ozone concentrations. Annual PE audit QA data are submitted to the Air Quality System (AQS) database.

As of December 2019, the network is comprised of 95 active rural sampling sites across the United States and Canada, cooperatively operated by the Environmental Protection Agency (EPA), the National Park Service (NPS), Bureau of Land Management – Wyoming State Office (BLM-WSO) and several independent partners. Wood Environment and Infrastructure Solutions (Wood) is responsible for operating the EPA sponsored sites and Air Resource Specialist, Inc. (ARS) is responsible for operating the NPS and BLM-WSO sponsored sites.

2.0 Project Objectives

The objectives of this project are to establish an independent and unbiased program of performance and systems audits for all CASTNET sampling sites. Ongoing QA programs are an essential part of any long-term monitoring network.

Performance audits verify that all reported parameters are consistent with the accuracy goals as defined in the CASTNET Quality Assurance Project Plan (QAPP). The acceptance criteria have changed over the years and EEMS relies on the CASTNET contractor to provide updates to the acceptance criteria. The current criteria are included in Table 2-1.

Due to budgetary necessity, the meteorological measurements were shifted to operating on an as-funded basis. The meteorological sensors were audited on an as directed basis.

Table 2-1. Performance Audit Challenge and Acceptance Criteria

Sensor	Parameter	Audit Challenge	Acceptance Criteria
Precipitation	Response	10 manual tips	1 DAS count per tip
Precipitation	Accuracy	2 introductions of known amounts of water	≤ ±10.0% of input amount
Relative Humidity	Accuracy	Compared to reference instrument or standard solution	≤ ±10.0%
Solar Radiation	Accuracy	Compared to WRR traceable standard	≤ ±10.0% of daytime average
Surface Wetness	Response	Distilled water spray mist	Positive response
Surface Wetness	Sensitivity	1% decade resistance	N/A
Shelter Temperature	Average Difference	Comparison to RTD at 3 observed points	2 ºC
Temperature	Accuracy	Comparison to 3 NIST measured baths (~ 0° C, ambient, ~ full-scale)	≤ ± 0.5° C

Sensor	Parameter	Audit Challenge	Acceptance Criteria
Delta Temperature	Accuracy	Comparison to temperature sensor at same test point	≤ ± 0.50° C
Wind Direction	Orientation Accuracy	Parallel to alignment rod/crossarm, or sighted to distant point	≤ ±5° from degrees true
Wind Direction	Linearity	Eight cardinal points on test fixture	≤ ±5° mean absolute error
Wind Direction	Response Threshold	Starting torque tested with torque gauge	< 10 g-cm Climatronics; < 20 g-cm R. M. Young
Wind Speed	Accuracy	Shaft rotational speed generated and measured with certified synchronous motor	≤ ±0.5 mps below 5.0 mps input; ≤ ±5.0% of input at or above 5.0 mps
Wind Speed	Starting Threshold	Starting torque tested with torque gauge	< 0.5 g-cm
Mass Flow Controller	Flow Rate	Comparison with Primary Standard	≤ ± 5.0% of designated rate
Ozone	Slope	Linear regression of multi-point test gas concentration as measured with a certified transfer standard	0.9000 ≤ m ≤ 1.1000
	Intercept		-5.0 ppb ≤ b ≤ 5.0 ppb
	Correlation Coefficient		0.9950 ≤ r
	Percent Difference	Comparison with Standard Concentration	Audit levels 3 through 10: ≤ ±15.1% of test gas concentration Audit levels 1 and 2: ≤ ± 0.15 ppb difference or ≤ ±15.1%
DAS	Accuracy	Comparison with certified standard	≤ ± 0.003 VDC

The accuracy goals defined for ozone monitors in the CASTNET QAPP Table 4-12 are the same as those of 40 CFR, Part 58 Appendix A, for quality assurance for CASTNET site. To comply with Appendix A, the CASTNET audit program includes annual independent ozone PE. The EEMS field scientists who conduct ozone PE maintain annual certification from the Office of Air Quality

Planning and Standards (OAQPS) through the annual National Performance Audit Program (NPAP) training which EEMS attended in October 2019 (see end of Appendix for NPAP training certifications). EEMS personnel performed the Through-The-Probe (TTP) pollutant monitor audits following EPA's Quality Assurance Guidance Document – Method Compendium – Field Standard Operating Procedures (SOP) for the Federal $PM_{2.5}$ Performance Evaluation Program and NPAP-TTP Audit Standard Operating Procedures (SOP). All procedures and guidance documents used to perform these audits can be found at the EPA OAQPS website:
https://www3.epa.gov/ttn/amtic/npepqa.html

The NPAP is a QA program implemented by the OAQPS to conduct audits of gaseous air pollutant monitors by standard methods throughout each region of the U.S. The method includes introduction of National Institute of Standards and Traceability (NIST) traceable audit gases to the station monitors through the ambient sample inlet, including all filters and fittings. This method evaluates measurement system accuracy including the entire sample train. The audit gas concentrations are also measured and verified with an audit analyzer on-site. For gases other than ozone the audit analyzer is calibrated at the time of the audit.

Performance audits are conducted using standards that are certified as currently traceable to the NIST or another authoritative organization. All standards are certified annually with the exception of ozone standards which are verified as level 2 standards at EPA regional labs at least twice per year.

Site systems audits are intended to provide a qualitative appraisal of the total measurement system. Site planning, organization, and operation are evaluated to ensure that good Quality Assurance/Quality Control (QA/QC) practices are being applied. At a minimum the following audit issues are addressed at each site systems audit:

- Site locations and configurations match those provided in the CASTNET QAPP.
- Meteorological instruments are in good physical and operational condition and are sited to meet EPA ambient monitoring guidelines (EPA-600/4-82-060).
- Sites are accessible, orderly, and if applicable, compliant with OSHA safety standards.
- Sampling lines are free of leaks, kinks, visible contamination, weathering, and moisture.
- Site shelters provide adequate temperature control.
- All ambient air quality instruments are functional, being operated in the appropriate range, and the zero air supply desiccant is unsaturated.
- All instruments are in current calibration.
- Site documentation (maintenance schedules, on-site SOPs, etc.) is current and log book records are complete.

- All maintenance and on-site SOPs are performed on schedule.
- Corrective actions are documented and appropriate for required maintenance/repair activity.
- Site operators demonstrate an adequate knowledge and ability to perform required site activities, including documentation and maintenance activities.

3.0 CASTNET Sites Visited in 2019

This report covers the CASTNET sites audited in 2019. Only those variables that were supported by the CASTNET program were audited. From February through December 2019, EEMS conducted field performance and systems audits at 59 monitoring sites. Meteorological sensors at four of the sites were also audited. The locations, sponsor agency and dates of the audits along with states and EPA Regions are presented in Table 3-1.

Table 3-1. Systems and Performance Site Audits

Site ID	Sponsor Agency	Site Location	State and EPA Region	Audit dates
ACA416	NPS	Acadia NP	ME / R1	9/18/2019
ALC188	EPA	Alabama-Coushatta	TX / R6	2/25/2019
ALH157	EPA	Alhambra	IL / R5	12/16/2019
BAS601	EPA	Basin	WY / R8	8/19/2019
BBE401	NPS	Big Bend NP	TX / R6	2/27/2019
BFT142	EPA	Beaufort	NC / R4	12/17/2019
BUF603	BLM	Buffalo	WY / R8	8/20/2019
BVL130	EPA	Bondville	IL / R5	11/7/2019
BWR139	EPA	Blackwater NWR	MD / R3	11/19/2019
CAD150	EPA	Caddo Valley	AR / R6	4/16/2019
CDR119	EPA	Cedar Creek St. Park	WV / R3	11/12/2019
CDZ171	EPA	Cadiz	KY / R4	12/17/2019
CHC432	NPS	Chaco NHP	NM / R6	8/5/2019
CHE185	EPA	Cherokee Nation	OK / R6	4/15/2019
CKT136	EPA	Crockett	KY / R4	11/11/2019
CND125	EPA	Candor	NC / R4	6/14/2019
CNT169	EPA	Centennial	WY / R8	7/16/2019
CVL151	EPA	Coffeeville	MS / R4	4/13/2019
DCP114	EPA	Deer Creek St. Park	OH / R5	10/24/2019
EGB181	EPA	Egbert	ON	11/12/2019

Site ID	Sponsor Agency	Site Location	State and EPA Region	Audit dates
EVE419	NPS	Everglades NP	FL / R4	3/19/2019
GLR468	NPS	Glacier NP	MT / R8	7/3/2019
GRS420	NPS	Great Smoky Mountains NP	TN / R4	10/7/2019
GTH161	EPA	Gothic	CO / R8	8/6/2019
KIC003	EPA	Kickapoo Res	KS / R7	10/23/2019
KNZ184	EPA	Konza Prairie	KS / R7	10/22/2019
LAV410	NPS	Lassen Volcanic NP	CA / R9	5/7/2019
LRL117	EPA	Laurel Hill St. Park	PA / R3	9/26/2019
MAC426	NPS	Mammoth Cave NP	KY / R4	10/17/2019
MCK131	EPA	Mackville	KY / R4	11/5/2019
MCK231	EPA	Mackville (precision site)	KY / R4	11/5/2019
NEC602	EPA	Newcastle	WY / R8	7/23/2019
NIC001	EPA	Nick's Lake	NY / R2	7/10/2019
OXF122	EPA	Oxford	OH / R5	10/25/2019
PAL190	EPA	Palo Duro	TX / R6	3/1/2019
PAR107	EPA	Parsons	WV / R3	9/25/2019
PED108	EPA	Prince Edward	VA / R3	7/26/2019
PIN414	NPS	Pinnacles NM	CA / R9	5/8/2019
PND165	EPA	Pinedale	WY / R8	7/1/2019
PRK134	EPA	Perkinstown	WI / R5	8/27/2019
QAK172	EPA	Quaker City	OH / R5	11/10/2019
ROM206	EPA	Rocky Mountain NP	CO / R8	6/11/2019
ROM406	NPS	Rocky Mountain NP	CO / R8	6/6/2019
SAN189	EPA	Santee Sioux	NE / R7	10/25/2019
SEK430	NPS	Sequoia NP	CA / R9	5/14/2019
SHE604	BLM	Sheridan	WY / R8	8/20/2019

Site ID	Sponsor Agency	Site Location	State and EPA Region	Audit dates
SHN418	NPS	Shenandoah NP - Big Meadows	VA / R3	10/22/2019
STK138	EPA	Stockton	IL / R5	11/5/2019
THR422	NPS	Theodore Roosevelt NP	ND / R8	7/22/2019
UND002	EPA	Underhill	VT / R1	7/9/2019
VIN140	EPA	Vincennes	IN / R5	11/7/2019
VOY413	NPS	Voyageurs NP	MN / R5	8/29/2019
VPI120	EPA	Horton Station	VA / R3	9/24/2019
WFM105	EPA	White Face Mountain	NY / R2	7/2/2019
WNC429	NPS	Wind Cave NP	SD / R8	7/24/2019
WSP144	EPA	Washington Crossing St. Park	NJ / R2	6/17/2019
YEL408	NPS	Yellowstone NP	WY / R8	7/2/2019
YOS404	NPS	Yosemite NP	CA / R9	5/13/2019
ZIO433	NPS	Zion NP	UT / R8	8/3/2019

In addition to the sites listed in Table 3-1 that were visited for complete systems and performance audits, the 30 sites listed in Table 3-2 were visited to conduct TTP ozone and other pollutant gas PE.

Table 3-2. Site Ozone PE Visits

Site ID	Sponsor Agency	Site Location	State and EPA Region	Audit dates
ABT147	EPA	Abington	CT / R1	9/25/2019
ANA115	EPA	Ann Arbor	MI / R5	8/22/2019
ARE128	EPA	Arendtsville	PA / R3	7/24/2019
ASH135	EPA	Ashland	ME / R1	9/19/2019
BEL116	EPA	Beltsville	MD / R3	11/18/2019
CAN407	NPS	Canyonlands NP	UT / R8	8/7/2019
CHA467	NPS	Chiricahua NM	AZ / R9	4/11/2019

Site ID	Sponsor Agency	Site Location	State and EPA Region	Audit dates
COW137	EPA	Coweeta	NC / R4	6/13/2019
CTH110	EPA	Connecticut Hill	NY / R2	7/15/2019
DEN417	NPS	Denali NP	AK / R10	9/5/2019
DIN431	NPS	Dinosaur NM	UT / R8	8/8/2019
ESP127	EPA	Edgar Evins St. Park	TN / R4	4/28/2019
GAS153	EPA	Georgia Station	GA / R4	3/26/2019
GRB411	NPS	Great Basin NP	NV / R9	9/16/2019
GRC474	NPS	Grand Canyon NP	AZ / R9	4/9/2019
HOX148	EPA	Hoxeyville	MI / R5	8/23/2019
HWF187	EPA	Huntington Wildlife Forest	NY / R2	7/5/2019
IRL141	EPA	Indian River Lagoon	FL / R4	3/19/2019
KEF112	EPA	Kane Experimental Forest	PA / R3	7/24/2019
MKG113	EPA	M. K. Goddard St. Park	PA / R3	7/25/2019
NPT006	EPA	Nez Perce Tribe	ID / R10	7/8/2019
PET427	NPS	Petrified Forest NP	AZ / R9	4/8/2019
PNF126	EPA	Cranberry	NC / R4	10/5/2019
PSU106	EPA	Penn State University	PA / R3	7/25/2019
SAL133	EPA	Salamonie Reservoir	IN / R5	5/8/2019
SND152	EPA	Sand Mountain	AL / R4	4/27/2019
SPD111	EPA	Speedwell	TN / R4	11/6/2019
SUM156	EPA	Sumatra	FL / R4	3/27/2019
UVL124	EPA	Unionville	MI / R5	8/22/2019
WST109	EPA	Woodstock	NH / R1	8/19/2019

4.0 Performance Audit Results

This section provides the summarized performance evaluation (audit) results of each variable challenged at each station visited except for trace gas audit results. CASTNET operates trace gas monitors at several sites including three sites that are part of the NCORE Network (GRS420, MAC426, and BVL130). Performance evaluation audits of the CASTNET trace gas monitors were performed at BVL130, ROM206, PND165, HWF187, GRS420, and PNF126 in 2019. Results of the NO_y, CO, and SO_2 monitor audits for those sites have been uploaded to the EPA AQS database and are not included in this report. All PE results for all monitors were within acceptance limits. The NO_y PE audit was not performed at MAC426 due to site monitor malfunction.

Performance audit results are discussed for each variable in the following sections. Tables are included to summarize the average and maximum error between the audit challenges and site results as recorded by the on-site Data Acquisition System (DAS). Linear regression and percent difference (% diff) calculation results are included where appropriate. Results that are outside the CASTNET QAPP acceptance criteria are shaded in the tables.

The errors presented in the tables in the following sections are reported as the difference of the measurement recorded by the DAS and the audit standard. Where appropriate, negative values indicate readings that were lower than the standard, and positive values indicate readings that were above the standard value. The results are arranged by audit date. Viewing the results in this order helps to detect any errors that could have been caused by the degradation or drift of the audit standards during the year. The audit standards are transported and handled with care, and properly maintained to help prevent such occurrences. No known problems with the standards were apparent during the year. All standards were within specifications when re-certified at the end of the year. Errors for all parameters other than ozone appear to be random and without bias.

The ozone results are sorted by the level 2 photometer standard used for the audit and arranged by audit date. The audit results obtained by the newest ozone standard (model 49iQPS) indicate a slight negative trend throughout the year. Ozone audit results in general indicate a slight negative bias which will be discussed in the following section.

Detailed reports of the field site audits, which contain all test points for each variable at each site, can be found in the Appendices of each of the 2019 Quarterly reports. The variable specific data forms included in Appendix A of each quarter's report contain the challenge input values, the output of the DAS, additional relevant information pertaining to the variable and equipment, and all available means of identification of the sensors and equipment for each site.

Table 4.1 summarizes the number of test failures by variable tested. All station data are recorded from the station’s primary datalogger.

Table 4-1. Performance Audit Results by Variable Tested

Variable Tested	Number of Tests	Number of tests Failed	% Failed
Ozone	80	14	17.5
Flow Rate	57	1	1.8
Shelter Temperature (average)	52	1	1.9
Wind Direction Orientation Average Error	4	1	25
Orientation Maximum Error	4	2	50
Wind Direction Linearity Average Error	4	0	0
Linearity Maximum Error	4	0	0
Wind Direction Starting Torque	4	1	25
Wind Speed Low Range Average Error	3	0	0
Low Range Maximum Error	3	0	0
Wind Speed High Range Average Error	3	1	33.3
High Range Maximum Error	3	1	33.3
Wind Speed Starting Torque	4	0	0
All Temperature Sensors	58	0	0
Relative Humidity	3	0	0
Solar Radiation	4	0	0
Precipitation	4	0	0
DAS Analog to Digital	33	0	0

4.1 Ozone

Eighty ozone performance evaluation audits were performed in 2019. All ozone challenges were conducted to comply with the OAQPS NPAP-TTP Standard Operating Procedures (SOP) which can be found at https://www3.epa.gov/ttn/amtic/npapsop.html. Each ozone monitor was challenged with ozone-free air and four up-scale concentrations. The ozone test gas concentrations were measured with a NIST-traceable photometer that was verified as a level 2 standard by USEPA. The results of the ozone audits were uploaded to the AQS database at the end of each quarter.

