Sensor Calibration, Validation System Design

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1 DESCRIPTION

1.1 Purpose

This document presents the design concept of the Calibration and Validation laboratories which will be used to ensure that all sensors and data collecting equipment meet all accuracy requirements needed to make the NEON project successful. The purpose of this document is to describe the sensor and metadata flow, location and frequency of calibrations, validation methods, and laboratory layout.

1.2 Scope

The centralized Calibration and Validation laboratory will have two major functions:

(1) An instrument calibration and validation section;

(2) a facilities validation section for auditing the performance of contracted laboratories.

The Calibration and validation laboratories described in this document are for the Fundamental Instrumentation Unit (FIU) and the Aquatics/Stream Observation Network (STREON) sensors. The sensor calibration and validation laboratory is made up of three sub-labs:

- the indoor sensor laboratory known as the sensor Cal/Val lab (SCVL),
- the outdoor laboratory at the Longmont Airport (CVALLA) and
- the Mobile Cal/Val lab (MCVL).

The audit Cal/Val lab will be described in a separate document.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

AD[01]	NEON.DOC.005505 CVL Technical and Operating Requirements
AD[02]	NEON.DOC.005506 CVL Sensor Lab Infrastructure Requirements
AD[03]	NEON.DOC.005507 CVL Facilities Audit Lab Infrastructure Requirements
AD[04]	DOORS® ID 36688 NEON Project Requirements Database

2.2 Reference Documents

RD[01]	NEON.DOC.000008 NEON Acronym List
RD[02]	NEON.EHS.004300 EHS Safety Policy and Program Manual
RD[03]	International Organization for Standardization (ISO), 1993: *International vocabulary of basic and general terms in metrology*. International Organization for Standardization (ISO), Geneva, Switzerland, 60 pp.
RD[04]	NEON.DOC.000243 NEON Glossary of Terms

2.3 Acronyms

For definitions of acronyms found in this document reference RD [01].

2.4 Definitions

The following definitions taken from the Calibration and Validation Laboratory Technical and Operating Requirements apply to the context of this document:

Accuracy-is the closeness of a measured value to the true value of the measured quantity (ISO 1993).

Precision-is the closeness of the repeated measurements of a specific quantity when the measurements are made under identical conditions (ISO 1993).

Calibration-is the process of quantitatively defining the system responses to known and controlled signal inputs. The process also includes periodically checking and adjusting sensors and instrumentation to ensure the specified accuracy and precision that are traceable to national or recognized standards.

Validation-the process of assessing, by independent means, the quality of data products derived from the system outputs. It is also the establishment of documented evidence that a sensor does as it purports to do.

Other definitions that apply to the context of this document are:

Error- Error refers to the disagreement between a measurement and the true or accepted value.

Primary Standard- Is a standard that has direct traceability to a recognized national laboratory. It is also a standard that is not calibrated by or subordinate to other standards.

Secondary Standard-is a standard that is calibrated against a primary standard and used in NEON's calibrations and validation laboratories. This is done to assure that secondary working standards are also traceable to internationally recognized standards, and to provide a basis to determine the uncertainty in all measurements.

Sensor- in this text is defined as the entire sensor system (*i.e.,* instrument, sensor, sensor element, and sensor system).

Transfer Standard-A standard that is calibrated against a primary standard and used for field-based validation and verification, *e.g*., sent to the sites for field calibration activities.

Uncertainty- A parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measure and; i.e. uncertainty of a measured value is an interval around that value such that any repetition of the measurement will produce a new result that lies within this interval. This uncertainty interval is assigned by the engineer/scientist following established principles of uncertainty estimation.

3 SENSOR CALIBRATION AND VALIDATION LABORATORY DESCRIPTION

NEON is a distributed observatory designed to detect ecological changes over time and space. In order to understand and forecast the effects of climate change, land use change, and invasive species on continental scale ecology NEON must produce accurate and precise long-time series measurements data from multiple instruments at multiple locations. The specific accuracy requirements are listed in DOORS® ID 36688 _ NEON Project Requirements Database, AD [04]. These are also the requirements that the NEON CVALs are designed to meet.

The elements of calibration and validation of a sensor are composed of all the physical attributes that make up the sensor, the functional aspects that determine the operational capability of the sensor, and finally the parameters that determine the frequency of verification, the sensor variables that determine the operational range, and the process/sensor standards that will be used during the verification phase of the sensor. The decision on where a sensor is calibrated, whether it is a NEON or outsourced facility that performs the calibration, or which NEON CVAL is responsible for the calibration is determined by using the flow chart in Figure 1 and the Calibration Frequency, Location, and Duration Matrix located in Appendix A.

The calibration and validation practices for any sensor used in the NEON Project shall be:

1. The calibration periodically checked;
2. Its function adjusted or tracked to maintain accurate and precise measurements;
3. Calibration and Validation uncertainties documented and data stored;
4. Traceable to national or recognized standards; and
5. The documentation of all practices.

