

Water Research Centre Procedure for the Determination of L_C and L_D (and ISO/IUPAC determination of L_Q)

Introduction

The Water Research Centre (WRC) in England included a procedure for the estimation of detection limits in the first edition of "Manual on Analytical Quality-Control for the Water Industry."(1) The procedure was based on the definitions for detection of small concentrations given in the papers by A.L. Wilson (2) and L.A. Currie (3). These definitions and procedures for estimating detection used by the Water Research Centre are the same as those approved by the International Union of Pure and Applied Chemistry (IUPAC) (4). While the equations are the same, the terminology used by the WRC and IUPAC are different. Since the IUPAC terminology is better known in the U.S., it is used in the following procedure. Like IUPAC, the WRC uses default values for alpha and beta of 0.05 in their definitions, and, like IUPAC, one can specify different alpha and beta values if desired.

Definitions and Procedure for calculating L_C and L_D

The critical value, L_C , and the detection limit, L_D , are calculated from the following equations:

$$L_C = 2.33\sigma_{wb} \text{ and } L_D = 4.65 \sigma_{wb}$$

where σ_{wb} is the within batch standard deviation of the blank (the term "within-batch" signifies analyses made under the same experimental conditions at essentially the same time)

For samples of a population, when the population standard deviation, σ_{wb} , is not known, the following equations are used:

$$L_C = t_{0.1}(\sqrt{2})s_{wb} \text{ and } L_D = 2 t_{0.1}(\sqrt{2})s_{wb}$$

where $t_{0.1}$ = the 10% point of the t-distribution (2-sided table)

and s_{wb} is the estimate of the population within batch standard deviation

s_{wb} is calculated from a series of duplicate determinations, using the following pooling equation:

$$s_{wb} = \sqrt{(\sum D^2/2m)}$$

where D = the positive difference between each pair of results

and m = the number of pairs of results

Example Calculation

The following example for a spectrophotometric method is taken from the "Manual on Analysis for Water Pollution Control" (5)

Day	1	2	3	4	5	6	7	8	9	10
Blank 1	0.034	0.026	0.031	0.037	0.035	0.033	0.023	0.031	0.034	0.028
Blank 2	0.038	0.029	0.031	0.035	0.036	0.029	0.025	0.030	0.034	0.026
Difference between blanks	0.004	0.003	0.000	0.002	0.001	0.004	0.002	0.001	0.000	0.002

In this example, $m = 10$

substituting a value of $m = 10$ and the values of the differences into the equation $s_{wb} = \sqrt{(\sum D^2/2m)}$

we obtain $s_{wb} = 0.00166$ mg/L

Then, since for 10 degrees of freedom $t_{0.1} = 1.81$,

we calculate $L_C = t_{0.1}(\sqrt{2})s_{wb} = 1.81(1.41)(0.00166) = 0.00425$ mg/L

and $L_D = 2 t_{0.1}(\sqrt{2})s_{wb} = 2(1.81)(1.41)(0.00166) = 0.0085$ mg/L

The above definitions and calculations are based on the following assumptions, which may not always hold:

1. that the within-batch standard deviations of both the blank and samples containing very small concentrations of the analyte are the same
2. that the sample and blank are not biased with respect to each other (that is, there are no interfering substances in the sample or the blank)
3. that the analytical response is not zero for finite concentrations of the analyte

If any one of the assumptions is not true, then the limit of detection cannot be calculated using the equations given above.