Results of all ozone audits performed are included in Table 4-2. Fourteen monitors tested failed the annual PE with a level 2 test point difference above ± 1.5 ppb. These are highlighted in the table below. The monitors at THR422, ACA416 and WNC429 are not CASTNET monitors, and are operated by state agencies. It was determined that the monitor at UVL124 required maintenance.

Some monitors responded low to ozone-free air which may also contribute to low response at the level 2 audit point.

Table 4-2. Performance Audit Results for Ozone

Site ID	Actual Difference for Level 2	Average (% diff) for Levels 3, 4 and 6	Maximum (% diff) for Levels 3, 4 and 6	Ozone Slope	Ozone Intercept	Ozone Correlation	EEMS Standard Number	Date
ALC188	-0.34	-3.2	-4.2	0.96029	0.55012	0.99988	1110	2/25/2019
BBE401	-0.22	-0.6	-0.7	0.99057	0.23958	0.99999	1110	2/27/2019
PAL190	-0.4	-1.2	-1.8	0.99603	-0.33515	0.99999	1110	3/1/2019
PET427	-0.38	-1.3	-2.4	0.98967	-0.11093	0.99997	1110	4/8/2019
GRC474	-0.48	-0.8	-1.6	0.99520	-0.13062	0.99996	1110	4/9/2019
CHA467	-0.37	-1.7	-2.0	0.97661	0.55123	0.99994	1110	4/11/2019
LAV410	-1.28	-4.0	-6.9	0.98111	-0.72695	0.99986	1110	5/7/2019
PIN414	-0.33	0.3	0.7	1.00749	-0.27178	0.99999	1110	5/8/2019
YOS404	-0.6	0.2	-1.2	1.01307	-0.42535	0.99995	1110	5/13/2019
SEK430	-0.59	-3.8	-4.2	0.96157	0.10304	0.99998	1110	5/14/2019
ROM406	-1.86	-4.6	-5.8	0.97271	-1.15458	0.99999	1110	6/6/2019
ROM206	-1.01	-1.3	-3.3	1.00644	-0.90695	0.99996	1110	6/11/2019
PND165	-2.25	-9.5	-13.5	0.95438	-2.08948	0.99964	1110	7/1/2019

Site ID	Actual Difference for Level 2	Average (% diff) for Levels 3, 4 and 6	Maximum (% diff) for Levels 3, 4 and 6	Ozone Slope	Ozone Intercept	Ozone Correlation	EEMS Standard Number	Date
YEL408	-0.31	0.3	0.6	1.00478	-0.1015	0.99999	1110	7/2/2019
GLR468	-0.04	2.5	3.6	1.03800	-0.521	0.99997	1110	7/3/2019
NPT006	-0.42	-0.7	-1.7	1.00136	-0.45783	0.99999	1110	7/8/2019
CNT169	0.39	3.5	4.0	1.03170	0.05684	1	1110	7/16/2019
THR422	-1.7	-6.0	-8.1	0.96757	-1.34024	0.99998	1110	7/22/2019
NEC602	-1.81	-4.8	-6.8	0.97785	-1.07778	0.99981	1110	7/23/2019
WNC429	0.73	-0.5	-1.2	0.97856	1.03205	1	1110	7/24/2019
ZIO433	-0.51	-1.9	-2.0	0.98129	-0.02606	1	1110	8/3/2019
CHC432	-0.3	-0.5	-0.8	0.99233	0.12613	0.99999	1110	8/5/2019
GTH161	-0.05	1.0	1.9	1.01969	-0.35367	0.99998	1110	8/6/2019
CAN407	-1	-4.0	-5.2	0.97119	-0.339	0.99995	1110	8/7/2019
DIN431	-0.75	-2.0	-2.6	0.99070	-0.52028	0.99998	1110	8/8/2019
BAS601	-0.54	-1.2	-3.5	0.99416	-0.21771	0.99981	1110	8/19/2019
DEN417	1.62	5.5	6.6	1.03417	1.35257	0.99995	1110	9/5/2019
GRB411	-0.99	-3.1	-3.9	0.97911	-0.40853	0.99996	1110	9/16/2019
SAN189	-1.45	-3.9	-5.4	0.98555	-1.28329	0.99999	1110	10/25/2019
ALH157	0.19	-0.3	-0.8	0.99500	0.11306	0.99999	1110	12/16/2019
CDZ171	-0.85	-1.3	-3.5	1.01071	-1.10155	0.99997	1110	12/17/2019
IRL141	-1.12	-1.6	-2.6	1.00208	-1.09943	1	1114	3/19/2019
GAS153	-1.97	-4.6	-6.9	0.98742	-1.85433	1	1114	3/26/2019
SUM156	-1.64	-1.1	-2.9	1.02263	-2.10227	1	1114	3/27/2019
CVL151	-0.27	-1.2	-2.3	0.98143	0.14908	0.9999	1114	4/13/2019
CHE185	0.18	-0.6	-0.9	0.99049	0.12824	0.99999	1114	4/15/2019
CAD150	-1.66	-2.5	-3.3	0.98939	-1.43004	0.99988	1114	4/16/2019
SND152	-1.14	-2.8	-3.8	0.99028	-0.99572	1	1114	4/27/2019
ESP127	-0.58	0.0	-0.7	1.01038	-0.61174	1	1114	4/28/2019
SAL133	-0.37	-0.8	-1.6	1.00057	-0.48793	1	1114	5/8/2019

Site ID	Actual Difference for Level 2	Average (% diff) for Levels 3, 4 and 6	Maximum (% diff) for Levels 3, 4 and 6	Ozone Slope	Ozone Intercept	Ozone Correlation	EEMS Standard Number	Date
WSP144	-0.89	-0.1	-1.1	1.01500	-0.94684	1	1114	6/17/2019
HWF187	-0.66	-2.7	-2.8	0.97682	-0.2718	1	1114	7/5/2019
CTH110	-0.83	-4.3	-4.6	0.96273	-0.36734	1	1114	7/15/2019
KEF112	-0.28	-0.5	-1.2	1.00429	-0.46454	1	1114	7/24/2019
MKG113	-1.02	-3.9	-4.2	0.97286	-0.68795	0.99999	1114	7/25/2019
PED108	0.02	-0.9	-1.7	0.99796	-0.29137	0.99999	1114	7/26/2019
CND125	-0.1	-2.3	-2.5	0.97601	0.12496	1	1114	7/31/2019
ANA115	-0.26	0.4	0.8	1.00901	-0.33313	0.99999	1114	8/22/2019
UVL124	-3.54	-9.0	-12.3	0.96589	-3.15365	0.99993	1114	8/22/2019
HOX148	-0.55	-1.8	-2.6	0.99012	-0.37417	1	1114	8/23/2019
PRK134	-2.08	-5.5	-6.9	0.9664	-1.33743	0.99999	1114	8/27/2019
VOY413	-0.47	-0.2	-0.5	1.00464	-0.49771	0.99999	1114	8/29/2019
VPI120	-0.6	-4.0	-4.9	0.96526	-0.04806	0.99996	1114	9/24/2019
PAR107	-1.17	-1.9	-3.3	0.98162	-0.62791	0.99985	1114	9/25/2019
LRL117	-0.99	-2.6	-3.6	0.98045	-0.50137	0.99994	1114	9/26/2019
PNF126	-1.05	-1.0	-2.3	1.00778	-1.06583	1	1114	10/5/2019
GRS420	-0.78	-1.3	-2.0	0.99738	-0.61972	1	1114	10/7/2019
MAC426	1.86	2.9	5.8	0.98781	2.24646	0.99999	1114	10/17/2019
STK138	-0.53	-2.2	-2.4	0.97775	-0.12925	0.99999	1114	11/5/2019
BVL130	-0.67	-2.6	-2.9	0.97565	-0.11353	1	1114	11/7/2019
BEL116	-0.73	-1.5	-1.8	0.99282	-0.54196	0.99999	1114	11/18/2019
BWR139	-1.39	-4.3	-4.9	0.97304	-1.01079	0.99999	1114	11/19/2019
BFT142	-1.21	-4.3	-5.1	0.96728	-0.58271	1	1114	12/17/2019
COW137	-1.28	-3.9	-5.6	0.96767	0.17821	0.99958	1115	6/13/2019
ARE128	-0.78	-2.4	-2.9	0.97944	-0.31014	0.99998	1115	7/24/2019
PSU106	-0.74	-4.1	-4.3	0.95555	0.12622	1	1115	7/25/2019
WST109	-0.81	-3.8	-4.0	0.96271	-0.07811	0.99999	1115	8/19/2019

Site ID	Actual Difference for Level 2	Average (% diff) for Levels 3, 4 and 6	Maximum (% diff) for Levels 3, 4 and 6	Ozone Slope	Ozone Intercept	Ozone Correlation	EEMS Standard Number	Date
ACA416	-0.23	4.6	5.9	1.06837	-1.25419	0.99999	1115	9/18/2019
ASH135	-2.51	-4.2	-5.7	0.99454	-2.50547	0.99993	1115	9/19/2019
ABT147	-0.39	-0.9	-1.3	0.99630	-0.32338	1	1115	9/25/2019
SHN418	-0.6	-2.0	-2.3	0.98595	-0.2997	0.99999	1115	10/22/2019
DCP114	-1.3	-4.4	-4.8	0.96442	-0.53192	0.99999	1115	10/24/2019
OXF122	-1.21	-2.3	-3.3	0.99496	-1.07432	1	1115	10/25/2019
MCK131	-1.4	-2.6	-4.4	0.99511	-1.37691	0.99993	1115	11/5/2019
MCK231	-1.51	-2.3	-3.0	1.00181	-1.68192	0.99994	1115	11/5/2019
SPD111	-1.24	-2.2	-3.6	0.99213	-1.02793	0.99988	1115	11/6/2019
VIN140	-1.01	-1.6	-1.9	0.99069	-0.37885	0.99997	1115	11/7/2019
QAK172	-0.93	-1.4	-3.2	1.00619	-1.01653	0.99999	1115	11/10/2019
CKT136	-2.1	-8.7	-9.2	0.92747	-0.93752	0.99999	1115	11/11/2019
CDR119	-0.5	0.3	1.0	1.01370	-0.6245	0.99999	1115	11/12/2019

4.1.1 Ozone Bias

EEMS is aware of the EPA *Technical Assistance Document* "Transfer Standards for Calibration of Air Monitoring Analyzers for Ozone" *October 2013* which can be found at the AMTIC website: https://www3.epa.gov/ttn/amtic/files/ambient/qaqc/OzoneTransferStandardGuidance.pdf.

The document provides the rationale for standard photometer designation and the procedures required to ensure photometer stability. The process involves comparisons to a higher-level standard (in this case a regional EPA level 1 standard) and multiple comparisons on separate days, known as "6x6 verification". As described in the document, once the transfer standard comparison relationship with the level 1 standard has been established and the stability requirements are met, the actual ozone concentration is calculated by:

$$Std.O_3\ conc. = \frac{1}{\bar{m}}\ (Indicated\ O_3\ conc. - \bar{I})$$

Where:

$\bar{m}$ = average slope

$\bar{I}$ = average intercept

EEMS used this equation prior to 2017 with a rolling 6x6 average slope and intercept to correct level 2 standard photometer measurements back to the regional EPA level 1 standard reference photometer (SRP) for ozone PE audits. Since the technical assistance document also states that if any adjustments are made to the transfer standard a new 6x6 verification is required, EEMS did not adjust the physical settings (background and span) of the level 2 standards unless the photometer did not meet the criteria (+/- 3 %) comparison to the level 1 standard. Thereby only mathematical corrections were applied to the level 2 standard photometers.

Review of data prior to 2017 indicated that this procedure may have introduced a bias to the standard since the level 2 standards are only compared to the level 1 SRP two or three times per year. The rolling 6x6 slope and intercept averages may not have reflected the current relationship between the level 2 and the level 1 standards. This bias was observed in the data from the 2016 ozone PE audits.

In 2017, EEMS elected to deviate from the EPA Technical Assistance Document and began correcting the level 2 standard photometer using the most recent verification results rather than the rolling 6x6 results. All ozone audit standard measurements have been corrected back to the EPA level 1 standard using most recent slope and intercept relationship to the SRP since 2017.

The remainder of this section will focus on only Level 2 audit results. Data presented includes not only EEMS audit data, but audit data available in AQS from other audit agencies. Station monitor response to ozone-free (zero-air) audit gas are not available in AQS. Since EEMS frequently observes negative responses to zero-air from station monitors, it is likely that the lowest audit concentrations are impacted. Level 2 audit results provide the lowest concentration data with enough data points for a cursory comparison, therefore only level 2 audit data are compared.

Figures 4-1 presents annual PE ozone results for Level 2 concentrations performed by EEMS in 2017 and 2018 respectively. As previously stated, beginning in 2017 calculations of standard values only include the most recent comparison to the SRP (not a rolling 6x6 average) and little if any bias is evident in the audit results. In 2018 it appears that there may be a slight negative increase in bias.

Figure 4-1. 2017 and 2018 Ozone PE Actual Difference Level 2 Audits Performed by EEMS

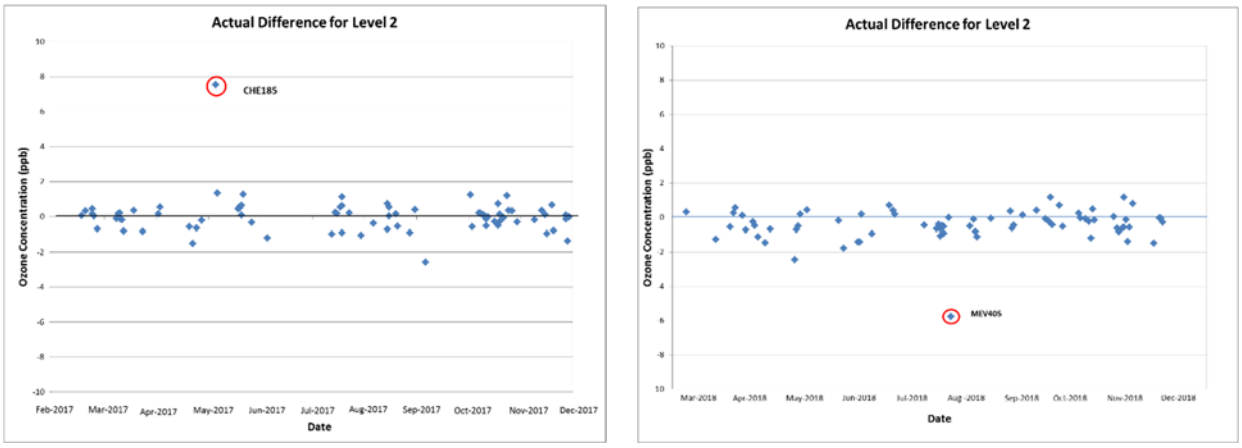
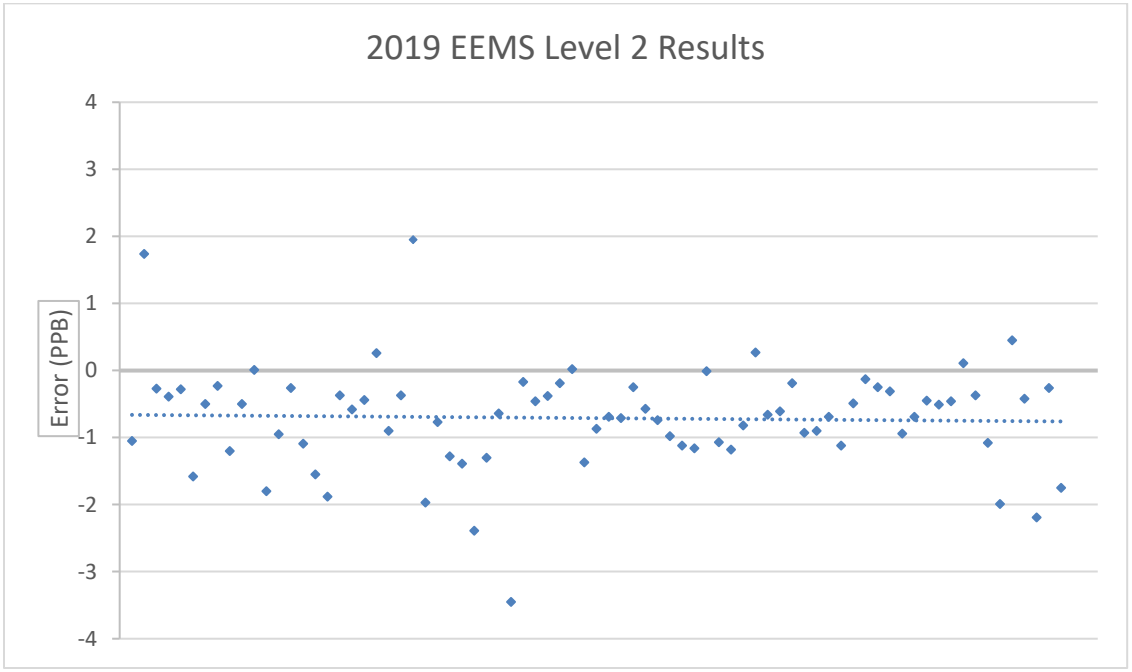


Figure 4-2 presents 2019 Level 2 annual PE audit results performed by EEMS. It seems clear that the negative bias trend has increased from 2018 through 2019.