The approach taken in order to achieve calibration and validation practices was to identify the following by taking known sensors (see disclaimer in section 1.3) and setting up a cal/val matrix (see Calibration Frequency, Location, and Duration matrix located in Appendix A):

1. The frequency of calibration requirement;
2. The in-process adjustment of sensors to maintain their functional state in order that transduction, transmission, and measurement and calculations be achieved in real or near-real time; and
3. Traceable standards identified.

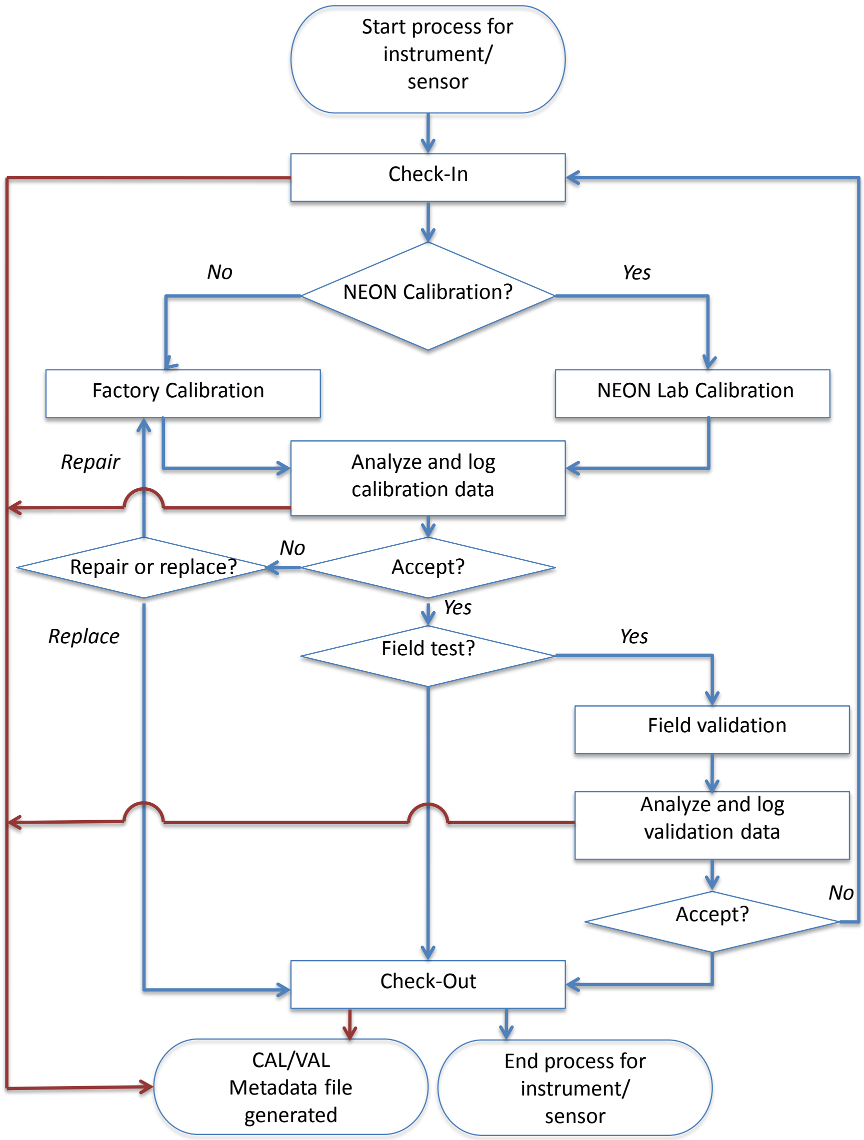

Figure 1 CVAL Work Flow

3.1 Levels of Calibration and Validation

The three different calibration and validation processes that have been identified for NEON sensors are:

Level 1- Initial calibration and validation-preformed on new sensors. This process follows the sensor flow shown in Figure 1. The process starts after the sensor has been checked in by shipping and receiving and has passed an incoming inspection. An asset number will be assigned to a sensor prior to the start of the calibration process.

Level 2- Scheduled recalibration and validation follow the same sensor flow as initial calibration but the process is performed twice. The first run of calibration will be performed on the sensor as it was received from the site; this data will be used to document any calibration drift if any caused by being exposed to the elements. The second calibration run will be performed on the sensor once it has completed its maintenance run, this data will be used to set the calibration reference point.

Level 3- Unscheduled recalibration and validation is conducted on sensors that have come back for repair or identified as out-of-calibration. Once the sensor is repaired it will be handled in the same way as if it was new sensor as far as the sensor/material/metadata flow. The one difference is that a repaired sensor will have a history file on the CVAL database.

All this processes entail that the sensors are checked in at the first station identified as the CVAL Incoming QA/QC and Asset Entry workstation. The check-in process involves scanning (or entering) the asset number associated with the particular sensor which will start the flow of calibration and validation work orders and procedures.

3.2 Calibration Methods

In order to calibrate and NEON sensors over the widely distributed range of NEON sites, a variety of techniques will be employed. NEON will perform some tests on specially designed calibration benches in its sensor laboratory. Alternatively, NEON CVAL will distribute reference materials or transfer standards to field sites. In a limited number of cases, NEON CVAL cannot economically acquire the capacity for sensor calibration (e.g. a wind tunnel is needed for sonic anemometer calibration) and calibrations will need to be done by the manufacturer or by a qualified outside laboratory. In these cases, NEON CVAL will validate instrument performance following calibration.

