Region 4 U.S. Environmental Protection Agency Laboratory Services & Applied Science Division Athens, Georgia	
Operating Procedure	
Title: Field Measurement Uncertainty	**ID: FSBPROC-014-R3**
Issuing Authority: Field Services Branch Chief	
Effective Date: April 19, 2024	**Next Review Date: April 19, 2028**
Method Reference: N/A	**SOP Author: Derek Little**

Purpose

The purpose of this procedure is to provide direction regarding reporting uncertainty of field measurements.

Scope/Application

Environmental field measurements pose unique challenges for estimating measurement uncertainty. This procedure addresses these uncertainty issues related to field measurements and field instrumentation and provides a methodology for estimating uncertainty for environmental measurements conducted in the field by LSASD investigators. See Section 3 of this procedure for more detail on the issues associated with estimating uncertainty for environmental field measurements and the methodologies employed by LSASD for estimating field measurement uncertainty. Uncertainty statements can only be made for data collected following the initial effective date of this operating procedure. Mention of trade names or commercial products in this procedure does not constitute endorsement or recommendation for use.

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1. Summary

ISO/IEC 17025:2017 requires reporting of measurement uncertainty in test reports under three conditions:

1. When measurement uncertainty is relevant to the validity or application of the test results,
2. When a customer's instruction so requires, and/or
3. When the measurement uncertainty affects conformity to a specification limit.

Uncertainty statements are typically requested by the customer in the planning phase of a project. If a customer requests an uncertainty statement following completion of the project, LSASD management will determine whether it is feasible to report the uncertainty. For field data appearing in reports, uncertainty should be calculated and reported for data that directly affects compliance to a regulatory limit. For data collected as indicator parameters, (e.g., measurements to verify stabilization of a monitoring well or to develop strata for sample collection) uncertainty statements will not be reported unless the customer requests it, or the Project Leader deems it necessary.

The overall goal of documenting measurement uncertainty is to provide information that can be used for decision making. To achieve this goal, it is important to know if measurement uncertainty related to detection limits, field analytical bias, lack of precision and susceptibility to interferences is significant.

1.1. Definitions

Accuracy of measurement (Accuracy)
Closeness of agreement between a measured quantity value and the true value of the measurand. Accuracy is a function of both precision and bias.

Precision
Closeness of agreement between results obtained by replicate measurements on the same or similar objects under specific conditions.

Bias
Systematic measurement error or its estimate, with respect to a reference quantity value.

Qualitative Measurement
Detection techniques used to identify the compounds or physical properties associated within the sample.

Quantitative Measurement
Measurement techniques used to determine the amount of each compound, or the amount of physical property associated with the sample.

Detection Limits
The lowest concentration or amount of target analyte that can be identified, measured, and reported with confidence that the analyte concentration is not a false positive.

Standard Deviation
A measure of how much the data in a sample population are scattered around its mean value. It is usually denoted σ (lowercase sigma). A standard deviation is defined as the square root of the variance.

Significant
Having an outcome unlikely to be caused by chance and therefore indicating a systematic relationship between measurements and conditions.

(Internationa Vocabulary of Metrology - Basic and General Concepts and Assiciated Terms (VIM) 3rd Edidtion, 2006)

2. Methodology

2.1. Estimating Quantitative Uncertainty

When estimating field measurement uncertainty, field investigators will try to identify all the major uncertainty contributors and make a reasonable estimation. When an uncertainty statement is required, as discussed previously in Section 1, the uncertainty statement will be prepared taking into consideration the instrument uncertainty, calibration standard uncertainty, the data quality objectives, and any other applicable factors.

The quantitative uncertainty of a field measurement is not synonymous with the procedural control limits of the instrument. The quantitative uncertainty of a measurement should always be less than the control limits of the measurement procedure. Control limits are established to determine if a field instrument needs to be recalibrated or if data is of sufficient quality to be utilized for decision making purposes. For more information on the control limits used for LSASD field measurements, reference the specific LSASD field measurement operating procedures.