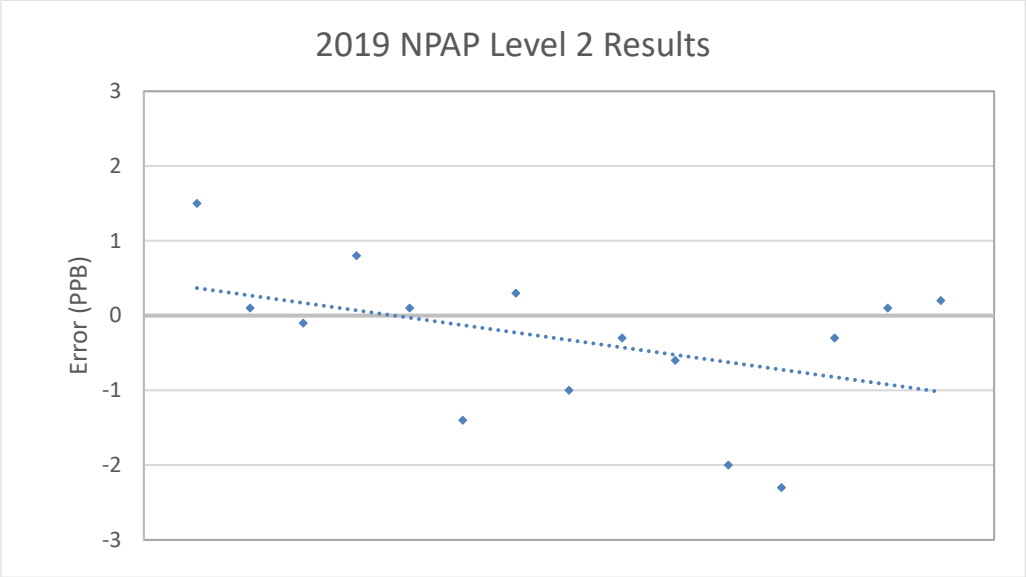
Figure 4-2. 2019 Ozone PE Actual Difference Level 2 Audits Performed by EEMS



EEMS has not observed this bias when performing ozone audits for stations that are not part of CASTNET (see previous annual reports). Although data are not included in this report, the contractors responsible for calibrations and maintenance of CASTNET ozone monitors have not reported negative responses to zero-air or bias low audit results. Therefore, as further investigation, audit data of CASTNET ozone monitors performed by other agencies was obtained from AQS.

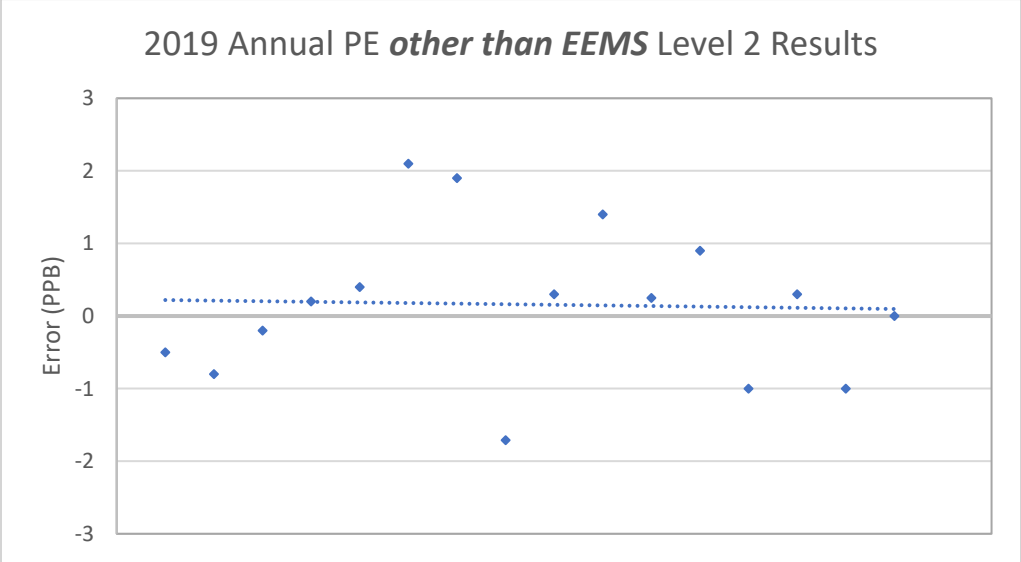
Figure 4-3 presents 2019 NPAP Level 2 audit data. NPAP audits are performed at each CASTNET site approximately once every three years by each EPA regional laboratory or contractor. NPAP audit data should be directly comparable to EEMS annual PE audit data since the identical method is used by NPAP and EEMS field scientists and both NPAP and EEMS use very similar mobile laboratory systems to perform the audits. Most notably the zero-air generator and dilution systems are identical. The data were downloaded from AQS but not parsed to determine which regional mobile lab or agency performed the NPAP audit. Data are not available to indicate the site monitor response to zero-air. It is most likely that data are obtained from more than one NPAP mobile laboratory and field scientist. Although not as prominent as EEMS annual PE results, there appears to be a slight negative bias.

Figure 4-3. 2019 Actual Difference Level 2 NPAP Audits



Several state and local agencies perform annual ozone PE at CASTNET stations. Those data were downloaded from AQS for those audits performed in 2019. Figure 4.4 presents the level 2 concentration audit results. It is unknown what methods and equipment the state and local agencies use to perform the audits. It is not known if the audits are performed TTP or back-of-the-analyzer (BOA). Data were not parsed to determine which sites were audited or which agency performed the audits. No data are available to indicate the station response to zero-air. It appears there is no bias at the level 2 audit concentration for audits performed by state and local agencies.

Figure 4-4. 2019 Ozone PE Actual Difference Level 2 Audits *Not Performed* by EEMS



The data, and observations of monitor response to audit zero-air, indicate that the bias at low concentrations might be attributed to the negative response to ozone-free audit gas. A likely theory is that the audit gas is much drier than the ambient air that is being sampled by the monitor prior to the audit. The moisture contained in the ambient air has likely coated and permeated the sample lines and filters upstream of the monitor and is slightly impacting the response. This could also explain why the effect is not observed at sites other than CASTNET, since the sample lines at those sites are much shorter and usually do not contain a filter at the inlet that is subject to moisture permeation.

The zero-air generators used by EEMS and NPAP produce very dry air. The audit gas dew point is most likely much lower than the on-site zero-air system, and the zero-air systems used by the state and local agencies to generate audit gas. This may be why the EEMS and NPAP results differ from the automatic on-site checks and audits by local agencies.

EEMS is continuing to investigate the observed bias. Thirty EPA sponsored CASTNET ozone monitors incorporate an inline Nafion™ dryer to help dry the sample air as it enters the monitor. The dryer is located near the back of the monitor inside the station shelter and is operated by vacuum from the dry deposition filter pump. In 2020 EEMS is performing ozone PE with the vacuum pump engaged and the dryer active. This has not been done in previous years.

A more thorough analysis of this phenomenon could include investigation of correlation with site humidity and elevation. It is also suspected that on-site calibration methods could contribute to the impact depending on the flow rate and pressure of the calibration gas generated.

4.2 Flow Rate

The controlled flow rate operated by the CASTNET filter pack system was audited at 57 sites in 2019. All flow rates are in standard temperature and pressure (at 25 ºC) (STP). A NIST-traceable dry-piston primary flow rate device was used for the tests. The readings obtained from this primary standard are the STP flow rate observed, while the DAS flow rate was read from the on-site data logger. All but one (MAC426) of the flow rate data accuracy results were found to be within the acceptance limits.

4.3 Shelter Temperature

At each site reporting ozone concentrations to AQS, the hourly average shelter temperature must be maintained between 20.0 to 30.0 degrees C or per manufacturers specifications if designated to a wider temperature range. Shelter temperature was audited at 52 of the sites visited. All but two (CHC432 and ZIO433) of the shelter temperature data accuracy results were found to be within the acceptance criterion of ± 2 °C. The method consisted of placing the audit standard in close proximity (in situ) to the shelter temperature sensor and recording either instantaneous observations of both sensors, or averages from both sensors. A Resistance Temperature Detector (RTD) was used as the audit standard.

Nearly all of the site sensors were observed to lag behind the audit sensor during the rapid changes in temperature inside the shelter as the air conditioning or heating cycled on and off. In most instances the shelter temperature sensors never reached the minimum or maximum temperature measured with the audit standard. This is not likely to add a large error to the hourly averaged shelter temperature measurements. However, since the output of the shelter temperature sensors follow a sine wave curve but the actual shelter temperature does not change following a sine wave curve, if the shelter temperature is set near the lower or higher allowable limits (20 to 30 degrees C)[1] the actual hourly averages may be lower or higher than those measured by the site sensors.

The shelter temperature and flow rate audit results are summarized in Table 4-3. Flow rate and shelter temperature data are reported only for the sites that were visited for complete systems and performance audits.

[1] The revised acceptable operating temperature range for Thermo 40*i* monitor is 5 to 40 degrees C.

Table 4-3. Performance Audit Results Shelter Temperature, and Flow Rate

Site ID	Shelter Temp. Average Error (C)	Shelter Temp. Maximum Error (C)	STP Flow Rate Primary Standard (lpm)	STP Flow Rate Site DAS (lpm)	Flow Error (% diff)	Audit date
ALC188	-0.93	-0.96	1.54	1.50	-2.38	2/25/2019
BBE401	0.30	1.08	2.98	3.00	0.67	2/27/2019
PAL190	-0.34	1.99	3.02	3.00	-0.55	3/1/2019
EVE419	--	--	3.02	3.01	-0.44	3/19/2019
CVL151	-0.11	-0.16	1.52	1.50	-1.32	4/13/2019
CHE185	0.14	0.33	1.53	1.50	-1.96	4/15/2019
CAD150	0.27	0.31	1.52	1.50	-1.32	4/16/2019
LAV410	-0.05	-1.75	3.02	3.01	-0.22	5/7/2019
PIN414	0.11	0.74	2.97	3.01	1.23	5/8/2019
YOS404	1.61	2.31	3.00	3.00	-0.33	5/13/2019
SEK430	0.29	0.46	3.04	3.01	-1.10	5/14/2019
ROM406	2.00	2.98	3.00	2.95	-1.66	6/6/2019
ROM206	0.97	1.49	3.04	3.00	-1.31	6/11/2019
CND125	1.03	1.13	1.50	1.50	-0.22	6/14/2019
WSP144	-0.05	0.31	1.49	1.50	0.45	6/17/2019
PND165	-0.60	-1.14	3.04	3.00	-1.21	7/1/2019
WFM105	--	--	2.96	3.00	1.47	7/2/2019
WNC429	0.82	1.13	2.99	3.08	3.12	7/2/2019
YEL408	-0.08	1.17	2.98	3.00	0.54	7/2/2019
GLR468	-0.99	-1.09	3.01	3.00	-0.33	7/3/2019
UND002	--	--	3.04	3.00	-1.21	7/9/2019
NIC001	--	--	3.00	3.00	-0.11	7/10/2019
CNT169	-0.13	-0.41	3.02	2.99	-0.77	7/16/2019
THR422	1.70	2.1	3.05	3.07	0.77	7/22/2019
NEC602	0.88	1.06	3.12	3.00	-3.64	7/23/2019
PED108	0.55	1.47	1.47	1.50	2.04	7/26/2019
ZIO433	2.4	3.44	--	--	--	8/3/2019
CHC432	2.32	2.88	--	--	--	8/5/2019
GTH161	0.04	0.13	3.04	3.01	-1.10	8/6/2019

Site ID	Shelter Temp. Average Error (C)	Shelter Temp. Maximum Error (C)	STP Flow Rate Primary Standard (lpm)	STP Flow Rate Site DAS (lpm)	Flow Error (% diff)	Audit date
BAS601	0.43	0.45	3.04	3.00	-1.42	8/19/2019
BUF603	--	--	2.92	3.00	2.86	8/20/2019
SHE604	--	--	3.03	3.11	2.88	8/20/2019
PRK134	-0.26	-0.28	1.49	1.50	0.90	8/27/2019
VOY413	0.18	0.28	2.99	3.00	0.22	8/29/2019
ACA416	1.83	2.1	1.53	1.52	-0.44	9/18/2019
VPI120	0.72	0.87	1.50	1.50	0.00	9/24/2019
PAR107	0.17	0.61	1.54	1.51	-2.16	9/25/2019
LRL117	-0.08	-0.94	1.50	1.49	-0.45	9/26/2019
GRS420	0.15	0.35	2.92	3.00	2.62	10/7/2019
MAC426	-0.06	0.53	1.59	1.51	-5.03	10/17/2019
KNZ184	0.10	1.23	2.99	2.99	-0.11	10/22/2019
SHN418	-0.04	-0.06	1.52	1.50	-1.53	10/22/2019
KIC003	--	--	2.98	2.99	0.45	10/23/2019
DCP114	1.32	1.42	1.53	1.50	-2.17	10/24/2019
OXF122	0.09	0.46	1.51	1.50	-0.88	10/25/2019
SAN189	-0.03	0.42	2.98	3.00	0.78	10/25/2019
MCK131	0.00	0.30	1.55	1.51	-3.00	11/5/2019
MCK231	0.56	0.98	1.54	1.51	-2.16	11/5/2019
STK138	-0.67	-0.8	1.43	1.50	4.65	11/5/2019
BVL130	0.08	0.28	1.51	1.50	-0.88	11/7/2019
VIN140	-0.17	-0.98	1.53	1.50	-1.96	11/7/2019
QAK172	0.59	0.80	1.49	1.50	0.67	11/10/2019
CKT136	1.07	1.12	1.50	1.50	-0.22	11/11/2019
CDR119	0.71	0.9	1.51	1.50	-0.66	11/12/2019
EGB181	-0.55	-0.56	1.47	1.49	1.36	11/12/2019
BWR139	0.49	0.61	1.54	1.50	-2.39	11/19/2019
ALH157	-0.41	-0.67	1.48	1.50	1.35	12/16/2019
BFT142	0.09	0.20	1.49	1.49	0.22	12/17/2019
CDZ171	-0.02	-1.04	1.54	1.50	-2.39	12/17/2019

4.4 Wind Speed

The wind speed sensors at three sites (only low speed tested at BVL130) equipped for meteorological measurements were audited. The wind speed data accuracy results at ACA416 were above the acceptance limit. The results of the wind speed performance audits are presented in Table 4-4. The state of Maine operates the meteorological sensors at ACA416. Audits in previous years have indicated similar results. The sensor appears to be accurate up to speeds above 20 m/s (over 45 mph) and then fails at higher speeds. It is likely that the sensor is not tested by the state at high wind speeds and this is not a concern.

4.4.1 Wind Speed Starting Threshold

The condition of the wind speed bearings was evaluated as part of the performance audits. The data acceptance criterion for wind speed bearing torque is not defined in the QAPP. However, ***Appendix 1: CASTNET Field Standard Operating Procedures***, states that the wind speed bearing torque should be ≤ 0.2 g-cm. To establish the wind speed bearing torque criterion for audit purposes the rational described in the QAPP measurement criteria was applied. The QAPP states that field criteria are more stringent than DQO and established to maintain the system within DQO. Typically, field measurement criteria are set at approximately one-half the DQO. Therefore, 0.5 g-cm was used for the acceptance limit for audit purposes. This value is within the manufacturers' specifications for a properly maintained system.

4.5 Wind Direction

Two separate tests were performed to evaluate the accuracy of each wind direction sensor:

- A linearity test was performed to evaluate the ability of the sensor to function properly and accurately throughout the range from 1 to 360 degrees. This test evaluates the sensor independently of orientation and can be performed with the sensor mounted on a test fixture.
- An orientation test was used to determine if the sensor was aligned properly when installed to measure wind direction accurately in degrees true. An audit standard compass was used to perform the orientation tests.

The results of the wind direction performance audits are presented in Table 4-4. The average errors for all sensors were within the acceptance limits or the linearity test. The average errors for all sensors except ZIO433 were within the acceptance limits or the orientation test.