The selection of calibration approach is based first on the accuracy requirement. The calibration approach must guarantee conditions that permit accurate calibration. Secondarily, but importantly, the calibration approach should minimize cost to the observatory and minimize the loss of measurement time.

NEON will conduct a wide variety of measurements and therefore will need a large number of different calibration and validation approaches. The detailed calibration methods will be developed as a construction deliverable. In Table 1, we list a number of general approaches for calibration that are described briefly below with examples. In addition, one listed instrument is self-calibrating.

Bench Calibration- A specialized calibration bench will be designed and installed in the NEON sensor laboratory. Instruments will be cycled through the laboratory at intervals specified by the CVAL requirements (AD [04]). A limited amount of tooling will be required to build the calibration benches (e.g. brackets to hold radiation sensors at a fixed distance from a calibrated lamp). One group of instruments, the gas analyzers, dominates the bench calibration category because they rely upon standard gases that are difficult to transport.

Transfer Calibration (Field Calibrations)- Transfer standards will be mainly high accuracy instruments or calibrated materials that can be transported to field locations or high accuracy reference measurements maintained at a fixed location. Field instruments will be tested and calibrated against the transfer standards. In some cases, the transfer standards (principally the radiation standards) are maintained by NOAA at the Table Mountain Test site and cannot be moved.

Proprietary- NEON will rely on the proprietary calibration procedures of instrument manufacturers for a limited number of instruments. These instruments will be validated where possible against independent standards. For example, dew point generators will be calibrated by the manufacturer but will be validated against NIST traceable chilled mirror hygrometer standards.

4 CVAL LABORATORY DESIGN

The sensor Cal/Val lab will have a multipurpose function. Along with the calibration of sensors will be the preparation of reference materials that will be distributed to field sites and to outside contracted laboratory facilities. Standard reference materials (*e.g.,* calibrated, traceable gas mixtures) will be used periodically to test and calibrate field instrumentation at NEON's Cal/Val laboratories. NEON will maintain primary reference materials in the sensor Cal/Val lab. Working reference materials and gases (calibrated against the reference standards known as "transfer standards", see above for definition) will be distributed to the field sites.

The Cal/Val lab design includes bench fixtures that are specialized for a given sensor type. These calibration benches are designed and installed in the sensor lab and CVALLA outdoor facility. The fixtures are designed so that a limited amount of tooling is required to install sensors for the calibration process (*e.g.,* brackets to hold radiation sensors at a fixed distance from a calibrated lamp). Where practicable, the measurement equipment that makes up the test fixtures will be 10 times more accurate than the sensor under cal/val, *i.e.,* 1-order of magnitude.

In order to avoid faulty calibrations and validations, a policy will be put in place for measurement/test, primary standard, and secondary standard equipment calibration. Effective inspection, measurement and calibration of equipment will result in reduced costs due to eliminating wasted effort and materials due to faulty calibrations and validations. Thus, in order for CVAL personnel to know what to measure, it is NEON's CVAL policy to adhere to ISO 9001 section 4.11 Standard of Inspection, Measuring, and Test Equipment, and always state the required measurement accuracy of the measurement/test equipment, previously stated as 10 times or better. This policy entails that all measurement/test equipment will be controlled, calibrated, and inspected. The calibration shall be done against a nationally recognized, traceable standard. In order to guarantee that all calibrations and validations are done correctly the following check list was put in place:

- All established safety protocols are strictly adhered to;
- Indentify the measurement to be made;
- Identify the accuracy required;
- Select the appropriate calibration method;
- Identify, calibrate, and adjust all inspection, measuring/test equipment, and devices that can affect product quality at prescribed intervals, or prior to use, against certified equipment having a known valid relationship to nationally recognized standards. Where no such standards exist, the basis used for calibration shall be well documented, and developed taking traceable, first-principles into account;
- Establish, document, and maintain calibration procedures, including detail of equipment type, identification number, location, frequency of checks, check method, acceptance criteria, and the action to be taken when results are unsatisfactory;
- Only use equipment in a manner that ensures that the measurement uncertainty is known and is consistent with the required measurement capability;
- Ensure that the calibration measuring/test equipment is capable of the accuracy and precision necessary;
- Indentify calibration of the measurement/test equipment with an affixed visual indicator that shows the calibration status;
- Maintain and archive calibration records to reference when equipment appears to be out of calibration;
- Ensure that the environmental conditions are suitable for the cal/val being performed. This will be done prior to setup;
- Ensure that the handling, preservation, and storage of calibration measurement/test equipment is such that the accuracy and fitness for use is maintained;
- Safeguard calibration and validation equipment, including both test hardware and test software, from adjustments that invalidate the calibration setting; and
- When test software is generated to be part of a cal/val fixture, it shall be validated to show that it is 100% capable of being part of the calibration measurement. This shall be done prior to commissioning of the laboratory.

