# DoD Environmental Data Quality Workgroup Factsheet

## Subject: Detection and Quantitation

## What Project Managers and Data Users Need to Know

*June 29, 2026*

As a Project Manager and data user, you may use environmental data to accomplish one or more of the following tasks:

- Determine whether an analyte is absent or present in an environmental sample at or above background or some threshold value or action level;
- Verify that a pollutant concentration remains below a permit limit;
- Evaluate potential risks to human health or the environment;
- Monitor changes in concentrations of contaminants; or
- Determine the effectiveness of remediation activities.

Making correct decisions in these cases often depends on the ability of an analytical method to detect and measure extremely low concentrations of an analyte.

This Fact Sheet has been prepared to: 1) provide Project Managers and data users with basic information about detection and quantitation concepts; 2) acquaint the reader with detection and quantitation terminology and requirements contained in the *DoD Quality Systems Manual for Environmental Laboratories (DoD QSM),* Version 6.0; and 3) provide data users with a reference for establishing the detection and quantitation limits. This information should help clarify the uncertainty associated with reporting low-concentration data. It should also help project teams understand the importance of selecting analytical methods that are sensitive enough for their intended uses, i.e., capable of generating reliable data (data of known precision and bias) at the project-specific decision levels.[1]



[1] A discussion on the detection and quantitation concepts for radiological data is beyond the scope of this Fact Sheet.

## Measures of Sensitivity – Basic Concepts

The following terms are used to describe the routine sensitivity of analytical procedures:

- DL – Detection Limit
- LOD – Limit of Detection
- LOQ – Limit of Quantitation

All measures of sensitivity are specific to the analyte, sample matrix, test method, instrumentation, and analyst/laboratory performance, commonly referred to as an analyte-matrix-method (e.g., reagent water, clean sand, etc.) combination. DLs, LODs, and LOQs are therefore dependent on the combination of the analyte-matrix-method used and the laboratory performing the testing and may vary slightly from one laboratory to another. Accordingly, analytical performance must be demonstrated for each variable (e.g., it is possible that two "identical" instruments from the same manufacturer may exhibit different sensitivities). A graphical representation of these terms is shown in Figure 1.

The **Detection Limit (DL)** is the smallest analyte concentration that can be demonstrated to be different from zero or a blank concentration with 99% confidence. This is synonymous with the EPA Method Detection Limit (MDL) definition. At the DL, the false positive rate (Type I error) is 1% (red shaded region in Figure 1). A DL may be used as the lowest concentration for confirming presence of a specific analyte in a specific matrix with a specific method with 99% confidence but cannot tell you exactly how much. Figure 1 provides a visualization of the DL.

For reporting purposes, a measured result at or above the DL indicates that the analyte is present with approximately 99% confidence; however, the inverse is not true. A result below the DL is by nature inconclusive, as one cannot confidently determine whether the analyte is present or absent. Specifically, if the analyte is present at a concentration equal to the DL, there is a 50% chance the analyte was not detected (blue shaded region in Figure 1). Therefore, reporting the sample result as "<DL," is inappropriate because the false negative rate at the DL can be as high as 50%.