4.5.1 Wind Direction Starting Threshold

The condition of the wind direction bearings were evaluated as part of the performance audits. The data acceptance criterion for wind direction bearing torque is not defined in the QAPP. However,

Appendix 1: CASTNET Field Standard Operating Procedures, states that the wind direction bearing torque should be ≤ 10 g-cm for R. M. Young sensors. The manufacturer states that a properly maintained sensor will be accurate up to a starting threshold of 11 g-cm. To establish the wind direction bearing torque criterion for audit purposes the rational described in the QAPP measurement criteria was applied. The QAPP states that field criteria are more stringent than DQO and established to maintain the system within DQO. Typically, field criteria are set to approximately one-half the DQO. For audit purposes 20 g-cm was used for the acceptance limit for R. M. Young sensors. Climatronics sensors typically have a lower starting torque. For audit purposes a threshold of 10 g-cm was selected for Climatronics sensors. The sensor at ACA416 tested outside of acceptance limits for wind direction starting threshold. The test results are provided in Table 4-4.

Table 4-4. Performance Audit Results for Wind Sensors

Site ID	Wind Direction					Wind Speed				
	Orientation Error		Linearity Error		Starting Torque (g-cm)	Low Range Error		High Range Error		Starting Torque (g-cm)
	Ave (deg)	Max (deg)	Ave (deg)	Max (deg)		Ave (m/s)	Max (m/s)	Ave (% diff)	Max (% diff)	
ACA416	-3.8	-5.2	1.78	3.2	11.5	-0.08	-0.21	-7.0	-25.67	0.45
BVL130	0.3	-2	1.0	2.0	14	-0.07	-0.20	NP	NP	0.4
CHC432	-1.4	-3.2	1.73	4.4	10	-0.05	-0.20	0.10	0.20	0.3
ZIO433	-9.5	-12	1.35	2.9	15	-0.05	-0.20	0.0	0.0	0.3

*** Note: The wind systems acceptance criteria were applied to the average of the results. The data validation section of the CASTNET QAPP states that if any wind direction or wind speed challenge result is outside the acceptance criterion the variable is flagged. (NP = not performed)**

4.6 Temperature and Two-Meter Temperature

The EPA sponsored site temperature measurement systems consist of a temperature sensor mounted on a tower approximately 9 meters above ground-level. Sites operated by the Park Service have moved the temperature sensors to approximately two meters above the ground (2-meter temperature).

The BLM has recently upgraded the temperature sensors at their sites to submersible RTD sensors. However, the sensor operating at NPS sponsored CHC432 site, is a combined relative humidity and temperature sensor and not standalone RTD or encased thermistor temperature sensor. Due to the design of the RH/Temperature sensor, it cannot be submerged in water baths to challenge the sensor at different temperature audit levels. For that reason, the combination RH/Temperature sensor was audited by placing the sensor in a watertight chamber (RH salt chamber) and then placing the chamber in an ice-water bath, ambient bath, and hot water bath. Therefore, the

temperature audit results for site CHC432 are not directly comparable to audit results of RTD or encased thermistor sensors, and not reported.

All sites use shields to house the sensors that are either mechanically aspirated with forced air, or naturally aspirated. In all cases the sensors were removed from the sensor shields and placed in a uniform temperature bath with a precision NIST-traceable RTD, during the audit.

A total of 58 temperature sensors were tested, and all were found to be within the acceptance criterion. It should be noted that one of those sensors (CHC432) is a combination RH/Temperature sensor as described above and cannot be submersed in a water-bath. The average errors for all sensors are presented in Table 4-5.

4.6.1 Temperature Shield Blower Motors

All fourteen of the temperature systems with sensor shield blower motors (forced-air aspiration) encountered during the site audits conducted during 2019 were found to be functioning.

4.7 Relative Humidity

The three relative humidity systems that were audited were tested with a combination of primary standard salt solutions, and a NIST traceable transfer standard relative humidity probe. The results of the average and maximum errors throughout the measurement range of approximately 30% to 95% are presented in Table 4-5. All humidity sensors were within the acceptable limits.

As in previous years, operation of both temperature and humidity sensors with respect to natural or forced-air aspiration can vary between sites. At most EPA sponsored sites temperature and humidity sensors are operating in naturally aspirated shields. At most NPS sponsored sites temperature and humidity sensors are operating in shields designed to be mechanically aspirated with forced-air blowers.

During humidity audit tests with the primary standard salt solutions, the sensors were removed from the shields and placed in a temperature-controlled enclosure. During audit tests with the transfer standard probe, the sensor and transfer were placed in the same ambient conditions. Therefore, the audit tests do not account for differences in the operation of the sensors due to the different shield configurations.

Table 4-5. Performance Audit Results for Temperature and Relative

Audit Date	Site ID	9-meter Temperature Ave. Error (deg C)	2-Meter Temperature Ave. Error (deg C)	Relative Humidity	
				Range 0 – 100%	
				Ave. Error (%)	Max. Error (%)
2/25/2019	ALC188	-0.26	--	--	--
2/27/2019	BBE401	--	0.26	--	--
3/1/2019	PAL190	-0.03	--	--	--
4/13/2019	CVL151	-0.05	--	--	--
4/15/2019	CHE185	-0.33	--	--	--
4/16/2019	CAD150	-0.05	--	--	--
5/7/2019	LAV410	--	-0.05	--	--
5/8/2019	PIN414	--	-0.15	--	--
5/13/2019	YOS404	--	-0.15	--	--
5/14/2019	SEK430	--	-0.23	--	--
6/6/2019	ROM406	--	0.22	--	--
6/11/2019	ROM206	-0.10	--	--	--
6/14/2019	CND125	0.32	--	--	--
6/17/2019	WSP144	-0.11	--	--	--
7/1/2019	PND165	-0.04	--	--	--
7/2/2019	WFM105	0.12	--	--	--
7/2/2019	YEL408	--	-0.29	--	--
7/3/2019	GLR468	--	0.23	--	--
7/9/2019	UND002	0.06	--	--	--
7/10/2019	NIC001	0.00	--	--	--
7/16/2019	CNT169	0.05	--	--	--
7/22/2019	THR422	--	0.04	--	--
7/23/2019	NEC602	--	0.09	--	--
7/24/2019	WNC429	--	0.11	--	--
7/26/2019	PED108	-0.13	--	--	--

Audit Date	Site ID	9-meter Temperature Ave. Error (deg C)	2-Meter Temperature Ave. Error (deg C)	Relative Humidity	
				Range 0 – 100%	
				Ave. Error (%)	Max. Error (%)
8/3/2019	ZIO433	--	0.30	--	--
8/5/2019	CHC432	--	--	-1.81	-2.7
8/6/2019	GTH161	0.09	--	--	--
8/19/2019	BAS601	--	0.12	--	--
8/20/2019	BUF603	--	0.08	--	--
8/20/2019	SHE604	--	0.07	--	--
8/27/2019	PRK134	-0.07	--	--	--
8/29/2019	VOY413	--	-0.37	--	--
9/18/2019	ACA416	--	0.10	-0.79	-2.2
9/24/2019	VPI120	-0.01	--	--	--
9/25/2019	PAR107	-0.19	--	--	--
9/26/2019	LRL117	-0.04	--	--	--
10/7/2019	GRS420	--	0.01	--	--
10/17/2019	MAC426	--	0.18	--	--
10/22/2019	KNZ184	-0.13	--	--	--
10/22/2019	SHN418	--	0.11	--	--
10/23/2019	KIC003	0.08	--	--	--
10/24/2019	DCP114	0.07	--	--	--
10/25/2019	OXF122	0.33	--	--	--
10/25/2019	SAN189	-0.06	--	--	--
11/5/2019	MCK131	0.05	--	--	--
11/5/2019	MCK231	-0.20	--	--	--
11/5/2019	STK138	-0.01	--	--	--
11/7/2019	BVL130	-0.08	0.03	0.53	3.1
11/7/2019	VIN140	0.05	--	--	--
11/10/2019	QAK172	0.17	--	--	--

Audit Date	Site ID	9-meter Temperature Ave. Error (deg C)	2-Meter Temperature Ave. Error (deg C)	Relative Humidity	
				Range 0 – 100%	
				Ave. Error (%)	Max. Error (%)
11/11/2019	CKT136	0.28	--	--	--
11/12/2019	CDR119	0.07	--	--	--
11/12/2019	EGB181	-0.10	--	--	--
11/19/2019	BWR139	0.10	--	--	--
12/16/2019	ALH157	-0.03	--	--	--
12/17/2019	BFT142	0.08	--	--	--
12/17/2019	CDZ171	-0.08	--	--	--

4.8 Solar Radiation

The ambient conditions encountered during the audit visits were suitable (high enough light levels) for accurate comparisons of solar radiation measurements. A World Radiation Reference (WRR) traceable Eppley PSP radiometer and translator or a model 8-48 were used as the audit standard system.

Three sites were tested. All sites had daytime average results that were within the acceptance criterion. The results of the individual tests for each site are included in Table 4-6. The percent difference of the maximum single-hour average solar radiation value observed during each site audit is also reported in Table 4-6 although this criterion is not part of the CASTNET data quality indicators. All maximum values were also within ±10%.

4.9 Precipitation

The four sites audited used a tipping bucket rain gauge for obtaining precipitation measurement data. The audit challenges consisted of entering multiple amounts of a known volume of water into the tipping bucket funnel at a rate equal to approximately 2 inches of rain per hour. Equivalent amounts of water entered were compared to the amount recorded by the DAS. The results are summarized in Tables 4-6. All sensors were within the acceptance criteria.

Table 4-6. Performance Audit Results for Solar Radiation and Precipitation

Site ID	Solar Radiation Error				Precipitation Ave. Error (% diff)
	Daytime Ave. (% diff)	Std. Max. Value (w/m2)	Site Max. Observed (w/m2)	Max. Value (% diff)	
ACA416	--	--	--	--	-2.0
BVL130	7.5	481	523	8.7	2.0
CHC432	-1.6	991	963	-3.4	-0.9
ZIO433	-0.8	791	794	-2.3	-0.1

4.10 Data Acquisition Systems (DAS)

All of the NPS sponsored sites visited utilized an ESC logger as the primary and only DAS. All EPA sites visited operated Campbell Scientific loggers as their only DAS. The results presented in table 4-7 include the tests performed on the logger at each site. The BLM sites utilize a Campbell Scientific CR1000. The CR1000 and some of the other loggers encountered are not configured to allow analog tests.

4.10.1 Analog Test

The accuracy of each logger was tested on two different channels (if two channels were available to be used) with a NIST-traceable Fluke digital voltmeter. At the EPA sponsored sites the channels above analog channel 8 could not be tested since there were no empty channels available to test. All data loggers were within the acceptance criterion of ± 0.003 volts.

4.10.2 Functionality Tests

Other performance tests used to evaluate the DAS included the verification of the date and time. All site data loggers were found to be set to the correct date and within ±5 minutes per the acceptance criterion for time except for EGB181. The NPS sponsored site data loggers were found to be set to the correct date and within ±5 minutes of the acceptance criterion for time. However, most of the NPS clocks were found to be 1 to 3 minutes different than the standard, whereas the EPA sponsored site clocks were all within 2-3 seconds. The Campbell Scientific logger clocks at the EPA sites are synchronized with the internet, whereas the ESC loggers at the NPS sites are not.

Table 4-7. Performance Audit Results for Data Acquisition Systems

Audit Date	Site ID	Analog Test Error (volts)				Date Correct (Y/N)	Time Error (minutes)
		Low Channel		High Channel			
		Average	Maximum	Average	Maximum		
2/25/2019	ALC188	0.0001	0.0004	--	--	Y	0.00
2/27/2019	BBE401	--	--	0.0000	-0.0003	Y	-1.85
3/1/2019	PAL190	0.0001	0.0002	--	--	Y	-1.00
3/19/2019	EVE419	0.0000	0.0002	--	--	Y	-1.72
4/13/2019	CVL151	-0.0001	-0.0002	--	--	Y	0.00
4/15/2019	CHE185	-0.0020	-0.0030	--	--	Y	-0.15
4/16/2019	CAD150	0.0000	-0.0001	--	--	Y	0.00
5/7/2019	LAV410	--	--	-0.0001	-0.0004	Y	1.45
5/8/2019	PIN414	--	--	0.0002	0.0005	Y	-0.95
5/13/2019	YOS404	-0.0001	-0.0003	--	--	Y	0.92
5/14/2019	SEK430	--	--	0.0003	0.0008	Y	1.90
6/6/2019	ROM406	--	--	--	--	Y	-1.25
6/11/2019	ROM206	-0.0002	-0.0005	--	--	Y	0.00
6/14/2019	CND125	-0.0001	-0.0001	--	--	Y	0.02
6/17/2019	WSP144	-0.0001	-0.0002	--	--	Y	-0.08
7/1/2019	PND165	-0.0001	-0.0004	--	--	Y	-0.05
7/2/2019	YEL408	0.0000	-0.0004	--	--	Y	-0.08
7/3/2019	GLR468	--	--	-0.0001	-0.0005	Y	-0.67
7/16/2019	CNT169	-0.0001	-0.0003	--	--	Y	0.08
7/22/2019	THR422	--	--	0.0002	0.0004	Y	1.10
7/24/2019	WNC429	-0.0001	-0.0003	--	--	Y	-1.67
7/26/2019	PED108	-0.0001	-0.0003	--	--	Y	0.00
8/3/2019	ZIO433	-0.0002	-0.0003	--	--	Y	-0.75
8/5/2019	CHC432	0.0003	0.0007	--	--	Y	0.95
8/6/2019	GTH161	-0.0002	-0.0010	--	--	Y	0.00
8/27/2019	PRK134	0.0000	-0.0001	--	--	Y	0.03
8/29/2019	VOY413	0.0000	0.0001	--	--	Y	1.83

Audit Date	Site ID	Analog Test Error (volts)				Date Correct (Y/N)	Time Error (minutes)
		Low Channel		High Channel			
		Average	Maximum	Average	Maximum		
9/18/2019	ACA416	--	--	-0.0006	-0.0019	Y	-0.17
9/24/2019	VPI120	0.0000	0.0001	--	--	Y	0.00
9/25/2019	PAR107	0.0000	-0.0001	--	--	Y	0.00
9/26/2019	LRL117	0.0000	0.0001	--	--	Y	0.00
10/7/2019	GRS420	-0.0001	-0.0002	--	--	Y	-0.13
10/17/2019	MAC426	0.0000	0.0001	--	--	Y	-0.73
10/22/2019	KNZ184	0.0000	0.0003	--	--	Y	-0.08
10/24/2019	DCP114	0.0000	-0.0001	--	--	Y	0.00
10/25/2019	OXF122	-0.0001	-0.0001	--	--	Y	0.00
10/25/2019	SAN189	0.0001	0.0003	--	--	Y	0.00
11/5/2019	MCK131	0.0000	0.0000	--	--	Y	0.00
11/5/2019	MCK231	0.0000	0.0000	--	--	Y	0.00
11/5/2019	STK138	0.0001	0.0002	--	--	Y	0.00
11/7/2019	BVL130	0.0002	0.0003	--	--	Y	0.00
11/7/2019	VIN140	0.0000	0.0001	--	--	Y	0.00
11/10/2019	QAK172	0.0000	-0.0001	--	--	Y	0.03
11/11/2019	CKT136	-0.0001	-0.0001	--	--	Y	0.00
11/12/2019	CDR119	0.0000	-0.0001	--	--	Y	-0.02
11/12/2019	EGB181	-0.0001	-0.0002	--	--	Y	5.75
11/19/2019	BWR139	0.0000	0.0001	--	--	Y	-1.00
12/16/2019	ALH157	0.0000	0.0002	--	--	Y	0.00
12/17/2019	BFT142	0.0000	0.0001	--	--	Y	-0.05
12/17/2019	CDZ171	0.0001	0.0002	--	--	Y	-0.03

5.0 Systems Audit Results

The following sections summarize the site systems audit findings and provide information observed regarding the measurement processes at the sites. Conditions that directly affect data accuracy have been reported in the previous sections. Other conditions that affect data quality and improvements to some measurement systems or procedures are suggested in the following sections.

5.1 Siting Criteria

All of the sites that were visited have undergone changes during the period of site operation which include population growth, road construction, and foresting activities. None of those changes were determined to have a significant impact on the siting criteria that did not exist when the site was initially established.

Some sites that are located in state and national parks are not in open areas and have trees within the 50 meter criterion established in the QAPP. Given the land use and aesthetic concerns, these sites are acceptable and represent an adequate compromise with regard to siting criteria and the goal of long-term monitoring. For sites that measure ozone data designated as NAAQS compliant, these sites may violate recommended siting criteria in 40 CFR Part 58.

The CASTNET QAPP is currently being revised to more closely follow 40 CFR Part 58 Appendix E. The audit program will incorporate those changes when they are implemented beginning with audits in 2020.

5.2 Sample Inlets

Based on the siting criteria information provided in the CASTNET QAPP, with consideration given to the siting criteria compromises described in the previous section, all but four sites (LAV410, YEL408, VOY413, and CDR119) visited in 2019 have ozone monitor sample trains that are sited properly and in accordance with the CASTNET QAPP. All ozone sample inlets are currently being evaluated with respect to obstructions above the inlet. The acceptance criterion requires that there should be no obstructions (including trees) within a 26.6 degree angle (object distance must be at least two times the height) above the ozone inlet. There are trees that violate the 26.6 degree sample inlet requirement at the four sites listed above.