The lab is setup so that sensors flow smoothly through the physical structure without interfering with other calibration and validation areas (material flow). As stated in the previous section, the first stop in the sensor lab is the Incoming QA/QC and Asset Entry workstation. Once the sensor is checked in it will be placed in the waiting area for pre-calibrated equipment. This first stop is crucial in controlling what goes in and out of the sensor lab. New sensors that do not have an asset number will be rejected and sent back to shipping and receiving. The sensor will be accepted once the asset number is assigned and affixed to the sensor. Sensors coming in from the sites without an asset number will be rejected and sent back to shipping and receiving until the issue is resolved.

Once that sensor is checked in and the work order is generated, it will be put in the waiting area until the calibration/validation fixture is available. The calibration/validation fixtures are described in the next section. When the sensor has gone through and completed the calibration process it will be sent to the final stop which is the Cal/Val Equipment Data Entry Wrap Up station. At the wrap up station the asset number is compared to the documentation asset number to avoid any confusion or mismatch in metadata/sensor information (this number comparison is also done at the beginning of every step of the calibration process). Once the number is verified at the final stop the documentation will be checked for completeness. The status for Pass/Fail of the cal/val process is checked. If the documentation shows that the sensor passed the cal/val it will be moved to the assembly inventory storage area. If for some reason the report shows a failure the sensor will be sent to the repair and maintenance facility for inspection. It will be repaired, if necessary, and the cal/val process will start again. If the sensor fails the cal/val process for the second time, it will be sent to the manufacturer for further diagnostics and calibration.

4.1 Sensor CVAL Laboratory

4.1.1 Sensor Cal/Val Fixtures

NEON will calibrate a large number of sensors. Whenever possible, calibration should be automated both to save labor and to minimize errors. All instruments and sensors will be tracked using unique identifiers in the property management system. Calibration information will be passed to the NEON cyberinfrastructure in a standardized file format that will include the unique sensor identifier, the parameters resulting from the calibration, the time, date, and location of the calibration, the operator, calibration conditions (e.g. temperature, humidity, etc.), identification and provenance of materials used in the calibration (AD [6]). Along with the standard information, all calibration files will include a section for operator observations. All calibration information, except were protected by proprietary agreements, will be available to observatory users.

Cal/val fixtures will be designed to handle the volume of sensors needing calibration and validation for construction and operations. The designs will be such that ease of setup is increased and setup error is decreased. This will aid in the PA/QA process when large volumes of sensors are introduced to the Cal/Val lab. In some cases, fixtures will be shared from one measurement sensor to another. The following is a list of identified calibration bench fixtures:

- **H2O, CO2 Laser, and IRGA**- this fixture consists of a rack to mount the equipment, temperature and pressure controls for the instrument (its internal optic bench), gas cylinders of CO2 standards, $\delta^{18}O$ primary, $\delta^{13}C$ standard, a dew point vapor generator, a precision chilled mirror, a Gilibrator, a data acquisition system, pumps (if needed), a computer for metadata entry, and auxiliary equipment needed to interface the gas cylinders with the test fixture. Note: standard in this fixture refers to primary and secondary;

- **PPFD/PAR**-this fixture consists of calibrated light source and enclosure, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Sunphotometer**- this fixture consists of calibrated light source and enclosure, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **H2O and RH**-this fixture consists of a chilled mirror dew point hygrometer, an environmental chamber, dew point vapor generator, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Temperature**- this fixture consists of a triple point calibrator that includes an ice bath, mercury cell, gallium cell, and 3 aluminum cylinders (a thermal mass integrating volume), a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Soil CO2 IRGA**- this fixture consists of a rack to mount the equipment, gas cylinders of CO2 calibrated secondary standards, a data acquisition system, a computer for metadata entry, and auxiliary equipment needed to interface the gas cylinders to the test fixture;
- **Long Wave Radiation**-Blackbody calibrator, data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Precipitation**-Dribble calibrator, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **NOx Box**- this fixture consists of a rack to mount the equipment, gas cylinders of NO and NPN calibrated transfer standards, pumps (if needed) a data acquisition system, a computer for metadata entry, and auxiliary equipment needed to interface the gas cylinders to the test fixture, vented access to the outdoors;
- **Sonde and Water Temperature**- this fixture consists of calibration bath, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Nutrient Analyzer**- this fixture consists of a nutrient bath, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Discharge System**-flow bath, high precision pump, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Water Temperature/Water Temperature Profile**- see the Temperature fixture above;
- **Groundwater Well Sensor and Water Height (Pressure) Meter**-clear acrylic cylinder with graduated markings, water source, high precision pressure sensor, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **DO Meter**-this fixture consists of a sealed chamber, vacuum pump, high precision pressure sensor, a data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Precipitation**-flow rate and volume calibrator, a data acquisition system, a computer for metadata entry, and auxiliary equipment.
- **Data Acquisition System**-precision resistors, waveform generator, power supply, a computer for metadata entry, and auxiliary equipment.