The reader is referred to an analysis presented by Currie for corrections when assumptions 1 and 2 are not met. (4)(8)(9) In this analysis, adjustments can be made to allow for differences in the standard deviation for blank and sample responses ($\sigma_{wb} \neq \sigma_s$; called heteroscedasticity) and for different values for error of the 1st and 2nd kinds. Also, when systematic error cannot be assumed negligible, the limit of detection must be increased by an amount, $2 \Delta_m$, where Δ_m is assumed upper bound for the bias

i.e. $L_C' = L_C + \Delta_m$ and $L_D' = 2 L_C'$

When assumption 3 is not valid and the analytical response is zero for finite concentrations of analyte, then $\sigma_{wb} = 0$ and the special case described by Currie holds. (3) Currie states that "In this case, the effect is profound. L_C is necessarily zero, and any net positive signal definitely indicates detection ($\alpha=0$), $L_D=k\beta\sigma_D$, and $L_Q=k_Q\sigma_Q$ where σ_D and σ_Q now depend on the net signal only."

Due to the great variety of circumstances that may arise if the assumptions do not hold, it is difficult to produce a single set of instructions for all possible conditions. In these instances, the references cited should be consulted and procedures should be prepared that are method-specific.

It is worth noting that the Standing Committee of Analysts in Great Britain has adopted a policy of including an estimate of the limit of detection (or the within-batch standard deviation of the blank, which is used to calculate the limit of detection) as one of the "Performance Characteristics of the Method", and several of these estimates have been published.

Limit of Quantification, L_Q

The ISO/IUPAC equation for the limit of quantification also includes the within-batch standard deviation of the blank. The concentration for the limit of quantification is set at a concentration where the relative standard deviation is equal to 10%. This definition also assumes that the within-batch

standard deviations of the blank and samples containing very small concentrations of the analyte are the same, and specifically that the standard deviation is the same at L_Q as at L_C and L_D .

Thus, according to IUPAC (4) $L_Q = 10\sigma_{wb}$ or $3.1(4.65\sigma_{wb})$ (i.e., $3.1L_D$) in the case of a well known blank (10% RSD).

For the case of paired observations, $L_Q = 14.1\sigma_{wb}$ (multiply the value by $\sqrt{2}$ to account for the variability of the blank response).

So, for the above example, one can calculate the limit of quantification:

$$L_Q = 3.1(2t_{0.1})(\sqrt{2})s_{wb} = 3.1(2)(1.81)(1.41)(0.00166) = 0.0263 \text{ mg/L}$$

Finally, the WRC normally included the estimation of the within-batch standard deviation of the blank and the detection limit as part of an experimental design for precision and some sources of bias. This experimental design also estimated the within-batch standard deviations for standard solutions and samples and estimated whether bias due to interference was present. This experimental design is described in the most recent edition of "A Manual on Analytical Quality Control for the Water Industry" (6), as well as in the book "The Chemical Analysis of Water" (7). Parts of this experimental design could be used when evaluating those parameters and methods when modifications in the basic procedure are judged necessary.

References

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- (4) "Nomenclature in Evaluation of Analytical Methods Including Detection and Quantification Capabilities", prepared for publication by Lloyd A. Currie, *Pure & Appl. Chem.*, Vol. 67, No. 10, pp. 1699-1723, 1995.
- (5) Ekedahl, G., Røndell, B., and Wilson, A.L., "Chapter on Analytical Errors" in the "Manual on Analysis for Water Pollution Control", World Health Organization, Regional Office for Europe, 1974.
- (6) Cheeseman, R.V. and Wilson, A.L. (Revised by M.J. Gardner), "A Manual on Analytical Quality Control for the Water Industry", Water Research Centre publication NS 30, June 1989.
- (7) Hunt, D.T.E. and Wilson, A.L., "The Chemical Analysis of Water", 2nd edition, The Royal Society of Chemistry, Burlington House, London, W1V 0BN, 1986.
- (8) Currie, L.A., in "Treatise On Analytical Chemistry, Part 1, Volume 1, 2nd edition; Kolthoff, I.M and Elving, P.E. Eds.; John Wiley & Sons: New York, 1978; Chapter 4.
- (9) Currie, L.A., Ed., "Detection in Analytical Chemistry: Importance, Theory and Practice", ch. 1, ACS Symposium Series 361, American Chemical Society, Washington (1988).