2.2. Uncertainty Types

The Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM) and National Institute of Standards and Technology (NIST) documents discuss the evaluation of uncertainty according to a “Type A” or “Type B” method of evaluation. The Type A method evaluates standard uncertainty by the statistical analysis of a series of repeated observations. The Type B method evaluates uncertainty based on scientific judgment using all the relevant information available, which may include:

- previous measurement data
- experience with or general knowledge of the behavior and properties of relevant materials and instruments
- manufacturer’s specifications
- data provided in calibration certificates and other certificates.

Broadly, Type B uncertainty is either obtained from an outside source or obtained from an assumed distribution based on judgment using all information available.

3. Implementation

3.1. General

Environmental field measurements pose unique challenges for estimating measurement uncertainty. Unlike conducting a Type A uncertainty analysis in a laboratory setting, many times during field measurement activities it is impossible to perform replicate analyses. Supplying a known spike and attempting to determine percent recoveries for many field measurements is also often not possible. Qualitative uncertainty factors such as sample handling and constantly changing environmental conditions (temperature as one example), complicate and at times directly impede the ability to conduct a Type A uncertainty estimation of the environment measurements performed in the field. These qualitative uncertainty contributors make a Type A uncertainty estimation of the instruments' response to the environmental sample problematic. LSASD's routine methodology for estimating its field measurement uncertainty will use a Type B assessment. LSASD's implementation of this Type B uncertainty estimation is described in Section 3.2 of this procedure. Uncertainty associated with LSASD's field measurements are assumed to be produced from random effects and will be treated as existing in a normal distribution.

In rare circumstances the Type B uncertainty estimation cited in Section 3.2 may not be sufficient for documenting the field measurement uncertainty. For field investigations performed under these circumstances, either a hybrid Type A/B uncertainty (See Section 3.3) or a Type A uncertainty (See Section 3.4) estimation of the field instrument's response to the actual environmental sample would be required. In such a case, the uncertainty evaluation will be interpreted in the context of a thorough understanding of the measurement method. For example, in large Category 1 projects with many mobile laboratory field measurements, statistical measures might be undertaken to define the uncertainty of the measurements. Even then, the statistical tests would only be reported in conjunction with the following important elements:

- Previous measurement data,
- Experience with, or general knowledge of, the behavior and property of relevant materials and instruments,
- Manufacturer's specifications,
- Data provided in calibration and other reports, and
- Uncertainties assigned to reference data taken from handbooks.

If it is determined that a hybrid Type A/B uncertainty estimation is needed for the measurements performed during a field investigation, then the Type A/B hybrid uncertainty estimation will be computed using Equations 1 through 5 of this procedure.

The Type A portion of this hybrid uncertainty estimation will be computed based on the instrument's response to known standards and not to the instrument's response to the environmental sample itself. Typically, a Type A uncertainty estimation would evaluate the variability of the instrument's response to the environmental sample and not the variability of the instrument's response to a known calibration standard. This is because the performance of an instrument against a known calibration standard will often be more precise than against an environmental sample. However, by combining a Type A uncertainty estimation based on a field instrument performance against known calibration standards along with a Type B estimation of the environmental sample, a total field measurement uncertainty can be estimated. For more detail on the methodology for the LSASD hybrid field measurement uncertainty estimation, refer to Section 3.3 of this procedure.

If a Type A uncertainty estimation is needed for the field measurements performed during an environmental investigation, the uncertainty estimation will be computed using the instrument's response to the environmental sample itself and will not be based on a response to calibration standards. For more detail on Type A uncertainty estimations computed solely on the measurements of the environmental sample, refer to Section 3.4 of this procedure.

Selection of the uncertainty methodology that best meets the Data Quality Objectives (DQOs) of the environmental investigation should be determined during the project planning phase. Using either the hybrid uncertainty estimation or the Type A uncertainty estimation requires that this decision be made prior to field measurements being performed. As such, if it is determined that the uncertainty estimation of the field measurements will use either the hybrid or Type A methodologies, this must be stated in the Sample Analysis Plan (SAP) and approved by LSASD management.