All but two CASTNET ozone monitors have sample inlet heights at 10 meters the exceptions are WNC429 at 3.35 meters and THR422 at 12.2 meters. With the exception of the state operated sites (WNC429 and THE422), the ozone zero, span, and precision calibration test gases are introduced at the ozone sample inlet, through all filters and the entire sample train. All sample

trains are comprised of only Teflon or Kynar fittings and materials. Sample inlet particulate filters of 5 micron are present at most sites.

The dry deposition filter packs are designed to sample from a height of 10 meters. Most of the filter pack sample lines are also Teflon. Inline filters are present in the sample trains to prevent moisture and particulates from damaging the flow rate controller. A few sites were configured with the dry deposition filter face below the edge of the rain shield enclosure. This may impact the size of the particles collected on the filter. The standard CASTNET configuration is the filter face must not extend below the edge of the enclosure.

5.3 Infrastructure

Sites continue to be improved by repairing the site shelters which had deteriorated throughout the years of operation. A few of the site shelters are still in need of repair, but overall, the condition of the sites has improved again during the past year. Wi-Fi routers with improved internet service have been installed at most sites.

5.4 Site Operators

Generally the site operators are very conscientious and eager to complete the site activities correctly. They are willing to, and have performed sensor replacements and repairs at the sites with support provided by the Wood and ARS field operations centers. In some cases, where replacements or repairs were made, documentation of the activities was not complete, and did not include serial numbers of the removed and installed equipment.

Many of the CASTNET site operators also perform site operator duties for the National Atmospheric Deposition Program (NADP). Many of the NPS site operators also perform other air, or environmental quality functions within their park. All are a valuable resource for the program.

Still many of the site operators have not been formally trained to perform the CASTNET duties by either Wood or ARS. They had been given instructions by the previous site operators and over the phone instructions from the field operation centers at Wood and ARS.

5.5 Documentation

The NPS site operator procedures are well developed and readily accessible at all of the NPS sites visited. There is an electronic interface (DataView 2) available to view, analyze, and print site data. There are electronic “checklists” for the site operator to complete during the site visits; however, all of the CASTNET filter pack procedures are not included in the “checklists”. Flow rates and leak check results are not recorded electronically.

An electronic logbook is included in the interface software. This system permits easy access to site documentation data. Complete calibration reports have been added to the system and accessible through the site computer, however the reports available on-site are not up to date.

5.6 Site Sensor and FSAD Identification

Continued improvement has also been made in the area of documentation of sensors and systems used at the sites. It is important to maintain proper sensor identification for the purposes of site inventory and to properly identify operational sensors for data validation procedures. Many sensors have had new numbers affixed for proper identification.

Where possible the identification numbers assigned (serial numbers and barcodes) are used within the field site audit database for all the sensors encountered during the site audits. The records are used for both the performance and systems audits. If a sensor is not assigned a serial number by the manufacturer, that field is entered as "none". If it is unknown whether an additional client ID number is assigned to a sensor, and a number is not found, the client ID is also entered as "none". If it is typical for a manufacturer and/or client ID number to be assigned to a sensor, and that number is not present, the field is entered as "missing". If either the serial number or the client ID numbers cannot be read, the field is entered as "illegible". An auto-number field is assigned to each sensor in the database in order to make the records unique.

6.0 Summary and Recommendations

The CASTNET Site Audit Program has been successful in evaluating the field operations of the sites. The results of performance and systems audits are recorded and archived in a relational database, the Field Site Audit Database (FSAD). CASTNET site operations are generally acceptable and continue to improve. Some differences between actual site operations and operations described in the QAPP have been identified and described. Procedural differences between EPA and NPS sponsored sites have also been described.

As discussed previously the shelters have received some much needed attention. It was also observed that improvements were made to the shelter temperature control systems. As a requirement in 40 CFR Part 58 for ozone monitoring, shelter temperature is an important variable. Additional improvement could be made to accurately measure and report shelter temperature.

The previous paragraphs and sections included some recommendations for improving the field operations systems. One recommendation for improving the audit program is presented in the following section.

6.1 In Situ Comparisons

An improvement to the audit procedures designed to evaluate the differences in measurement technique would be to develop an "In Situ" audit measurement system. This would require a suite of sensors that would be collocated with the site sensors. Ideally the audit sensors would address the inconsistent sensor installations observed throughout the network. By deploying a suite of certified NIST traceable sensors installed and operating as recommended by the manufacturer and to EPA guidelines, subtle differences in the operation of the existing CASTNET measurement systems could be evaluated. The "In Situ" sensors would be operated at each site for a 24 hour period and the measurements would be compared to the CASTNET measurements. A portable system of meteorological sensors would be beneficial for meteorological measurement evaluations particularly at BLM sponsored sites. EEMS is still pursuing this type of audit system.

7.0 References

Office of Air Quality and Planning Standards AMTIC website, SOP and guidance documents: www.epa.gov/ttn/amtic/

Quality Assurance Handbook for Air Pollution Measurement Systems: Volume II - Ambient Air Specific Methods – EPA.

Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV - Meteorological Measurements – EPA.

Clean Air Status and Trends Network (CASTNET) Quality Assurance Project Plan (2003) – EPA.

Quality Assurance Handbook for Air Pollution Measurement Systems: Volume I: - A Field Guide To Environmental Quality Assurance – EPA.

Quality Assurance Handbook for Air Pollution Measurement Systems: Volume II: Part1 Ambient Air Quality Monitoring Program Quality System Development – EPA.

Sensitivity of the National Oceanic and Atmospheric Administration multilayer model to instrument error and parameterization uncertainty: Journal of Geophysical Research, Vol. 105. No. D5, March 16, 2000.

Wind System Calibration, Recommended Calibration Interval, Procedure, and Test Equipment: November 1999, R. M. Young Company

Bowker, G.E., Schwede, D.B.; Lear, G.G.; Warren-Hicks, W.J., and Finkelstein, P.L., 2011. Quality assurance decisions with air models: a case study of imputation of missing input data using EPA's multi-layer model. Water, Air, and Soil Pollution 222, 391e402.

Schwede, D., & Lear, G.C. (2014). A novel hybrid approach for estimating total deposition in the United States. Atmospheric Environment, 92, 207-220.

APPENDIX 1

Audit Standards Certifications

Certificate Number
A3079040
Issue Date: 01/23/19

Certificate of Calibration

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01226

Description:	DIGITAL STIK THERMOMETER	Calibration Date:	01/23/2019
Manufacturer:	FLUKE	Calibration Due:	01/23/2020
Model Number:	1551A EX	Procedure:	FLUKE 1551A EX,52A EX Rev: 11/1/2010
Serial Number:	2085085	Temperature:	71 F
Technician:	STEVE TORRES	Humidity:	43 % RH
		As Found Condition:	**IN TOLERANCE**
On-Site Calibration: ☐		**Calibration Results:**	**IN TOLERANCE**

Comments: TUR is 2 to 1

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

This certificate shall not be reproduced, except in full, without the written permission of Technical Maintenance, Inc.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
05535	FLUKE	5609-12-D	7/3/2018	7/3/2019
660TL18010015	ADDITEL	ADT875PC-155	6/1/2018	6/1/2019
A88072	FLUKE/HART	1502A	12/17/2018	4/2/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3079040
Issue Date: 01/23/19

Certificate of Calibration

Data Sheet

Parameter	Nominal	Minimum	Maximum	As Found	As Left	Unit	ADJ/FAIL
Temperature Accuracy	-25.00	-25.05	-24.95	-25.02	-25.02	°C	
Temperature Accuracy	0.00	-0.05	0.05	0.00	0.00	°C	
Temperature Accuracy	100.00	99.95	100.05	99.99	99.99	°C	
Temperature Accuracy	150.00	149.95	150.05	149.96	149.96	°C	

EEMS # 01226

$m = 0.999875$

$b = -0.01046$

$r^2 = 1.00000$

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3079044
Issue Date: 01/23/19

Certificate of Calibration

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01229

Description:	DIGITAL STIK THERMOMETER	Calibration Date:	01/23/2019
Manufacturer:	FLUKE	Calibration Due:	~~01/23/2020~~
Model Number:	1551A EX	Procedure:	FLUKE 1551A EX,52A EX Rev: 11/1/2010
Serial Number:	3275143	Temperature:	71 F
Technician:	STEVE TORRES	Humidity:	43 % RH
		As Found Condition:	**IN TOLERANCE**
On-Site Calibration: ☐		**Calibration Results:**	**IN TOLERANCE**

Comments: TUR is 2 to 1

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

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Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
05535	FLUKE	5609-12-D	7/3/2018	7/3/2019
660TL18010015	ADDITEL	ADT875PC-155	6/1/2018	6/1/2019
A88072	FLUKE/HART	1502A	12/17/2018	4/2/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3079044
Issue Date: 01/23/19

Certificate of Calibration

Data Sheet

Parameter	Nominal	Minimum	Maximum	As Found	As Left	Unit	ADJ/FAIL
Temperature Accuracy	-25.00	-25.05	-24.95	-25.02	-25.02	°C	
Temperature Accuracy	0.00	-0.05	0.05	0.01	0.01	°C	
Temperature Accuracy	100.00	99.95	100.05	99.99	99.99	°C	
Temperature Accuracy	150.00	149.95	150.05	149.97	149.97	°C	

EEMS # 01229

$m =$ 0.999893

$b =$ -0.006489

$r^2 =$ 1.00000

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Date

2/12/2019 - - Calibration and certification of fluke Thermocouples

TMI Cert data -- 1/23/2019

	STD	EEMS RTD	diff	corrected
cert # =	A3079044	01229		
	-25.00	-25.02	0.020	-25.02
	0.00	0.01	-0.010	0.02
	100.00	99.99	0.010	100.01
	150.00	149.97	0.030	149.99
			0.000	0.01
			0.000	0.01

RTD 01229

2019 correction: slope= 0.99989313

intercept= -0.0064885

1.0000000

Eric Hebert 2/12/2019

At EEMS	Date 2/12/2019	fluke =	01311	offset -0.3	01312	offset -0.2	01310	offset 0.8
RTD 01229		thermo =	EEMS van3 01236		EEMS van 2 01237		EEMS van 1 01238	
raw	corrected		raw	corrected	raw	corrected	raw	corrected
0.02	0.03		0.7	0.14	0.1	-0.46	0.3	0.01
88.74	88.76		89.4	88.84	89.8	88.59	89.5	88.76
79.50	79.51		80.1	79.54	80.6	79.45	80.2	79.51
61.50	61.51		62.0	61.44	62.5	61.49	62.2	61.60
51.65	51.66		52.3	51.74	52.8	51.86	52.3	51.75
39.60	39.61		40.0	39.44	40.5	39.65	39.9	39.41
31.07	31.08		31.6	31.04	32.0	31.21	31.4	30.95
15.64	15.65		16.2	15.64	16.7	16.02	16.2	15.83
		Thermocouple offset =	-0.3		-0.2		0.3	
POST CALIBRATION CHECK								
20.88	20.89		20.9	20.34	21.0	20.29	20.9	20.51
		slope =	**1.00007**		**1.0073916**		**1.005088**	
		intercept =	**0.557902**		**0.5587589**		**0.289648**	
		correlation =	**1.0000**		**1.0000**		**1.0000**	

Date

2/12/2019 - - **Calibration and verification of three RTD meters with most recent certification of EEMS RTD**

TMI Cert data -- 1/23/2019				
	TMI STD	EEMS RTD 01229		
Cert #	A2380069			
			diff	corrected
	-25.00	-25.02	0.020	-25.016
	0.00	0.01	-0.010	0.016
	100.00	99.99	0.010	100.007
	150.00	149.97	0.030	149.993
				RTD 01229
		2019 correction:	slope=	0.99989313
			intercept=	-0.0064885
			corr= 1.0000000	

Eric Hebert 2/12/2019

At EEMS	Date 2/12/2019 RTD 01229		RTD 01230 / 01231 EEMS AER		RTD 01227 / 1 EEMS van3		RTD 01228 / 2 EEMS van1	
raw	corrected		raw	corrected	raw	corrected	raw	corrected
0.02	0.03		0.04	0.01	0.15	0.00	-0.09	0.02
10.32	10.33		10.35	10.34	10.56	10.09	10.31	10.57
21.10	21.11		21.12	21.12	21.43	20.89	21.19	21.35
30.30	30.31		30.32	30.33	30.67	30.30	30.47	30.30
40.00	40.01		39.98	40.00	40.46	40.02	40.28	40.03
47.91	47.92		47.89	47.92	48.40	47.90	48.23	47.90
25.00	25.01		25.00	25.00	25.34	25.01	25.14	25.02
		slope =	**0.998872**		**1.007333**		**1.009092**	
		intercept =	**0.026147**		**0.144973**		**-0.11036**	
		correlation =	**1.0000**		**1.0000**		**1.0000**	

Date

2/14/2019 - - **Calculation of correction factor for RH standard with n**

TMI Cert date =2/6/2019

	TMI STD	EEMS AZ 8723 01222	diff	corrected
Cert #	A3092730			
			0.0	2.0
			0.0	2.0
			0.0	2.0
	33.0	31.7	1.3	32.8
	50.0	49.6	0.4	50.3
	75.0	74.9	0.1	74.9

RH 01222

2019 correction: slope= 1.0273

intercept= -2.0396

corr = 0.9999400

Eric Hebert 2/14/2019

Certificate Number
A3092730
Issue Date: 02/06/19

Certificate of Calibration

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01222

Description:	PSYCHROMETER	Calibration Date:	02/06/2019
Manufacturer:	AZ INSTRUMENTS	Calibration Due:	02/06/2020
Model Number:	AZ 8723	Procedure:	TMI-M-HYGROTHERMOGRAPHS Rev: 2/22/2011
Serial Number:	10325187	Temperature:	71 F
Technician:	STEVE TORRES	Humidity:	43 % RH
		As Found Condition:	**IN TOLERANCE**
On-Site Calibration: ☐		**Calibration Results:**	**IN TOLERANCE**

Comments:

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
0710649	THUNDER SCIENTIFIC	2500ST	11/2/2018	6/23/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3092730
Issue Date: 02/06/19

Certificate of Calibration

Data Sheet

Parameter	Nominal	Minimum	Maximum	As Found	As Left	Unit	ADJ/FAIL
Temperature Accuracy	50.0	49.0	51.0	49.7	49.7	°F	
Temperature Accuracy	70.0	69.0	71.0	69.5	69.5	°F	
Temperature Accuracy	90.0	89.0	91.0	89.4	89.4	°F	
Humidity Accuracy	33.0	30.0	36.0	31.7	31.7	%RH	
Humidity Accuracy	50.0	47.0	53.0	49.6	49.6	%RH	
Humidity Accuracy	75.0	72.0	78.0	74.9	74.9	%RH	

EEMS # 01222

m = 1.0273

b = -2.0396

r^2 = 0.99994

2/14/19

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Date

2/14/2019 - - **Calculation of correction factor for RH standard with n**

TMI Cert date =2/6/2019

	TMI STD	EEMS AZ 8723 01223	diff	corrected
Cert #	A3092732			
			0.0	1.3
			0.0	1.3
			0.0	1.3
	33.0	32.0	1.0	32.8
	50.0	49.7	0.3	50.3
	75.0	74.7	0.3	74.9

RH 01223

2019 correction: slope= 1.0154

intercept= -1.3456

corr = 0.9999379

Eric Hebert 2/14/2019

Certificate Number
A3092732
Issue Date: 02/06/19

Certificate of Calibration

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01223

Description:	PSYCHROMETER	Calibration Date:	02/06/2019
Manufacturer:	AZ INSTRUMENTS	Calibration Due:	02/06/2020
Model Number:	AZ 8723	Procedure:	TMI-M-HYGROTHERMOGRAPHS Rev: 2/22/2011
Serial Number:	10325189	Temperature:	71 F
Technician:	STEVE TORRES	Humidity:	43 % RH
		As Found Condition:	**IN TOLERANCE**
On-Site Calibration: ☐		**Calibration Results:**	**IN TOLERANCE**

Comments:

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

This certificate shall not be reproduced, except in full, without the written permission of Technical Maintenance, Inc.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
0710649	THUNDER SCIENTIFIC	2500ST	11/2/2018	6/23/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3092732
Issue Date: 02/06/19

Certificate of Calibration

Data Sheet

Parameter	Nominal	Minimum	Maximum	As Found	As Left	Unit	ADJ/FAIL
Temperature Accuracy	50.0	49.0	51.0	49.5	49.5	°F	
Temperature Accuracy	70.0	69.0	71.0	69.7	69.7	°F	
Temperature Accuracy	90.0	89.0	91.0	89.4	89.4	°F	
Humidity Accuracy	33.0	30.0	36.0	32.0	32.0	%RH	
Humidity Accuracy	50.0	47.0	53.0	49.7	49.7	%RH	
Humidity Accuracy	75.0	72.0	78.0	74.7	74.7	%RH	