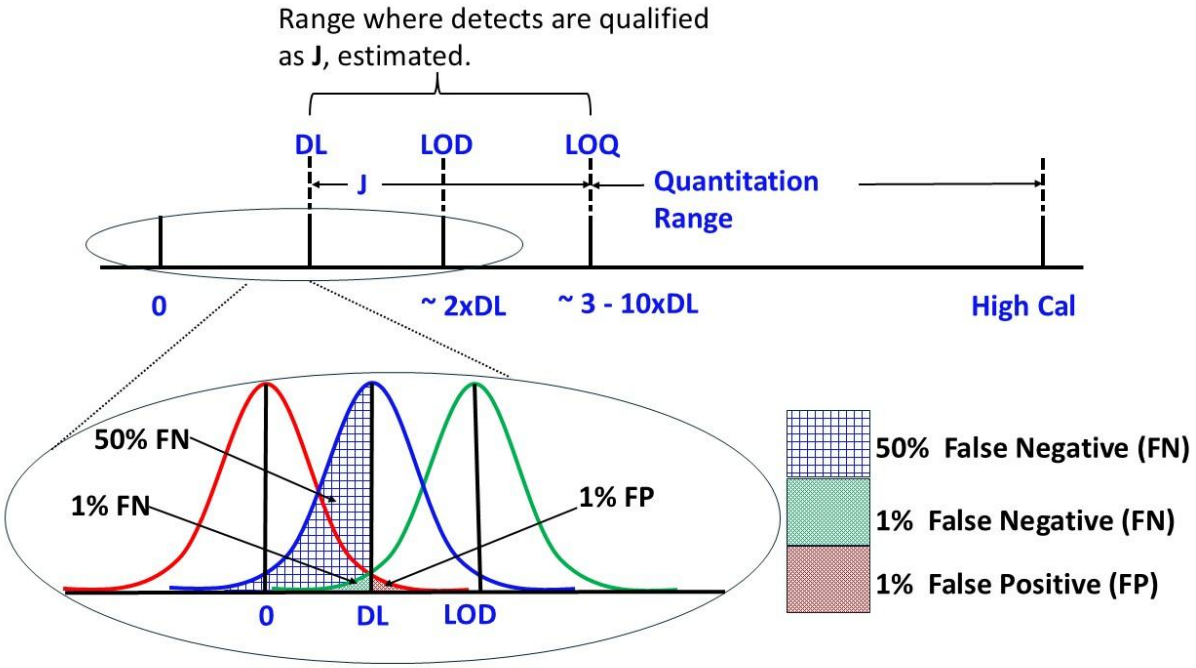


*Figure 1: Summary of data quality characteristics below and above the DL, and the LOD. The red trace shows the distribution of results given a sample with a true concentration of zero. The blue trace shows the distribution of results given a sample with a true concentration at the DL. The green trace shows the distribution of results given by a sample with a true concentration at the LOD. The red shaded region represents those results which would yield a false positive (i.e., the true concentration is zero, but the analytical result is detected). The blue and green shaded regions represent those results which would yield a false negative if the true concentration is at the reporting limit and the reporting limit is set at the DL or LOD, respectively (i.e., a sample with a true concentration at the DL has a 50% chance of yielding a false negative, and a sample with a true concentration at the LOD has a 1% chance of yielding a false negative).*

The **Limit of Detection (LOD)** is defined as the lowest concentration empirically determined for reliable reporting of a non-detect of a specific analyte-matrix-method combination at 99% confidence. At the LOD, the false negative rate (Type II error) is 1% (green shaded region in Figure 1). In other words, if a sample has a true concentration at the LOD, there is at least a 99% confidence of reporting a "detection" (a measured value ≥ DL) and a 1% chance of falsely reporting a non-detect (a false negative).

For reporting purposes, the failure to obtain a "detection" should be reported as "<LOD," because the false negative rate at the LOD is only 1%.

The **Limit of Quantitation (LOQ)** is the smallest concentration that produces a quantitative result with known and recorded precision and bias. For DoW projects, the LOQ shall be set at or above the concentration of the lowest non-zero initial calibration standard and within the calibration range. Following the requirements of the QSM, the relationship between these values must follow:

$$DL \leq LOD \leq LOQ$$

Quantitative results, with a known degree of precision and bias, can only be achieved at or above the LOQ. Detections between the DL and the LOQ assure the *presence* of the analyte, but their numeric values are estimates and are therefore indicated as such on test reports. Figure 2 summarizes the differences and the relationship between the DL, LOD, and LOQ.

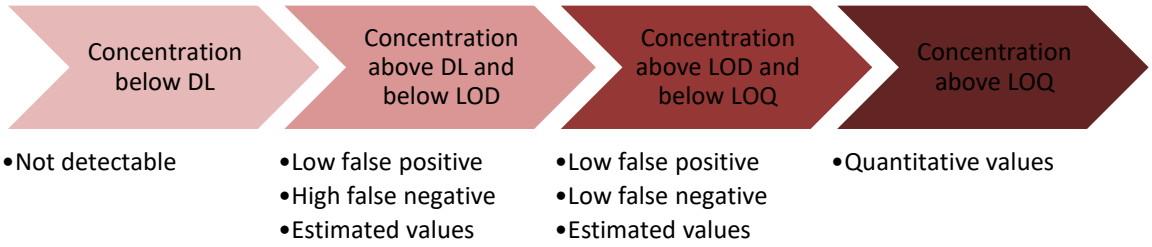


*Figure 2: Summary of data quality characteristics below and above the DL, LOD, and LOQ.*

## DoD QSM Requirements - Project Managers

Requirements for the DL, LOD and the LOQ are contained in DoD QSM Version 6.0 Module 4. Requirements that may be of note to Project Managers are:

- The DL, LOD, and LOQ shall be reported for all analyte-matrix-method combinations unless it is not applicable to the test or specifically excluded by project requirements.
- Laboratories are required to verify measures of sensitivity, in terms of the LOD and LOQ, at least quarterly unless otherwise stated.
- The laboratory procedure for establishing the LOQ shall empirically demonstrate precision and bias at the LOQ for each combination of analyte-matrix-method. The laboratory data package shall include the LOQ and associated precision and bias at the LOQ, where the determination of precision & bias at the LOQ is required for all DoW projects.