3.2. Routine LSASD Uncertainty Estimation for Field Measurements

Through a review of the logbooks of historical environmental sampling activities, manufacturer's instruction manuals and the best professional judgment of the Subject Matter Experts (SME)s for their respective field instruments, the LSASD Table of Field Measurement Uncertainties (Type B), FSBFORM-1400 (most recent version) has been developed to estimate the Type B uncertainty associated with each type of accredited field instrument utilized by LSASD. The uncertainty values found in this table will be used as the field instrument uncertainty for field measurements performed by LSASD. The LSASD Table of Field Measurement Uncertainties (Type B) is maintained on the LSASD local area network (LAN).

3.3. Hybrid Type A/B Uncertainty Methodology

If determined that LSASD's routine estimation of field measurement uncertainty is not sufficient for the project's DQOs, the field measurement uncertainty can be determined using a hybrid of Type A and Type B methodology. The Type B part of this hybrid methodology intends to account for the uncertainty associated with the environmental sample. The Type A part of the hybrid uncertainty assessment is limited to evaluating the instrument performance against known and traceable calibration standards, intended to determine instrument variability with respect to known and traceable calibration standards. The instrument response will be compared to the traceable calibration standards and not the environmental sample itself. If the DQOs of an environmental investigation require the field measurement uncertainty be solely determined by comparing the instrument's response to the environmental sample itself, field investigators will follow Section 3.4 of this procedure.

The assessment of uncertainty through this hybrid method will start with a field instrument's operating manual and the quoted uncertainties obtained from a calibration standard's certificate. Project leaders will perform a post-operation instrument verification check (aka unadjusted calibrations) along with daily calibrations, performed following the instrument's operating manual. This verification check will be performed using the proper standards at the end of the day or after all measurements have been completed for a particular period of operation. These measurements must be recorded in the field logbook as required per LSASDPROC-1002 (most recent version).

Type A uncertainty statistics will be computed for each instrument's performance based on these verification checks. At a minimum, the summary statistics will include mean instrument performance as defined by Equation 1, bounded by 95% confidence limits of the mean defined by Equation 4. The "Hybrid" Uncertainty will be computed as the sum of the Type A uncertainty (computed through verification checks), the Type B uncertainty found from FSBFORM-1400 (most recent version) and the uncertainty associated with the calibration standards. Equation 5 will be used to compute the estimated hybrid uncertainty. These instrument uncertainties will only be calculated and reported for field measurement equipment that is subject to the scope of field accreditation. Type B uncertainty estimation is used in Equation 5 to compute the hybrid uncertainty estimation; therefore, the hybrid uncertainty estimation will always be greater than the Type B uncertainty estimation. This difference can be minimized using accurate calibration standards and obtaining good agreement on the instrument verification checks, but the hybrid uncertainty estimation will always be greater than the Type B uncertainty estimation found from FSBFORM-1400 (most recent version).

In some cases, measurement uncertainties are provided in percent as opposed to standard deviations. For these cases, Equation 6 will be used to convert all uncertainties into standard deviations so that they may be used in Equation 5.

Summary statistics computed for the field instrument's performance against known traceable calibration standards will be computed using the equations in this section of the operating procedure; where Equation 1 is the mean of the verification checks, Equation 2 is the sample standard deviation, Equation 3 is the standard deviation of the mean (aka standard error) and Equation 4 is the 95% confidence limits for the standard deviation of the mean. Because uncertainty is a function of the number of field verification checks, it is not appropriate to compute the field measurement uncertainty using Equations 1 through 5 for environmental field investigations that have a small number of instrument verification checks. For this reason, project leaders should endeavor to obtain 7 or more instrument verification checks for a particular measurement type if the below equations are intended to be used to estimate the field measurement uncertainty.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Equation 1: Mean

where x_i is the measured verification check, N is the total number of field verification checks, and $\bar{x}$ is the mean of the verification checks

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

Equation 2: Sample Standard Deviation

where x_i is the measured verification check, N is the total number of field verification checks, $\bar{x}$ is the mean of the verification checks, and s is the sample standard deviation

$$\sigma_a = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N(N-1)}} = \frac{s}{\sqrt{N}}$$