EEMS # 01223

$m = 1.0154$

$b = -1.3456$

$r^2 = 0.99994$

2/14/19

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Date

2/14/2019 - - **Calculation of correction factor for RH standard with n**

TMI Cert date =2/6/2019

	TMI STD	EEMS Hygropalm 01220 / 01225	diff	corrected
Cert #	A3092720			
			0.0	-2.7
			0.0	-2.7
			0.0	-2.7
	33.0	34.2	-1.2	33.1
	50.0	50.2	-0.2	49.8
	75.0	74.3	0.7	75.1

RH 01220 / 01225

2019 correction: slope= 0.9555

intercept= 2.5795

corr = 0.9999784

Eric Hebert 2/14/2019

Certificate Number
A3092720
Issue Date: 02/06/19

Certificate of Calibration

Van 2

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01225 / 01220

Description:	THERMO HYGROMETER	Calibration Date:	02/06/2019
Manufacturer:	ROTRONIC	Calibration Due:	02/06/2020
Model Number:	HYGROPALM	Procedure:	TMI-M-HYGROTHERMOGRAPHS Rev: 2/22/2011
Serial Number:	40861 002/124431	Temperature:	71 F
Technician:	STEVE TORRES	Humidity:	43 % RH
On-Site Calibration: ☐		**As Found Condition:**	**IN TOLERANCE**
Comments:		**Calibration Results:**	**IN TOLERANCE**

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
05535	FLUKE	5609-12-D	7/3/2018	7/3/2019
0710649	THUNDER SCIENTIFIC	2500ST	11/2/2018	6/23/2019
A88072	FLUKE/HART	1502A	12/17/2018	4/2/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3092720
Issue Date: 02/06/19

Certificate of Calibration

Data Sheet

Parameter	Nominal	Minimum	Maximum	As Found	As Left	Unit	ADJ/FAIL
Temperature Accuracy	15.0	14.6	15.4	14.9	14.9	C	
Temperature Accuracy	25.0	24.6	25.4	24.7	24.7	C	
Temperature Accuracy	35.0	34.6	35.4	34.7	34.7	C	
Humidity Accuracy	33.0	31.4	34.6	34.2	34.2	%	
Humidity Accuracy	50.0	48.4	51.6	50.2	50.2	%	
Humidity Accuracy	75.0	73.4	76.6	74.3	74.3	%	

EEMS#
01220 / 01225
Van 2

$m = 0.9555$

$b = 2.5795$

$r^2 = 0.99998$

2/14/19

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

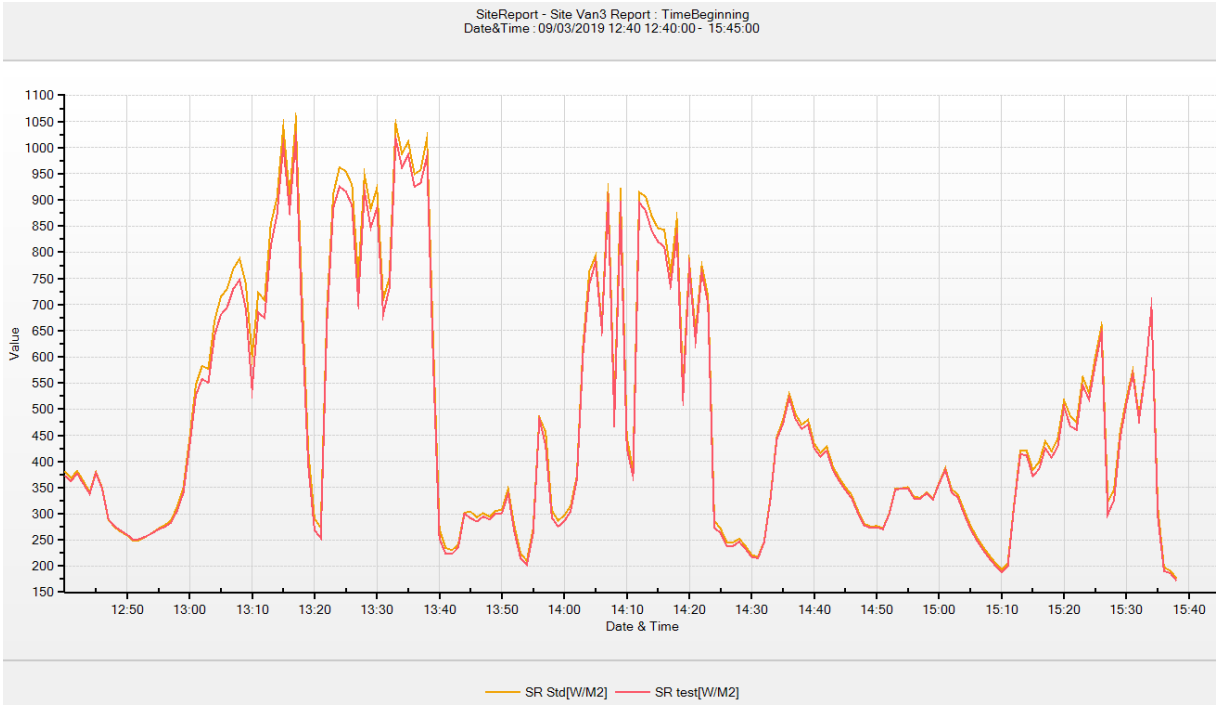
ANSI/NCSL Z540-1-1994

EEMS 01240 --- Licor LI-200 and RMY solar radiation system

- Range = 0 to 1 volt = 0 to 1400 w/m2

Compared with EEMS 01245/01246 Eppley PSP standard.

3/9/2019 At EEMS by Eric Hebert



slope =	0.9646
intercept =	4.3322
correlation =	0.99959

EPLAB

THE EPPLEY LABORATORY, INC.

12 Sheffield Avenue, PO Box 419, Newport, Rhode Island USA 02840
Phone: 401.847.1020 Fax: 401.847.1031 Email: info@eppleylab.com

Calibration Certificate

EEMS # 01245
01246

Instrument: Precision Spectral Pyranometer, Model PSP, Serial Number 34341F3

Procedure: This pyranometer was compared in Eppley's Integrating Hemisphere according to procedures described in ***ISO 9847 Section 5.3.1*** and Technical Procedure, TP01 of The Eppley Laboratory, Inc.'s Quality Assurance Manual on Calibrations.

Transfer Standard: Eppley Precision Spectral Pyranometer, Model PSP, Serial Number 21231F3

Results: **Sensitivity:** **$S = 9.29\ \mu V / Wm^{-2}$**

Uncertainty: $U_{95} = \pm 0.91\%$ (95% confidence level, k=2)

Resistance: 699 Ω at 23°C

Date of Test: January 22, 2019

Traceability: This calibration is traceable to the World Radiation Reference (WRR) through comparisons with Eppley's AHF standard self-calibrating cavity pyrheliometers which participated in the Twelfth International Pyrheliometric Comparisons (IPC XII) at Davos, Switzerland in September-October 2015. Unless otherwise stated in the remarks section below or on the Sales Order, the results of this calibration are "AS FOUND / AS LEFT".

Due Date: Eppley recommends a minimum calibration cycle of five (5) years but encourages annual calibrations for highest measurement accuracy.

Customer: EEMS
Gainesville, FL

Signatures: Debra L. Gentry — In Charge of Test: Thomas J. Kirk — Reviewed by:

Eppley SO: 65367

Date of Certificate January 23, 2019

Remarks: Amplifier #10765 set with gain of 76.89 so pair produces 1 V = 1400 Wm^{-2}.

End of Report

PACKING LIST

The Eppley Laboratory, Inc.
12 Sheffield Ave.

Phone # 401-847-1020 Fed. ID No. 05-0136490

S.O. No. 65367

1/23/2019

Page 2 of 2

EEMS #
01245
01246

Name / Address

EEMS
Att: Eric Hebert
1128 NW 39th Drive
Gainesville, FL 32605

Ship To

EEMS
Att: Eric Hebert
1128 NW 39th Drive
Gainesville, FL 32605

P.O... Ship Date 1/30/2019 Ship Via FedEx COLLECT

Recalibration Model 8-48 # 23824

Recalibration of Model PSP # 34341F3 w/ SHIELD + CABLE

Reset Amplifier # 10765

SET GAIN SO $1\ V = 1400\ W m^{-2}$

$1400 \times S = V_{full}$

$S = \boxed{9.29}$

$V_{full}(mV) = S \times 1400 = 13006$

$V_{full}(V) = 0.013006$

$GAIN = \frac{1V}{V_{full}(V)} = \frac{1}{0.013006} = \boxed{76.89}$

Made in USA

Terms Credit Card

FOB Newport, RI USA

EPLAB

THE EPPLEY LABORATORY, INC.

12 Sheffield Avenue, PO Box 419, Newport, Rhode Island USA 02840
Phone: 401.847.1020 Fax: 401.847.1031 Email: info@eppleylab.com

EEMS # 01247

Calibration Certificate

Instrument: Black & White Pyranometer, Model 8-48, Serial Number 23824

Procedure: This pyranometer was compared in Eppley's Integrating Hemisphere according to procedures described in ***ISO 9847 Section 5.3.1*** and Technical Procedure, TP01 of The Eppley Laboratory, Inc.'s Quality Assurance Manual on Calibrations.

Transfer Standard: Eppley Black & White Pyranometer, Model 8-48, Serial Number 14061

Results: **Sensitivity: S =8.80 µV / Wm^{-2}**
Uncertainty: U_{95} = ±0.91% (95% confidence level, k=2)
Resistance: 347 Ω at 23°C

Date of Test: January 22, 2019

Traceability: This calibration is traceable to the World Radiation Reference (WRR) through comparisons with Eppley's AHF standard self-calibrating cavity pyrheliometers which participated in the Twelfth International Pyrheliometric Comparisons (IPC XII) at Davos, Switzerland in September-October 2015. Unless otherwise stated in the remarks section below or on the Sales Order, the results of this calibration are "AS FOUND / AS LEFT".

Due Date: Eppley recommends a minimum calibration cycle of five (5) years but encourages annual calibrations for highest measurement accuracy.

Customer: EEMS
Gainesville, FL

Signatures: Debra L. Gentry In Charge of Test: Thomas D. Kuh Reviewed by:

Eppley SO: 65367

Date of Certificate January 23, 2019

Remarks:

End of Report

EEMS# 01265

Warren-Knight Instrument Company
2045 Bennett Road
Philadelphia, PA 19116
Phone: 215-464-9300; Fax: 215-464-9303
Web: http://www.warrenind.com

Van 2

Calibration Data Record			Temperature: 71° Humidity: 27%
Customer Name	GC-MS	Item Name	USHIKATA
Manufacturer		Model	S-25
Serial Number	190037	Calibration Date	1-23-19
Calibration Frequency		Job Card Number	S-26076
Customer Reference Number		Date of Certification	1-23-19

Measurement Standards

Theodolite Wild T-3 S/N 18801 Calibration 01/16/19 Due 01/16/20 NIST Number 738/229329-83 738/223398

Optical Wedge K&E 71-7020 S/N 5167 Calibration; 01/16/19 Due 01/16/24, NIST Number 731/244084-89 731/221617

Initial Report

Vanes		Direction (Degree)	Tolerance (Minute)	Compass Needle Error (Minute)
Pivot in line with Circle/Sights	☐ Pass ☐ Fail	0	+/- 30	
Needle		45	+/- 30	
Pivot Sharpness	☐ Pass ☐ Fail	90	+/- 30	
Straightness (+/-15 Minutes)	☐ Pass ☐ Fail	135	+/- 30	
Balance	☐ Pass ☐ Fail	180	+/- 30	
Lifter Function	☐ Pass ☐ Fail	225	+/- 30	
Azimuth Ring		270	+/- 30	
Control Knob Function	☐ Pass ☐ Fail	315	+/- 30	
Pinion Gear	☐ Pass ☐ Fail			
Graduation Clarity	☐ Pass ☐ Fail			
Graduation less than 1 minute in any position	☐ Pass ☐ Fail			
Level Bubble				
Bubble in Level	☐ Pass ☐ Fail			
Physical Condition	☐ Pass ☐ Fail			

Pass/Repair/Replace

Pass	N/A	Replace	Repair	
☐	☐	☐	☐	Needle ☐ Sharpen ☐ Magnetize
☐	☐	☐	☐	Cap with Jewel
☐	☐	☐	☐	Pivot ☐ Sharpen
☐	☐	☐	☐	Level ☐ Remount
☐	☐	☐	☐	North Sight
☐	☐	☐	☐	North Sight Block
☐	☐	☐	☐	South Sight
☐	☐	☐	☐	South Sight Block
☐	☐	☐	☐	Vane Spring
☐	☐	☐	☐	Drive
☐	☐	☐	☐	Control Knob Assembly
☐	☐	☐	☐	Cover Glass
☐	☐	☐	☐	Cover Glass Gasket
☐	☐	☐	☐	Clamp Screw
☐	☐	☐	☐	Pinion Gear
☐	☐	☐	☐	Compass Ring

Final Report

Vanes		Direction (Degree)	Tolerance (Minute)	Compass Needle Error (Minute)
Pivot in line with Circle/Sights	☑ Pass ☐ Fail	0	+/- 30	< 30
Needle		45	+/- 30	< 30
Pivot Sharpness	☑ Pass ☐ Fail	90	+/- 30	< 30
Straightness (+/-15 Minutes)	☑ Pass ☐ Fail	135	+/- 30	< 30
Balance	☑ Pass ☐ Fail	180	+/- 30	< 30
Lifter Function	☑ Pass ☐ Fail	225	+/- 30	< 30
Azimuth Ring		270	+/- 30	< 30
Control Knob Function	☑ Pass ☐ Fail	315	+/- 30	< 30
Pinion Gear	☑ Pass ☐ Fail			
Graduation Clarity	☑ Pass ☐ Fail			
Graduation less than 1 minute in any position	☑ Pass ☐ Fail			
Level Bubble				
Bubble in Level	☑ Pass ☐ Fail			
Physical Condition	☑ Pass ☐ Fail			

Certification

Joseph Paologgi	John Noga, Quality Assurance
Repair Technician	John Noga

EEMS # 01272

Warren-Knight Instrument Company
2045 Bennett Road
Philadelphia, PA 19116
Phone: 215-464-9300; Fax: 215-464-9303
Web: http://www.warrenind.com

Calibration Data Record			Temperature: 71° Humidity: 37%
Customer Name	EE-MS	Item Name	USHIKATA
Manufacturer		Model	S-25
Serial Number	199578	Calibration Date	1-23-19
Calibration Frequency		Job Card Number	S-76075
Customer Reference Number		Date of Certification	1-23-19

Measurement Standards

Theodolite Wild T-3 S/N 18801 Calibration 01/16/19 Due 01/16/20 NIST Number 738/229329-83 738/223398

Optical Wedge K&E 71-7020 S/N 5167 Calibration; 01/16/19 Due 01/16/24, NIST Number 731/244084-89 731/221617

Initial Report

Vanes		Direction (Degree)	Tolerance (Minute)	Compass Needle Error (Minute)
Pivot in line with Circle/Sights	☐ Pass ☐ Fail	0	+/- 30	
Needle		45	+/- 30	
Pivot Sharpness	☐ Pass ☐ Fail	90	+/- 30	
Straightness (+/-15 Minutes)	☐ Pass ☐ Fail	135	+/- 30	
Balance	☐ Pass ☐ Fail	180	+/- 30	
Lifter Function	☐ Pass ☐ Fail	225	+/- 30	
Azimuth Ring		270	+/- 30	
Control Knob Function	☐ Pass ☐ Fail	315	+/- 30	
Pinion Gear	☐ Pass ☐ Fail			
Graduation Clarity	☐ Pass ☐ Fail			
Graduation less than 1 minute in any position	☐ Pass ☐ Fail			
Level Bubble				
Bubble in Level	☐ Pass ☐ Fail			
Physical Condition	☐ Pass ☐ Fail			

Pass/Repair/Replace

Pass	N/A	Replace	Repair	
☐	☐	☐	☐	Needle ☐ Sharpen ☐ Magnetize
☐	☐	☐	☐	Cap with Jewel
☐	☐	☐	☐	Pivot ☐ Sharpen
☐	☐	☐	☐	Level ☐ Remount
☐	☐	☐	☐	North Sight
☐	☐	☐	☐	North Sight Block
☐	☐	☐	☐	South Sight
☐	☐	☐	☐	South Sight Block
☐	☐	☐	☐	Vane Spring
☐	☐	☐	☐	Drive
☐	☐	☐	☐	Control Knob Assembly
☐	☐	☐	☐	Cover Glass
☐	☐	☐	☐	Cover Glass Gasket
☐	☐	☐	☐	Clamp Screw
☐	☐	☐	☐	Pinion Gear
☐	☐	☐	☐	Compass Ring