4.1.2 Sensor Cal/Val Lab Physical Layout

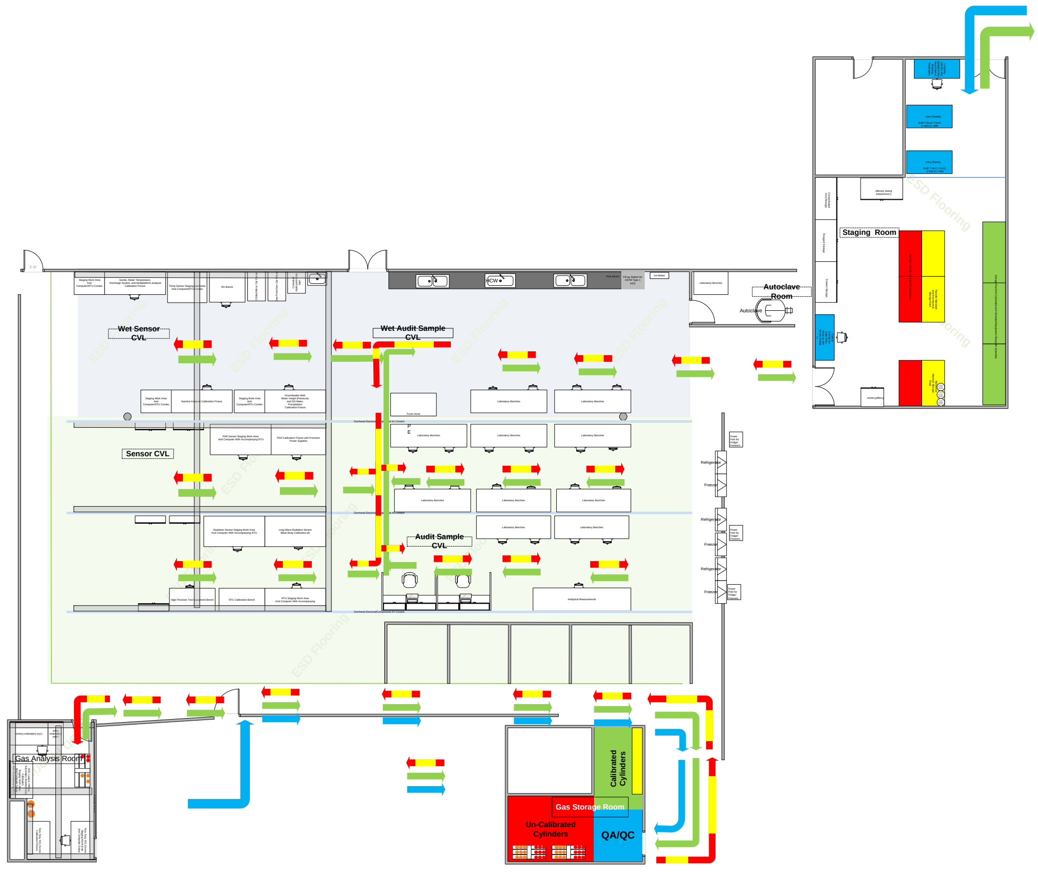

Figure 2 Sensor CVAL Layout and Sensor Flow

4.2 CVAL Longmont Airport Outdoor Facility Cal/Val Laboratory

The CVALLA consists of an outdoor facility with capabilities of calibrating short- and longwave radiation, photosynthetic photo flux density (PPFD), sonic wind, precipitation, and Sun-photometric sensors. All the fixtures, with the exception of the precipitation fixture, will have the capability of multiple sensor mounting and data acquisition interfaces of a given sensor type. The multi-sensor capability will allow sensors of high quantity per site or lengthy calibration duration time to be calibrated at once thus reducing the calibration throughput and optimizing labor time.

The primary and secondary standards/sensors will go through a recalibration procedure once they return to the Sensor CVAL.

4.2.1 CVAL Longmont Airport (CVALLA) Cal/Val Fixtures

The cal/val fixtures that make up the outdoor lab are:

- **Shortwave Radiation**-consists of primary and secondary standards, mounting platform and bench, a computer for metadata entry, and auxiliary equipment;
- **Photosynthetic Photon Flux density (PPFD),**-consists of secondary standards, mounting platform and bench, a computer for metadata entry, and auxiliary equipment;
- **Long Wave Radiation Fixture A**-consists of RTDs, soil heat flux plates, the sandbox, a mounting apparatus, a data acquisition system, a laptop computer for metadata entry, secondary standards and auxiliary equipment;
- **Long Wave Radiation Fixture B**-consists of RTDs, a mounting apparatus, a data acquisition system, a laptop computer for metadata entry, secondary standards and auxiliary equipment;
- **Spectral Photometers**-consists of a primary standard that stays mounted on the top of the a mounting apparatus, secondary standard, data acquisition system, a computer for metadata entry, and auxiliary equipment;
- **Sonics**- a mounting apparatus, fine wire thermocouples, secondary standards, a data acquisition system, and a computer for metadata entry;
- **Precipitation**-consists of a concrete pad/mounting apparatus, wind fence, a data acquisition system, a computer for metadata entry, and auxiliary equipment.