Equation 3: Standard Deviation of the Mean

where x_i is the measured verification check, N is the total number of field verification checks, and $\bar{x}$ is the mean of the verification checks, s is the sample standard deviation, and σ_a is the standard deviation of the verification check mean ($\bar{x}$)

$$\overline{X}_{\pm 95\%} = \bar{x} \pm t_{0.95,n-1} \cdot \sigma_a$$

Equation 4: 95% Confidence Limits of Sample Mean

where $\bar{x}$ is the mean of the verification checks, σ_a is the standard deviation of this mean, $t_{0.95,n-1}$ is the 95th quantile of a t-distribution with n-1 degrees of freedom, and $\overline{X}_{\pm 95\%}$ is the 95% confidence range of the mean verification checks

$$\sigma_{hybrid} = \sqrt{\sigma_a^2 + \sigma_b^2 + \sigma_c^2}$$

Equation 5: Hybrid Uncertainty Estimation

where σ_a is the type a uncertainty found through the standard deviation of this mean verification checks (Equation 3), σ_b is the Type B uncertainty for the field instrument of interest (found in FSBFORM-1400, most recent version), σ_c is the uncertainty associated with the calibration standards, and σ_{hybrid} is the estimated hybrid uncertainty.

$$RSD_x \equiv \frac{\sigma_x}{\overline{x}} * 100$$

Equation 6: Relative Standard Deviation

where σ_x is the standard deviation of the mean, $\overline{x}$ is the value of interest (mean), and RSD_x is the relative standard deviation (uncertainty) expressed as a percent

3.4. Environmental Type A Uncertainty Methodology

When the DQOs of an environmental field investigation require that the Type A uncertainty determination be computed solely on the environmental sample and not based on instruments' agreement to known calibration standards or utilizing a Type B uncertainty estimation, in addition to performing the required verification checks against the appropriate known standards, LSASD field investigators will perform multiple measurements of the environmental sample in question. A minimum of 7 repeat measurements per environmental sample will be performed to allow for a statistically sound sample size. Means of the instrument response to the environmental sample and their associated 95% confidence intervals will be computed. Means will be computed using Equation 1 of this procedure and the 95% confidence interval of this mean will be computed using Equation 4 of this procedure.

4. References

Laboratory Services Branch Laboratory Operations and Quality Assurance Manual, most recent version.

International Organization for Standardization (ISO). (1993, corrected and reprinted 1995). *Guide to the Expression of Uncertainty in Measurement* (GUM).

International Organization for Standardization (ISO). (2006, third edition). *International Vocabulary of Basic and General Terms in Metrology.*

National Enforcement Investigations Center Operating Procedure for Estimation of Measurement Uncertainty (NEICPROC/07-004), November 9, 2007.

National Institute of Standards and Technology (NIST). (1994). *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* (TN-1297).

National Institute of Standards and Technology (NIST). (October 2000). *Essentials of Expressing Measurement Uncertainty.* Retrieved February 28, 2007 from http://www.physics.nist.gov/cuu/Uncertainty/index.html

LSASD Operating Procedure for Logbooks (LSASDPROC-1002), most recent version.

LSASD Table of Field Measurement Uncertainties (FSBFORM-1400), most recent version.

William J. Tilstone, "Uncertainty of Measurement," *The FQS Update*, vol. 2, issue 2 (June 2007), pages 1-3.

SOP Revision History

History	Effective Date
FSBPROC-014-R3, *Field Measurement Uncertainty*, replaces SESDPROC-014-R2 Update SESD to LSASD and other organization changes. Other minor edits throughout. Section 1: Updated ISO/IEC 17025 reference and associated measurement uncertainty reporting language. Definitions: Updated definitions using more concise language.	April 19, 2024
SESDPROC-014-R2, Field Measurement Uncertainty, replaces SESDPROC-014-R1. **Cover Page:** SESD's reorganization was reflected in the authorization section by making John Deatrick the Chief of the Field Services Branch. The FQM was changed from Bobby Lewis to Hunter Johnson. **Revision History:** Changes were made to reflect the current practice of only including the most recent changes in the revision history. **General:** Corrected any typographical, grammatical and/or editorial errors. **Section 2.2:** The following was added to the third sentence: "representativeness of the sample" **Section 3.3:** Equation 6 was updated.	March 23, 2016
SESDPROC-014-R1, Field Measurement Uncertainty, replaces SESDPROC-014-R0.	April 30, 2012
SESDPROC-014-R0, Estimating Field Measurement Uncertainty, Original Issue	February 11, 2008