Final Report

Vanes		Direction (Degree)	Tolerance (Minute)	Compass Needle Error (Minute)
Pivot in line with Circle/Sights	☑ Pass ☐ Fail	0	+/- 30	< 30
Needle		45	+/- 30	< 30
Pivot Sharpness	☑ Pass ☐ Fail	90	+/- 30	< 30
Straightness (+/-15 Minutes)	☑ Pass ☐ Fail	135	+/- 30	< 30
Balance	☑ Pass ☐ Fail	180	+/- 30	< 30
Lifter Function	☑ Pass ☐ Fail	225	+/- 30	< 30
Azimuth Ring		270	+/- 30	< 30
Control Knob Function	☑ Pass ☐ Fail	315	+/- 30	< 30
Pinion Gear	☑ Pass ☐ Fail			
Graduation Clarity	☑ Pass ☐ Fail			
Graduation less than 1 minute in any position	☑ Pass ☐ Fail			
Level Bubble				
Bubble in Level	☑ Pass ☐ Fail			
Physical Condition	☑ Pass ☐ Fail			

Certification

Joseph Paloyan	John Noga, Quality Assurance John Noga
Repair Technician	

Certificate Number
A3081102
Issue Date: 01/25/19

Certificate of Calibration

Van #1

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:
EEMS #
ID Number: 01310

Description:	DIGITAL MULTIMETER	Calibration Date:	01/25/2019
Manufacturer:	FLUKE	Calibration Due:	01/25/2020
Model Number:	187	Procedure:	METCAL FLUKE 187 Rev: 6/15/2015
Serial Number:	86590148	Temperature:	70 F
Technician:	TAYLOR FLOYD	Humidity:	42 % RH
		As Found Condition:	**IN TOLERANCE**
On-Site Calibration: ☐		**Calibration Results:**	**IN TOLERANCE**

Comments:

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
7040208	FLUKE	5520A	3/12/2018	3/12/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3081104
Issue Date: 01/25/19

Certificate of Calibration

Van 3

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01311

Description:	DIGITAL MULTIMETER	Calibration Date:	01/25/2019
Manufacturer:	FLUKE	Calibration Due:	01/25/2020
Model Number:	287	Procedure:	METCAL FLUKE 287 Rev: 6/15/2015
Serial Number:	95740135	Temperature:	70 F
Technician:	TAYLOR FLOYD	Humidity:	42 % RH
On-Site Calibration: ☐		**As Found Condition:**	**IN TOLERANCE**
Comments:		**Calibration Results:**	**IN TOLERANCE**

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

This certificate shall not be reproduced, except in full, without the written permission of Technical Maintenance, Inc.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
7040208	FLUKE	5520A	3/12/2018	3/12/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

Certificate Number
A3081107
Issue Date: 01/25/19

Certificate of Calibration

Van 2

Customer: ENVIRONMENTAL ENGINEERING & MEASUREMENT SERVICES
1128 NW 39TH DRIVE
GAINESVILLE, FL 32605
FEDEX

P.O. Number:

ID Number: EEMS 01312

Description:	DIGITAL MULTIMETER
Manufacturer:	FLUKE
Model Number:	287
Serial Number:	95740243
Technician:	TAYLOR FLOYD
On-Site Calibration:	☐
Comments:	

Calibration Date:	01/25/2019
Calibration Due:	01/25/2020
Procedure:	METCAL FLUKE 287 Rev: 6/15/2015
Temperature:	70 F
Humidity:	42 % RH
As Found Condition:	**IN TOLERANCE**
Calibration Results:	**IN TOLERANCE**

Limiting Attribute:

This instrument has been calibrated using standards traceable to the SI units through the National Institute of Standards and Technology (NIST) or other National Metrological Institute (NMI). The method of calibration is direct comparison to a known standard, derived from natural physical constants, ratio measurements or compared to consensus standards.

Reported uncertainties are expressed as expanded uncertainty values at an approximately 95% confidence level using a coverage factor of k=2. Statements of compliance are based on test results falling within specified limits with no reduction by the uncertainty of the measurement.

TMI's Quality System is accredited to ISO/IEC 17025:2017 and ANSI/NCSL Z540-1-1994. ISO/IEC 17025:2017 is written in a language relevant to laboratory operations, meeting the principles of ISO 9001 and aligned with its pertinent requirements. This calibration complies with all the requirements of ANSI/NCSL Z540-1-1994 and TMI's Quality Manual, QM-1.

Results contained in this document relate only to the item calibrated. Calibration due dates appearing on the certificate or label are determined by the client for administrative purposes and do not imply continued conformance to specifications.

Measurements not currently on TMI's Scope of Accreditation are identified with an asterisk.

FRANK BAHMANN, BRANCH MANAGER

Scott Chamberlain, QUALITY MANAGER

Calibration Standards

Asset Number	Manufacturer	Model Number	Date Calibrated	Cal Due
7040208	FLUKE	5520A	3/12/2018	3/12/2019

TMI Technical Maintenance, Inc.
12530 TELECOM DRIVE, TEMPLE TERRACE, FL 33637
Phone: 813-978-3054 Fax 813-978-3758
www.tmicalibration.com

ANSI/NCSL Z540-1-1994

MesaLabs

EEMS# 01414

NVLAP®
NVLAP Lab Code 200661-0
Calibration

As Shipped Calibration Data

2/8/2019

Certificate No 281466
Technician Lilianna Malinowska

Lab. Pressure 748 mmHg
Lab. Temperature 21.3 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Shipped
25344 sccm	25183 sccm	0.64%	1.00%	In Tolerance
5017.9 sccm	5000.8 sccm	0.34%	1.00%	In Tolerance
1508.4 sccm	1501.65 sccm	0.45%	1.00%	In Tolerance
21.3 °C	21.3 °C	-	± 0.8°C	In Tolerance
748 mmHg	748 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	101897	01-May-2018	01-May-2019
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	2981392	18-Jul-2018	18-Jul-2019

Calibration Notes

The expanded uncertainty of flow, temperature, and pressure measurements all have a coverage factor of k = 2 for a confidence interval of approximately 95%.

Flow testing is in accordance with our test number PR18-13 with an expanded uncertainty of 0.18% using high-purity nitrogen or filtered laboratory air. Flow readings in sccm are performed at STP of 21.1°C and 760 mmHg.

Pressure testing is in accordance with our test number PR18-11 with an expanded uncertainty of 0.16 mmHg.

Temperature testing is in accordance with our test number PR18-12 with an expanded uncertainty of 0.04 °C.

Traceability to the International System of Units (SI) is verified by accreditation to ISO/IEC 17025 by NVLAP under NVLAP Code 200661-0.

Technician Notes:

By:

$m = 0.99331937$

$b = 0.009345$ (Lpm)

$r^2 = 0.99999$

2/15/19

Mohammed Aziz
Director of Engineering
Mesa Laboratories, Inc., Butler, NJ

MesaLabs

NVLAP®
NVLAP Lab Code 200661-0
Calibration

Calibration Certificate

CertificateNo. 281466
Product 200-530+ High Defender 530+ High Flow
Serial No. 159956
Cal. Date 08-Feb-2019

EEMS# 01414

Sold To:
Environmental Engineering & Measurement Services
8010 SW 17th Place
Gainesville, FL 32607
US

All calibrations are performed at Mesa Laboratories, Inc., 10 Park Place, Butler, NJ, 07405, an ISO 17025:2005 accredited laboratory through NVLAP of NIST. This report shall not be reproduced except in full without the written approval of the laboratory. Results only relate to the items calibrated. This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

As Received Calibration Data

Technician Lilianna Malinowska

Lab. Pressure 757 mmHg
Lab. Temperature 21.3 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Received
25880 sccm	25126 sccm	3.0%	1.00%	Out of Tolerance
5145.1 sccm	5000.7 sccm	2.89%	1.00%	Out of Tolerance
1542.4 sccm	1500.35 sccm	2.8%	1.00%	Out of Tolerance
22.4 °C	22.6 °C	-	± 0.8°C	In Tolerance
756 mmHg	757 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	103521	11-Jun-2018	11-Jun-2019
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	2981392	20-Jul-2018	20-Jul-2019

EEMS # 01416

MesaLabs

NVLAP®

NVLAP Lab Code 200661-0
Calibration

Calibration Certificate

CertificateNo. 322657

Product 200-220H Definer 220 High Flow

Serial No. 122974

Cal. Date 19-Jul-2019

Sold To: Environmental Engineering & Measurement Services
8010 SW 17th Place
Gainesville, FL 32607
US

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As Received Calibration Data

Technician Lilianna Malinowska

Lab. Pressure 754 mmHg
Lab. Temperature 22.4 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Received
25240.6 sccm	25289.71 sccm	-0.19%	1.00%	In Tolerance
5142.08 sccm	5128.72 sccm	0.26%	1.00%	In Tolerance
1599.51 sccm	1588.16 sccm	0.71%	1.00%	In tolerance
22.3 °C	22.3 °C	-	± 0.8°C	In Tolerance
754 mmHg	754 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	101897	03-May-2019	02-May-2020
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	41000LOB	27-Nov-2018	27-Nov-2019

EEMS #01416

MesaLabs

NVLAP®
NVLAP Lab Code 200661-0
Calibration

As Shipped Calibration Data

Certificate No	322657	**Lab. Pressure**	750 mmHg
Technician	Lilianna Malinowska	**Lab. Temperature**	22.4 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Shipped
25205.3 sccm	25276.27 sccm	-0.28%	1.00%	In Tolerance
5118.46 sccm	5120.13 sccm	-0.03%	1.00%	In Tolerance
1576.23 sccm	1580.85 sccm	-0.29%	1.00%	In Tolerance
22.8 °C	22.8 °C	-	± 0.8°C	In Tolerance
753 mmHg	753 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	101897	03-May-2019	02-May-2020
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	41000LOB	27-Nov-2018	27-Nov-2019

Calibration Notes

The expanded uncertainty of flow, temperature, and pressure measurements all have a coverage factor of k = 2 for a confidence interval of approximately 95%.

Flow testing is in accordance with our test number PR18-13 with an expanded uncertainty of 0.18% using high-purity nitrogen or filtered laboratory air. Flow readings in sccm are performed at STP of 21.1°C and 760 mmHg.

Pressure testing is in accordance with our test number PR18-11 with an expanded uncertainty of 0.16 mmHg.

Temperature testing is in accordance with our test number PR18-12 with an expanded uncertainty of 0.04 °C.

Traceability to the International System of Units (SI) is verified by accreditation to ISO/IEC 17025 by NVLAP under NVLAP Code 200661-0.

Technician Notes:

M = 0.99698188
B = 0.006417 lpm
R2 = 0.99999
Use uncorrected readings for
CASTNET range

By:

Eric Hebert

Mohammed Aziz
Director of Engineering
Mesa Laboratories, Inc., Butler, NJ

MesaLabs

EEMS # 01417

NVLAP®
NVLAP Lab Code 200661-0
Calibration

As Shipped Calibration Data

2/8/2019

Certificate No 281467
Technician Lilianna Malinowska

Lab. Pressure 748 mmHg
Lab. Temperature 21.6 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Shipped
25266 sccm	25112.5 sccm	0.61%	1.00%	In Tolerance
5043.7 sccm	5001.35 sccm	0.85%	1.00%	In Tolerance
1513.7 sccm	1501.4 sccm	0.82%	1.00%	In Tolerance
21.6 °C	21.6 °C	-	± 0.8°C	In Tolerance
748 mmHg	748 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	101897	01-May-2018	01-May-2019
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	2981392	18-Jul-2018	18-Jul-2019

Calibration Notes

The expanded uncertainty of flow, temperature, and pressure measurements all have a coverage factor of k = 2 for a confidence interval of approximately 95%.

Flow testing is in accordance with our test number PR18-13 with an expanded uncertainty of 0.18% using high-purity nitrogen or filtered laboratory air. Flow readings in sccm are performed at STP of 21.1°C and 760 mmHg.

Pressure testing is in accordance with our test number PR18-11 with an expanded uncertainty of 0.16 mmHg.

Temperature testing is in accordance with our test number PR18-12 with an expanded uncertainty of 0.04 °C.

Traceability to the International System of Units (SI) is verified by accreditation to ISO/IEC 17025 by NVLAP under NVLAP Code 200661-0.

Technician Notes:

$m = 0.99420885$

$b = -7.95194422$

$r^2 = 0.99999$

By:

Mohammed Aziz
Director of Engineering
Mesa Laboratories, Inc., Butler, NJ

EDW 2/15/19

MesaLabs

EEMS # 01417

NVLAP®
NVLAP Lab Code 200661-0
Calibration

Calibration Certificate

CertificateNo. 281467
Product 200-220H Definer 220 High Flow
Serial No. 131818
Cal. Date 08-Feb-2019

Sold To:
Environmental Engineering & Measurement Services
8010 SW 17th Place
Gainesville, FL 32607
US

All calibrations are performed at Mesa Laboratories, Inc., 10 Park Place, Butler, NJ, 07405, an ISO 17025:2005 accredited laboratory through NVLAP of NIST. This report shall not be reproduced except in full without the written approval of the laboratory. Results only relate to the items calibrated. This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

As Received Calibration Data

Technician Lilianna Malinowska

Lab. Pressure 757 mmHg
Lab. Temperature 21.6 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Received
0 sccm	25111.5 sccm	-100.0%	1.00%	Out of Tolerance
0 sccm	5001.3 sccm	-100.0%	1.00%	Out of Tolerance
0 sccm	1501 sccm	-100.0%	1.00%	Out of Tolerance
22.2 °C	22.3 °C	-	± 0.8°C	In Tolerance
759 mmHg	757 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	103521	11-Jun-2018	11-Jun-2019
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	2981392	18-Jul-2018	18-Jul-2019

MesaLabs

EEMS # 01421

3/4/2019

NVLAP®

NVLAP Lab Code 200661-0
Calibration

As Shipped Calibration Data

Certificate No 287690
Technician Lilianna Malinowska

Lab. Pressure 746 mmHg
Lab. Temperature 20.6 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Shipped
25125 sccm	25097.5 sccm	0.11%	1.00%	In Tolerance
5004.1 sccm	5001 sccm	0.06%	1.00%	In Tolerance
1502.7 sccm	1500.3 sccm	0.16%	1.00%	In Tolerance
20.6 °C	20.6 °C	-	± 0.8°C	In Tolerance
746 mmHg	746 mmHg	-	± 3.5 mmHg	In Tolerance

Mesa Laboratories Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML-800-44	101897	01-May-2018	01-May-2019
Percision Thermometer	305460	02-Oct-2018	02-Oct-2019
Precision Barometer	2981392	18-Jul-2018	18-Jul-2019

Calibration Notes

The expanded uncertainty of flow, temperature, and pressure measurements all have a coverage factor of k = 2 for a confidence interval of approximately 95%.

Flow testing is in accordance with our test number PR18-13 with an expanded uncertainty of 0.18% using high-purity nitrogen or filtered laboratory air. Flow readings in sccm are performed at STP of 21.1°C and 760 mmHg.

Pressure testing is in accordance with our test number PR18-11 with an expanded uncertainty of 0.16 mmHg.

Temperature testing is in accordance with our test number PR18-12 with an expanded uncertainty of 0.04 °C.

Traceability to the International System of Units (SI) is verified by accreditation to ISO/IEC 17025 by NVLAP under NVLAP Code 200661-0.

Technician Notes:

By:

$m = 1.003937$

$b = -11.8388$

$r^2 = 0.99999$

Mohammed Aziz
Director of Engineering
Mesa Laboratories, Inc., Butler, NJ

Use uncorrected readings for CASTNE

3/15/19

R.M. Young Company
2801 Aero Park Drive
Traverse City, Michigan 49686 USA

YAN 2

CERTIFICATE OF CALIBRATION AND TESTING

Model: 18802/18811
Serial Number: CA04353

Description: Anemometer Drive - 2 motors, 20 to 15,000 RPM
(18802 comprised of 18820A Control Unit and 18830A Motor Assembly)
(18811 comprised of 18820A Control Unit and 18831A Motor Assembly)

R. M. Young Company certifies that the above equipment was inspected and calibrated prior to shipment in accordance with established manufacturing and testing procedures. Standards established by R.M. Young Company for calibrating the measuring and test equipment used in controlling product quality are traceable to the National Institute of Standards and Technology.

Nominal Motor RPM RPM	27106D Output Frequency Hz (1)	Calculated RPM (2)	Indicated RPM (3)
18802	☑ Clockwise and Counterclockwise rotation verified.		
300	50	300	300
2700	450	2700	2700
5100	850	5100	5100
7500	1250	7500	7500
10200	1700	10200	10200
12600	2100	12600	12600
15000	2500	15000	15000
18811	☑ Clockwise and Counterclockwise rotation verified.		
30.0	5	30.0	30.0
150.0	25	150.0	150.0
300.0	50	300.0	300.0
450.0	75	450.0	450.0
600.0	100	600.0	600.0
750.0	125	750.0	750.0
990.0	165	990.0	990.0

(1) Measured output frequency of YOUNG model 27106D standard anemometer attached to motor shaft.
(2) YOUNG model 27106D produces 10 pulsed per revolution of the anemometer shaft.
(3) Indicated on the Control Unit LCD.

* Indicates out of tolerance.