4.2.2 CVAL Longmont Airport Outdoor Facility Physical Layout

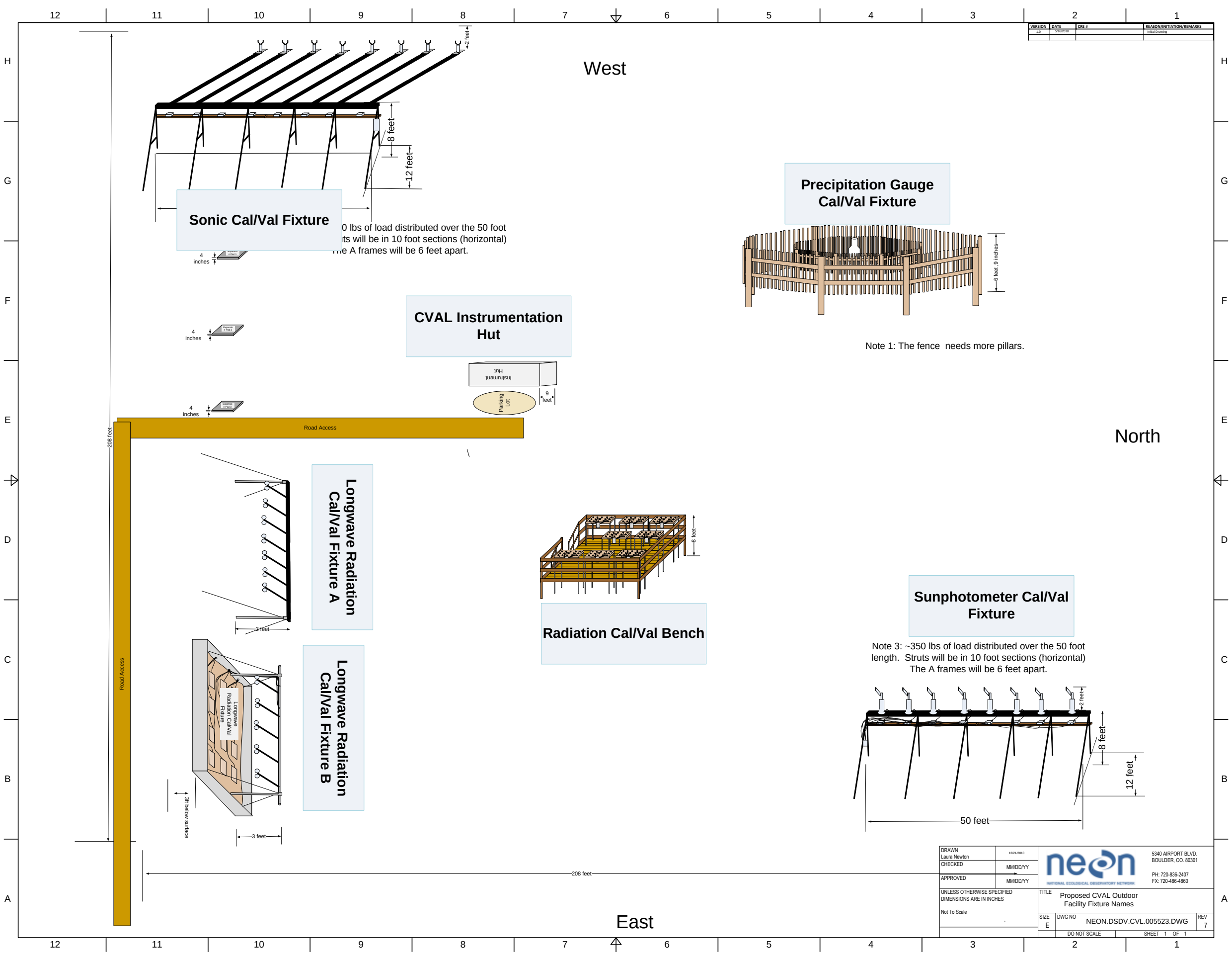

Figure 3 CVALLA Outdoor Facility Physical Layout

4.2.3 Mobile Cal/Val Lab

Managing whole system performance of sensors in the field takes a multi-faceted approach. As part of a robust CAL/VAL plan and routine calibrations, whole system validation will take place *in situ*, in the field. Roving transfer standards has proved successful in other Agency programs, *e.g.,* NASA AERONET, DOE-AmeriFlux, DOE-ARM, NOAA-GEWEX, and others. In this lab, the transfer standard (equipment kept under calibration at the Sensor CVAL) will be shipped to the site with all supporting equipment, and deployed *in situ*, pending need, priority, and on a case-by-case basis. The domain staff will perform the calibration, once completed the equipment will be placed in its original shipping container and returned to the Sensor CVAL. Once the piece of equipment has gone though shipping and receiving and cleared incoming inspection it will enter the re-calibration cycle, and re-deployed in the field as needed.

The candidate measurements/sensors for the Mobile CVAL are:

- **3D Windspeed and Sonic Temperature** -Sensor and associated equipment;
- **IRGA CO2/H2O (Atmosphere)-** analyzer and associated equipment;
- **Isotope Laser δ^{13}C** -analyzers and associated equipment;
- **Isotope Laser δ^{2}H & δ^{18}O-**analyzers and associated equipment;
- **Air/Soil Temp**-sensors and associated equipment.
- **Short- and longwave radiation-** sensors and associated equipment.
- **Atmospheric pressure**- sensors and associated equipment.