## Establishing Project-Specific Requirements for Method Sensitivity

Project teams should establish their project-specific requirements for method sensitivity in terms of a Project Action Limit (PAL) or a Project Screening Level (PSL) for each analyte-matrix-method combination. Per the EPA UFP-QAPP Manual, laboratory LOQs should be 3 to 10 times lower than PALs or PSLs. If the LOQ for a particular analytical method or laboratory cannot meet the PAL or PSL, then a project team has four options:

1. Consult with the laboratory to improve method performance or modify the method to achieve a lower LOQ.
2. Select a different laboratory or method with an LOQ less than or equal to the PAL or PSL.
3. Raise the PAL or PSL.
4. If no other options are available to meet project needs, discuss how the achievable sensitivity limit will contribute to uncertainty in project decisions and revisit the project Data Quality Objectives (DQOs).

Please note that precision and bias must be taken into consideration when assessing the LOQ versus the PAL or PSL. Also note that data below the PAL or PSL may be reported; however, they are estimated values if less than the LOQ. Although data reporting and qualification requirements are project-specific, all reported LOD and LOQ shall be adjusted for sample-specific factors (e.g., sample aliquot or weight of soil/sediment, final extraction volume, dilution factor, and percent moisture or percent solids).

## Reporting and Qualifying Analytical Data

The following example illustrates the proper use of the “U” and “J” data qualifiers for non-detect and estimated analytical results, respectively.

Data Qualifiers in this example are defined as:

- U- The analyte was not detected and is reported as less than the LOD. The LOD has been adjusted for any dilution or concentration of the sample.
- J- The reported result is an estimated value.

Example: Detection Limit (DL) = 2, Limit of Detection (LOD) = 4, Limit of Quantitation (LOQ) = 10, PAL or PSL for the project = 30, with precision and bias of the LOQ meeting precision and bias of the PAL or PSL. All samples are undiluted.

| | | |
|---|---|---|
| Sample #1: | Analytical Result: Non-detect | Reported Result: 4U |
| Sample #2: | Analytical Result: 3 | Reported Result: 3J |
| Sample #3: | Analytical Result: 5 | Reported Result: 5J |
| Sample #4: | Analytical Result: 15 | Reported Result: 15 |
| Sample #5: | Analytical Result: 30 | Reported Result: 30 |

Note that the laboratory may use additional data qualifiers or different letters or symbols to denote the qualifiers as long as they are appropriately defined within the laboratory data package, which is required by the DoD QSM.

## Understanding and Documenting Uncertainty for Low-Concentration Data

As mentioned above, detection and quantitation limits are laboratory specific. The following are some steps Project Managers can take to document measurement uncertainty for low concentration data.

- As part of the laboratory selection process, provide the laboratory with project-specific PAL or PSL, for each combination of analyte-matrix-method. Ask the laboratory to provide its DL, LOD, and LOQ with associated precision and bias for each target analyte in each combination of analyte-matrix-method and verify that these values meet project-specific PALs or PSLs. The project may request that the laboratory provide a detection and quantitation data package for review prior to sending samples to ensure the data will meet project needs.
- The project may ask the laboratory to verify the LOD by processing an LOD verification check sample with each batch of samples. This is a quality control sample that is spiked at a concentration at or slightly above the LOD to evaluate whether the analyte of interest is in fact “detectable” in the matrix of interest.
- If the project involves the collection of unusual or difficult matrices, or if the project-specific PAL or PSL is near the LOQ, ask the laboratory to verify the LOQ in the project-specific matrix by using the precision and bias recommended procedure outlined in the DoD QSM or by analyzing a minimum of four replicate samples with known concentrations at the LOQ.
- When reviewing low concentration results, if a result is reported above the DL, the signal to noise ratio and the relative concentrations of the sample and associated blank should be evaluated. This activity would typically be performed by a data validator on a subset of results during a Stage 4 validation and discussed as a project team during the data usability assessment.

## Types of Procedures for Estimating Sensitivity

Numerical estimates of the DL, LOD, or LOQ for a specific analyte-matrix- method combination can be determined using various statistical procedures, which involve spiking reagent water or other specific matrix with low concentrations of the analyte of interest.

### Estimator

The estimator that has been accepted for DoW/DOE projects with DoD QSM, Version 6.0 and commonly used by environmental laboratories is the EPA Method Detection Limit (MDL), which approximates the DL. EPA has defined the MDL as "*the minimum measured concentration of a substance* (analyte) *that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results*."[2] Calculating the MDL at 99% confidence means there is a 1% probability of a false positive when a sample has a result at the MDL. The EPA MDL was designed to protect against false positives; however, it does not protect against false negatives.

The EPA MDL procedure includes the requirements to determine and verify the MDL. The DoD QSM, Version 6.0 defines the procedures for determining and verifying the LOD and LOQ.