☐ New Unit ☑ Service / Repair Unit ☑ No calibration adjustments required ☐ As found ☐ As left

Traceable frequency meter used for calibration:
Model: 34405A Serial Number: TW46290020

Date: 16 April 2019
Calibration Interval: One year

Tested By : EC

Ozone Transfer Standard Verification Summary Report

U. S. Environmental Protection Agency
Region 4 Science and Ecosystem Support Division
Enforcement and Investigations Branch
Superfund and Air Section
980 College Station Rd.
Athens, GA 30605

EEMS # 01115

	EPA Standard	GUEST Instrument
Agency:	EPA Region 4	EEMS
Contact:	Keith Harris	Eric Hebert
Make:	NIST	TEI
Model:	SRP	49 iQps
S/N:	10	1180930075

SESD Project #: 19-0229
Test #: # 1 "as left"

Guest Test Status: PASS
Guest Known Offset: 0

Level 2	Slope	Intercept	R^2	High O_3	Lower O_3
Averages:	1.0080	-0.4021	0.9999972	465	0
Upper Tolerance:	1.0300	3.0000			
LowerTolerance:	0.9700	-3.0000			

Cycle Start Date / Time	File Name	Slope	Intercept	R^2	Upper Range (ppb O_3)	Lower Range (ppb O_3)
3/25/19 4:13 PM	Cal19032501.xls	1.0014	-0.5404	0.9999967	463	-0.14
3/25/19 5:54 PM	Cal19032502.xls	1.0020	-0.5316	0.9999971	465	-0.06
3/25/19 7:31 PM	Cal19032503.xls	1.0132	-0.4537	0.9999977	467	-0.17
3/25/19 9:09 PM	Cal19032504.xls	1.0121	-0.3056	0.9999979	466	-0.20
3/25/19 10:45 PM	Cal19032505.xls	1.0140	0.0000	0.9999975	464	0.12
3/26/19 12:22 AM	Cal19032600.xls	1.0057	-0.4967	0.9999960	465	0.05
3/26/19 1:59 AM	Cal19032601.xls	1.0073	-0.4869	0.9999976	465	0.14

Comments: New Level 2 standard. Prior to test one instrument was adjusted to more closely match the SRP.

Ozone calibration factors at time of test: O3 BKG: 0.31 ppb O3 COEF: 1.013

Verification Expires on: **March 26, 2020**

Keith Harris Date 03/26/19

Ozone Transfer Standard Verification Summary Report

U. S. Environmental Protection Agency
Region 4 Science and Ecosystem Support Division
Enforcement and Investigations Branch
Superfund and Air Section
980 College Station Rd.
Athens, GA 30605

EEMS #01114 (van 3)

	EPA Standard	GUEST Instrument
Agency:	EPA Region 4	EEMS
Contact:	Mike Crowe	Eric Hebert
Make:	NIST	Thermo
Model:	SRP	49i
S/N:	10	1180030022
Guest Test Status:		**PASS**
Guest Known Offset:		0

SESD Project #:

Test #: #1 "as found" and "as left"

Level 2 Averages:	Slope	Intercept	R^2	High O_3	Lower O_3
	0.9984	0.2709	0.9999986	363	0
Upper Tolerance:	1.0300	3.0000			
LowerTolerance:	0.9700	-3.0000			

Cycle Start Date / Time	File Name	Slope	Intercept	R^2	Upper Range (ppb O_3)	Lower Range (ppb O_3)
6/11/19 5:01 PM	Cal19061101.xls	0.9984	0.2057	0.9999981	360	0.24
6/11/19 6:37 PM	Cal19061102.xls	0.9975	0.3485	0.9999992	363	-0.02
6/11/19 8:13 PM	Cal19061103.xls	0.9992	0.1985	0.9999984	363	0.12
6/11/19 9:50 PM	Cal19061104.xls	0.9980	0.3826	0.9999987	364	-0.14
6/11/19 11:26 PM	Cal19061105.xls	0.9991	0.0000	0.9999981	364	-0.13
6/12/19 1:02 AM	Cal19061200.xls	0.9983	0.3572	0.9999990	365	0.12
6/12/19 2:39 AM	Cal19061201.xls	0.9986	0.4040	0.9999988	365	-0.05

Comments:

Instrument tested as found.
Ozone calibration factors at time of test: O3 BKG: -0.4 ppb O3 COEF: 0.990

Instrument within tolerance

Verification Expires on: **June 12, 2020**
September 12, 2019 (For NPAP use)

Mike Crowe Date 6/12/19

Ozone Certification Records

TEI # 49CPS-70008-364 **49 CPS** **EEMS# 01110** **Van 2**

settings at time of test: **bkg= 0.0** **coef= 1.018**

EPA file	date	start time	slope	intercept	correlatioin	location
cal19102801	28-Oct-19	17:34	1.00336	-0.10250	1	R-7
cal19102802	28-Oct-19	18:47	1.00323	-0.06933	1	R-7
cal19102803	28-Oct-19	20:03	1.00334	-0.03624	1	R-7
					1	R-7
					1	R-7
					1	R-7
					1	R-7
					1	R-7
		AVG =	**1.003310**	**-0.069357**	**1**	

TEI # 1180030022 **49i** **EEMS# 01114** **Van 3**

settings at time of test: **bkg= -0.4** **coef= 0.990**

EPA file	date	start time	slope	intercept	correlatioin	location
cal19102902	29-Oct-19	11:19	0.98637	0.39175	1	R-7
cal19102803	29-Oct-19	12:32	0.98590	0.47568	1	R-7
cal19102904	29-Oct-19	13:44	0.98574	0.38138	1	R-7
					1	R-7
					1	R-7
					1	R-7
					1	R-7
					1	R-7
		AVG =	**0.986003**	**0.416270**	**1**	

FINAL SUMMARY AUDIT REPORT CO BASED
EEMS Van-3

Site Name: EPA R-7 - LOW

Audit Date: 10/28/2019

Parameter	NPAP Lab Response (ppm)	Station Response (ppm)	Percent Difference	Actual Difference (ppm)	Pass/Fail	Warning
Ozone						
Pre Zero						
Ozone audit level 6					N/A	
Ozone audit level 5					N/A	
Ozone audit level 4					N/A	
Ozone audit level 3					N/A	
Ozone audit level 2					N/A	
Post Zero						
Carbon Monoxide						
Pre Zero	-0.0069	0.003		0.00976	Pass	
CO Audit level 4	2.6066	2.576	-1.2	-0.03039	Pass	
CO Audit level 4	1.5093	1.495	-1.0	-0.01476	Pass	
CO Audit level 3	0.5511	0.554	0.5	0.00303	Pass	
CO Audit level 2	0.1390	0.143	2.9	0.00402	Pass	
CO Audit level 1	0.0465	0.055	18.2	0.00847	Pass	
Post Zero	-0.0036	0.002		0.00516	Pass	
Oxides of Nitrogen						
Pre Zero	-0.00020	0.00000		0.00020	Pass	
NO Audit Point #1	0.07600	0.07460	-1.8	-0.00140	Pass	
NO Audit Point #2	0.04400	0.04360	-0.9	-0.00040	Pass	
NO Audit Point #3	0.01607	0.01580	-1.7	-0.00027	Pass	
NO Audit Point #4	0.00405	0.00410	1.2	0.00005	Pass	
NO Audit Point #5	0.00136	0.00140	2.9	0.00004	Pass	
Post Zero	-0.00010	0.00000		0.00010	Pass	
Pre Zero	-0.00020	0.00000		0.00020	Pass	
NOx Audit Point #1	0.07732	0.07450	-3.6	-0.00282	Pass	
NOx Audit Point #2	0.04477	0.04340	-3.1	-0.00137	Pass	
NOx Audit Point #3	0.01635	0.01570	-4.0	-0.00065	Pass	
NOx Audit Point #4	0.00412	0.00400	-2.9	-0.00012	Pass	
NOx Audit Point #5	0.00138	0.00130	-5.8	-0.00008	Pass	
Post Zero	-0.00011	0.00000		0.00011	Pass	
Pre Zero	0.00000	-0.00010		-0.00010		
NO2 Audit level 5	0.04930	0.04760	-3.4	-0.00170	Pass	
NO2 Audit level 4	0.01818	0.01690	-7.0	-0.00128	Pass	
NO2 Audit level 2	0.00435	0.00390	-10.3	-0.00045	Pass	
NO2 Audit level 1	0.00159	0.00140	-11.9	-0.00019	Pass	
Post Zero	0.00000	0.00000		0.00000	Pass	
Converter Efficiency NO2 level 5	101.7%				Pass	
Converter Efficiency NO2 level 4	100.6%				Pass	
Converter Efficiency NO2 level 2	102.5%				Pass	
Converter Efficiency NO2 level 1	100.0%				Pass	
Sulfur Dioxide						
Pre Zero	-0.00022	0.0000		0.0003	Pass	
SO2 Audit level 6	0.08235	0.0790	-4.1	-0.0033	Pass	
SO2 Audit level 5	0.04768	0.0455	-4.5	-0.0022	Pass	
SO2 Audit level 4	0.01741	0.0167	-4.3	-0.0007	Pass	
SO2 Audit level 2	0.00439	0.0040	-10.0	-0.0004	Pass	
SO2 Audit level 1	0.00147	0.0014	-5.4	-0.0001	Pass	
Post Zero	-0.00011	0.0001		0.0002	Pass	

FINAL SUMMARY AUDIT REPORT CO BASED
EEMS Van-2

Site Name: EPA-R7 - LOW

Audit Date: 10/29/2019

Parameter	NPAP Lab Response (ppm)	Station Response (ppm)	Percent Difference	Actual Difference (ppm)	Pass/Fail	Warning
Ozone						
Pre Zero						
Audit Level 6					N/A	
Audit Level 4					N/A	
Audit Level 3					N/A	
Audit Level 2					N/A	
Post Zero						
Carbon Monoxide						
Pre Zero	0.0011	-0.010		-0.01065	Pass	
CO Audit level 4	2.2014	2.257	2.5	0.05562	Pass	
CO Audit level 4	1.5373	1.550	0.8	0.01272	Pass	
CO Audit level 3	0.6120	0.617	0.8	0.00501	Pass	
CO Audit level 3	0.3315	0.334	0.8	0.00255	Pass	
CO Audit level 1	0.0544	0.064	17.6	0.00960	Pass	
Post Zero	-0.0115	-0.006		0.00532	Pass	
Oxides of Nitrogen						
Pre Zero	0.00003	0.0000		0.0000	Pass	
NO Audit Point #1	0.06568	0.0666	1.4	0.0009	Pass	
NO Audit Point #2	0.04586	0.0457	-0.3	-0.0002	Pass	
NO Audit Point #3	0.01826	0.0182	-0.3	0.0000	Pass	
NO Audit Point #4	0.00989	0.0090	-9.0	-0.0009	Pass	
NO Audit Point #5	0.00162	0.0021	29.6	0.0005	Pass	
Post Zero	-0.00034	0.0001		0.0004	Pass	
Pre Zero	0.00003	0.0000		0.0000	Pass	
NOx Audit Point #1	0.06563	0.0665	1.3	0.0009	Pass	
NOx Audit Point #2	0.04583	0.0455	-0.7	-0.0003	Pass	
NOx Audit Point #3	0.01825	0.0180	-1.4	-0.0003	Pass	
NOx Audit Point #4	0.00988	0.0098	-0.8	-0.0001	Pass	
NOx Audit Point #5	0.00162	0.0020	23.5	0.0004	Pass	
Post Zero	-0.00034	0.0000		0.0003	Pass	
Pre Zero	0.00000	-0.00010		-0.00010	Pass	
NO2 Audit level 5	0.04552	0.04530	-0.5	-0.00022	Pass	
NO2 Audit level 4	0.01853	0.01840	-0.7	-0.00013	Pass	
NO2 Audit level 3	0.00694	0.00670	-3.5	-0.00024	Pass	
NO2 Audit level 1	0.00257	0.00350	36.2	0.00093	Pass	
Post Zero	0.00000	-0.00010		-0.00010	Pass	
Converter Efficiency NO2 level 5	99.1%				Pass	
Converter Efficiency NO2 level 4	99.5%				Pass	
Converter Efficiency NO2 level 3	100.0%				Pass	
Converter Efficiency NO2 level 1	103.9%				Pass	Warning
Sulfur Dioxide						
Pre Zero	0.00003	0.00006		0.00003	Pass	
SO2 Audit level 6	0.06637	0.06771	2.0	0.00134	Pass	
SO2 Audit level 5	0.04635	0.04638	0.1	0.00003	Pass	
SO2 Audit level 4	0.01845	0.01845	0.0	0.00000	Pass	
SO2 Audit level 4	0.00999	0.00980	-1.9	-0.00019	Pass	
SO2 Audit level 1	0.00164	0.00207	26.2	0.00043	Pass	
Post Zero	-0.00035	0.00004		0.00039	Pass	

FINAL SUMMARY AUDIT REPORT CO BASED
EEMS Van-2

Site Name: EPA-R7 - LOW

Audit Date: 10/29/2019

Parameter	NPAP Lab Response (ppm)	Station Response (ppm)	Percent Difference	Actual Difference (ppm)	Pass/Fail	Warning
Ozone						
Pre Zero						
Audit Level 6					N/A	
Audit Level 4					N/A	
Audit Level 3					N/A	
Audit Level 2					N/A	
Post Zero						
Carbon Monoxide						
Pre Zero	0.0011	-0.010		-0.01065	Pass	
CO Audit level 4	2.2014	2.257	2.5	0.05562	Pass	
CO Audit level 4	1.5373	1.550	0.8	0.01272	Pass	
CO Audit level 3	0.6120	0.617	0.8	0.00501	Pass	
CO Audit level 2	0.1275	0.129	1.5	0.00190	Pass	
CO Audit level 1	0.0544	0.064	17.6	0.00960	Pass	
Post Zero	-0.0115	-0.006		0.00532	Pass	
Oxides of Nitrogen						
Pre Zero	0.00003	0.0000		0.0000	Pass	
NO Audit Point #1	0.06568	0.0666	1.4	0.0009	Pass	
NO Audit Point #2	0.04586	0.0457	-0.3	-0.0002	Pass	
NO Audit Point #3	0.01826	0.0182	-0.3	0.0000	Pass	
NO Audit Point #4	0.00380	0.0040	5.3	0.0002	Pass	
NO Audit Point #5	0.00162	0.0021	29.6	0.0005	Pass	
Post Zero	-0.00034	0.0001		0.0004	Pass	
Pre Zero	0.00003	0.0000		0.0000	Pass	
NOx Audit Point #1	0.06563	0.0665	1.3	0.0009	Pass	
NOx Audit Point #2	0.04583	0.0455	-0.7	-0.0003	Pass	
NOx Audit Point #3	0.01825	0.0180	-1.4	-0.0003	Pass	
NOx Audit Point #4	0.00380	0.0039	2.6	0.0001	Pass	
NOx Audit Point #5	0.00162	0.0020	23.5	0.0004	Pass	
Post Zero	-0.00034	0.0000		0.0003	Pass	
Pre Zero	0.00000	-0.00010		-0.00010	Pass	
NO2 Audit level 5	0.04565	0.04530	-0.8	-0.00035	Pass	
NO2 Audit level 4	0.01858	0.01840	-1.0	-0.00018	Pass	
NO2 Audit level 3	0.00697	0.00670	-3.9	-0.00027	Pass	
NO2 Audit level 1					N/A	
Post Zero	0.00000	-0.00010		-0.00010	Pass	
Converter Efficiency NO2 level 5	99.1%				Pass	
Converter Efficiency NO2 level 4	99.5%				Pass	
Converter Efficiency NO2 level 3	100.0%				Pass	
Converter Efficiency NO2 level 1					N/A	
Sulfur Dioxide						
Pre Zero	0.00003	0.00006		0.00003	Pass	
SO2 Audit level 6	0.06637	0.06771	2.0	0.00134	Pass	
SO2 Audit level 5	0.04635	0.04638	0.1	0.00003	Pass	
SO2 Audit level 4	0.01845	0.01845	0.0	0.00000	Pass	
SO2 Audit level 2	0.00384	0.00380	-1.0	-0.00004	Pass	
SO2 Audit level 1	0.00164	0.00207	26.2	0.00043	Pass	
Post Zero	-0.00035	0.00004		0.00039	Pass	

EPA United States Environmental Protection Agency

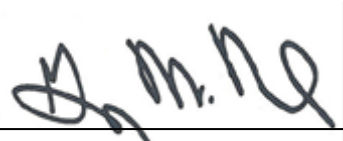
Field Scientist Certification

Eric Hebert

Has satisfactorily completed

The US Environmental Protection Agency's
"National Performance Audit Program (NPAP)
Field Scientist Re-certification Course"

Office of Air Quality Planning and Standards
Research Triangle Park, NC
Course Dates: October 2-4, 2019



Gregory W. Noah
NPAP National Coordinator
USEPA, OAQPS, AAMG

EPA United States Environmental Protection Agency

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Korey Devins

Has satisfactorily completed

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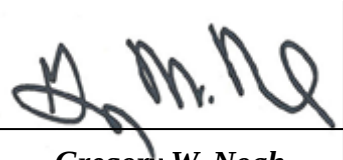

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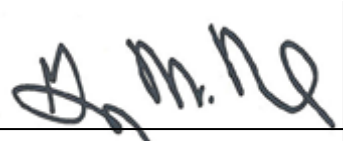

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