5 SENSOR CALIBRATION FREQUENCIES AND LOCATIONS

NEON has been designed to detect inter-annual changes and differences among sites in key ecological forcings and responses (AD [02]). At a minimum, the CVAL will conduct annual calibrations on all sensors. Most NEON sensors are designed by their manufacturers to be stable for at least one year under field conditions. Sensors will be calibrated annually by the CVAL lab or validated by the CVAL lab annually when the need for calibration is less frequent. When manufacturer specification or field experience indicates that it is necessary, routine maintenance and field-testing of sensors will include intermediate calibrations or checks. For example, infra-red gas analyzers used for eddy co-variance studies will be checked against secondary gas standards daily or more frequently using automated routines and recalibrated against secondary standards when the field checks fall outside of established ranges.

Where practical, NEON sensors will be calibrated in at the field locations or in a nearby field laboratory. This approach minimizes inventory of replacement sensors and shipping costs. It is simpler and cheaper to ship a single package of transfer standards than it is to ship multiple sensors. When field calibration is not practicable, NEON will conduct calibrations either at its sensor laboratory, at the Table Mountain test site, or at an outside facility including those maintained by instrument manufacturers. For example, high accuracy radiation sensors maintained by NOAA SURFRAD are available at Table Mountain. These sensors could not be shipped to NEON field locations. Similarly, NEON will maintain high accuracy standard gases in its sensor laboratory. It would not be economical to ship these gases and the associated gas handling equipment to multiple field sites.

The CVAL will conduct or oversee sensor calibrations at the three locations mentioned above (*field, Table Mountain, and sensor laboratory)*. Calibrations will be conducted either by CVAL technical staff or by NEON field technicians. The training of field technicians will include specific training in sensor calibration methods.

6 SENSOR CALIBRATION KEY

The following table lists NEON sensors measurements (see disclaimer section 1.3) and provides the calibration location frequency and science requirement. For engineering sensors and those sensors that do not have a calibration requirement, the table indicates "----" under location and approach. A series of notes that follows the table discusses validation approaches for sensors calibrated by the manufacturer or other outside facility as well as other details.

Calibration Frequency, Location, and Requirements Matrix

MEASUREMENT	CALIBRATION FREQUENCY	CALIBRATOR	NEON Location	DOORS Req (NOTES)
Air Temp	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, NEON Mobile CVAL**	**CVAL, Field Site**	**3.007-8**
Water/Soil Temp	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, NEON Mobile CVAL**	**CVAL, Field Site**	**3.007&9**
Sonic Temp	**Prior to deployment then annually thereafter**	**OEM**	**------**	**3.010-12 d**
Relative Humidity	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL**	**CVAL**	**3.016-18**
PPFD/PAR	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, NEON CVALLA**	**CVAL, CVALLA**	**3.030-35**
Short Wave Radiation (Primary Standard)	**Prior to deployment then annually thereafter**	**NREL/DAVOS**	**CVALLA**	**3.022-23**
Short Wave Radiation	**Prior to deployment then annually thereafter**	**NEON CVALLA**	**CVALLA**	**3.022-23**
Long Wave Radiation (Primary Standard)	**Prior to deployment then annually thereafter**	**NREL**	**-----**	**3.013-15**
Long Wave Radiation	**Prior to deployment then annually thereafter**	**NEON CVALLA**	**CVALLA**	**3.013&15**
Net Radiation	**Prior to deployment then annually thereafter**	**NEON CVALLA**	**CVALLA**	**3.038&39**
Direct & Diffuse Radiation	**Prior to deployment then annually thereafter**	**NEON NEON CVALLA (Direct only)**	**CVALLA**	**3.028&29**
3D Windspeed and Sonic Temperature	**Prior to deployment then annually thereafter**	**OEM, NEON CVALLA**	**CVALLA**	**3.064-67 d**
2D Windspeed & Direction	**Prior to deployment then annually thereafter**	**NEON CVALLA**	**CVALLA**	**3.064, 68-70 d**
Precipitation	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL and NEON CVALLA**	**CVAL, CVALLA**	**3.077-79**
Throughfall	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL**	**CVAL**	**3.077-79**