### Determining the DL

When performed correctly and consistently, MDLs determined using the EPA procedure can be useful for comparing the performance of different laboratories using the same methods or the performance of different methods within the same laboratory.

In 2017, the EPA updated the MDL procedure in 40 CFR Part 136 Appendix B, Revision 2 (commonly called MDL Rev. 2). This revision introduced new requirements for verifying the MDL and expanded the procedure to better reflect real-world laboratory conditions.

Under the MDL Rev. 2 procedure, the laboratory determines the MDL by preparing and analyzing low-level spikes (samples fortified with small, known amounts of target analyte) and method blanks (samples that do not knowingly contain the target analyte). These samples are prepared over multiple days, the samples are analyzed over multiple days, and when applicable analyzed on different instruments. This design helps capture normal day-to-day variation in laboratory performance, rather than producing a best-case scenario. The goal is to generate a more realistic picture of how sensitive a method truly is under routine operating conditions.

The MDL Rev. 2 procedure also includes provisions to account for various influence factors, such as: background contamination, sample preparation steps, instrument performance differences, analyst variability, and the analytical technology used.

[2] 40 Code of Federal Regulations (CFR) Part 136, Appendix B, Rev.2

Once the data is collected, the laboratory calculates the MDL for the low-level spikes, as well as the MDL for the method blanks. For method blanks, the laboratories will calculate the MDL depending on the data set, as specified by the EPA. The results used for the MDL calculation may not have statistical outliers removed. The MDL is then determined to be the greater of these two calculated values. These requirements ensure that the reported detection limit reflects the methods sensitivity, routine variability, and any background contamination that might affect the ability to detect very small amounts.

### Ongoing Verification of the DL

The MDL Rev. 2 procedure requires ongoing verification to confirm that the detection limits remain valid over time. Each quarter, in which samples are being analyzed, laboratories shall collect data from newly prepared low-level spikes and method blanks prepared as part of routine sample batches. The data are evaluated against acceptance criteria to verify that the method continues to perform at the expected sensitivity.

In addition, the MDL for the low-level spikes and method blank shall be recalculated and verified annually using this ongoing collected data to ensure that any changes in the laboratory's performance, equipment, or background contamination are reflected in the detection limit.

Laboratories are required to determine a DL for each combination of analyte-matrix-method, using a procedure compliant with 40 CFR Part 136 Appendix B, Revision 2 (EPA's MDL 2 Procedure).

### Determining the LOD and LOQ

After each DL determination, the laboratory shall determine the LOD and LOQ. It is specific to each combination of analyte-matrix-method using the combination of processes most likely to interfere with sensitivity (i.e., preparation method with all applicable cleanup steps including drying, grinding, and incremental sampling, where applicable).

The laboratory establishes the LOD by spiking a quality system (clean) matrix at a concentration greater than or equal to the DL. The analysis of the LOD spiked sample must meet requirements for detection of the analyte. The laboratory establishes the LOQ by spiking a quality system (clean) matrix at a concentration great than or equal to the LOD and greater than or equal to the lowest non-zero calibration standard. The analysis of the LOQ spiked sample must meet requirements on detection and recovery of the analyte.

The signal to noise (S/N) ratio at the LOD and LOQ should be at least three, and the results must meet all method requirements for analyte identification to be a valid LOD or LOQ determination.

Laboratories are required to determine the LOD and LOQ for each combination of analyte-matrix-method, following the requirements of the QSM.

### Ongoing Verification of the LOD and LOQ

Once the LOD and LOQ are determined the laboratory is required to verify the LOD and LOQ to ensure they remain valid over time. Typically, the ongoing LOD and LOQ verifications are performed quarterly, except in DoD QSM defined instances where quarterly verification is not required. The LOD and LOQ ongoing verification must meet all method requirements for analyte identification and S/N acceptance criteria of the initial LOD and LOQ defined by the DoD QSM.

If the laboratory has multiple instruments that use the same LOD and LOQ, then the LOD and LOQ verification is performed on each instrument. The results of the verifications on each instrument must meet acceptance criteria to be a valid verification.

The LOQ and associated precision and bias must meet the laboratories' established acceptance criteria and meet client requirements when available. At a minimum, the precision and bias associated with the LOQ is updated annually by the laboratory and should be available to the customer upon request.

If the laboratory modifies the method, it may be determined that the LOD and LOQ will need to be reverified following the requirements of the DoD QSM. Following modifications that would require a new LOQ be determined, the associated precision and bias at the LOQ must be demonstrated and should be available to the customer upon request.

Laboratories are required to verify the LOD and LOQ determinations for each combination of analyte-matrix-method and annually update the precision and bias following the requirements of the QSM. The results are available to the laboratory's customers upon results.