Particulate Mass and Particle Size	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL**	**CVAL**	**3.062-63**
IRGA CO2/H2O (Atmosphere)	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL/OEM**	**CVAL**	**3.040-49**
IRGA CO2/H2O (Soil)	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL/OEM**	**CVAL**	**3.050-52**
Soil Heat Flux		**Self Calibrating**	**-----**	**3.074-76**
Isotope Laser $\delta^{13}C$	**Prior to deployment then annually thereafter**	**OEM**	**-----**	**3.058-61**
Isotope Laser $\delta^{2}H$ & $\delta^{18}O$	**Prior to deployment then annually thereafter**	**OEM**	**------**	**3.058-61**
Spectral Photometer (Secondary Stanrard)	**Prior to deployment then annually thereafter**	**NEON CVAL/NASA AERONET**	**CVAL, CVALL A**	**3.037&37 d**
Spectral Photometer	**Prior to deployment then annually thereafter**	**NEON NEON CVALLA**	**CVAL, CVALL A**	**3.037&37 d**
NO-NOy	**Prior to deployment then annually thereafter**	**OEM**	**----**	**3.056-57**
Ozone Generator	**Prior to deployment then annually thereafter**	**OEM**	**----**	**3.053-55**
Ozone	**Prior to deployment then annually thereafter**	**OEM**	**-----**	**3.053-55**
Soil Water Content (point)	**Prior to deployment and upon removal from soil**	**NA**	**------**	**3.071-73**
Soil Water Content (profile)	**Prior to deployment and upon removal from soil**	**NA**	**--------**	**3.071-73**
MiniRhizotron	**Prior to deployment then annually thereafter**	**None**	**--------**	**------**
Digital Camera	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL, Field Site**	**3.096**
Calibration of Primary, Secondary and Transfer Standards: Lab Operation	**As needed**	**NEON CVAL/OEM**	**CVAL**	**3.002**
Dew Point generator	**Bi-Annually**	**NEON CVAL/OEM**	**CVAL**	**3.019-21 c**
Pressure Controllers	**Annually**	**NEON CVAL**	**CVAL**	**b**
Volumetric Flow meter	**Annually**	**NEON CVAL/Gilibrator**	**CVAL**	**b**
Press Cyl Manometers	**Annually**	**NEON CVAL**	**CVAL**	**b**
Data acquisition	**At purchase and then biennially**	**NEON CVAL**	**CVAL, Field Site**	**b**
Water CDOM Sonde			**CVAL, Field Site**	**a**
Multi-platform analyzer	**Prior to deployment then annually thereafter**	**OEM, Field Site Transfer Standard**	**CVAL, Field Site**	**3.084-89**
Discharge system	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL, Field Site**	**3.094-95**
Nutrient Analyzer	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL, Field Site**	**3.094-95**
Water Temperature Profile	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL**	**3.007-9**
DO Meter	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL, Field Site**	**3.033**
Water Height (Pressure) Meter	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL**	**3.092-93**

Data Acquisition System	**Prior to deployment then annually thereafter**	**NEON Sensor CVAL, Field Site Transfer Standard**	**CVAL**	**3.006**

Notes:

(a) The cDOM sensor provides a signal that is proportional in response to the concentration of a specific organic compound (e.g. quinine sulfate). This signal does not necessarily follow the same proportionality for all possible organics found in natural waters at NEON aquatic sites so there is no CVL requirement for cDOM. Instruments will be validated against a standard compound to test performance. Detailed, often time-dependent, site based investigations are needed to calibrate a cDOM instrument. These are beyond the scope of observatory operations.

(b) Sensor for engineering measurements that guarantee proper observatory function that will not require calibration by the CVL.

(c) Dew point generators will be validated against chilled mirror hygrometers or other traceable standards at least annually. If the instruments do not pass validation tests they will be sent to the manufacturer for calibration.

(d) NEON CVL will perform validation tests for these instruments following manufacturer calibration.

(e) Field validation tests are sufficient to assure proper functioning of this sensor.

(f) Gas analyzers for CO_2 and H_2O will be calibrated in the sensor laboratory in the same manner as gas analyzers for eddy covariance. Calibration accuracy requirements may be relaxed because of the lower detection thresholds required for soil flux measurements.

7 TRAINING AND MANUALS

All NEON employees that handle sensor/instrument calibration will be trained on the calibration procedures and each domain site will receive calibration manuals.

8 SAFETY

The Sensor CVAL, CVALLA, and Mobile CVAL shall adhere to safety rules as discussed in EHS Safety Policy and Program Manual RD [02], and compliance with all EHS requirements. The safety described below is for the Sensor CVAL. The safety requirements described below are specific for the Sensor CVAL.

8.1 Personnel

The sensor lab will be equipped with an emergency eye wash and shower station. In addition to the station will be a first aid kit. MSDS sheets for each chemical type will be kept in a common area identified by the Environmental, Health, and Safety (EHS) PT. All personnel will be trained to safely conduct their responsibilities. The sensor lab is also laid out so that there is always a 3’ (or larger) clearance for walkways.

8.2 Equipment

To avoid any damage to sensors due to electrostatic discharge ESD rated flooring will be installed in the indoor lab. Along with the ESD flooring will be the use of ESD smocks and heal straps. Wrist straps will be part of the bench fixtures in areas where is does not make sense to install ESD flooring.

The policy for working on sensors out at the CVALLA is to limit work to installation. All repairs shall be done at the technical facility where ESD precautions are in place. At no time shall a sensor be opened in the outdoor facility. Data logging equipment will need to be opened in order to make the sensor to data acquisition interface, in these cases there will be a wrist strap connection to the grounded calibration fixture.

8.3 Environment

Because the CVALLA is located outdoors, CVAL personnel shall become familiar and adhere to any policies documented in the EHS Environmental Protection Manual AD[11].