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Standard Guide for Developing Appropriate Statistical Approaches for Groundwater Detection Monitoring Programs at Waste Disposal Facilities[1]

This standard is issued under the fixed designation D6312; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

~~ε[1] NOTE—Editorial changes were made throughout in February 2012.~~

1. ~~Scope~~ Scope*

1.1 This guide covers the context of groundwater monitoring at waste disposal facilities. Regulations have required statistical methods as the basis for investigating potential environmental impact due to waste disposal facility operation. Owner/operators must typically perform a statistical analysis on a quarterly or semiannual basis. A statistical test is performed on each of many constituents (for example, 10 to 50 or more) for each of many wells (5 to 100 or more). The result is potentially hundreds, and in some cases, a thousand or more statistical comparisons performed on each monitoring event. Even if the false positive rate for a single test is small (for example, 1 %), the possibility of failing at least one test on any monitoring event is virtually guaranteed. This assumes you have ~~done~~performed the ~~correct statistic~~statistics correctly in the first place.

1.2 This guide is intended to assist regulators and industry in developing statistically powerful groundwater monitoring programs for waste disposal facilities. The purpose of this guide is to detect a potential groundwater impact from the facility at the earliest possible time while simultaneously minimizing the probability of falsely concluding that the facility has impacted groundwater when it has not.

1.3 When applied inappropriately, existing regulation and guidance on statistical approaches to groundwater monitoring often suffer from a lack of statistical clarity and often implement methods that will either fail to detect contamination when it is present (a false negative result) or conclude that the facility has impacted groundwater when it has not (a false positive). Historical approaches to this problem have often sacrificed one type of error to maintain control over the other. For example, some regulatory approaches err on the side of conservatism, keeping false negative rates near zero while false positive rates approach 100 %.

1.4 The purpose of this guide is to illustrate a statistical groundwater monitoring strategy that minimizes both false negative and false positive rates without sacrificing one for the other.

1.5 This guide is applicable to statistical aspects of groundwater detection monitoring for hazardous and municipal solid waste disposal facilities.

1.6 It is of critical importance to realize that on the basis of a statistical analysis alone, it can never be concluded that a waste disposal facility has impacted groundwater. A statistically significant exceedance over background levels indicates that the new measurement in a particular monitoring well for a particular constituent is inconsistent with chance expectations based on the available sample of background measurements.

1.7 Similarly, statistical methods can never overcome limitations of a groundwater monitoring network that might arise due to poor site characterization, well installation and location, sampling, or analysis.

1.8 It is noted that when justified, intra-well comparisons are generally preferable to their inter-well counterparts because they completely eliminate the spatial component of variability. Due to the absence of spatial variability, the uncertainty in measured concentrations is decreased, making intra-well comparisons more sensitive to real releases (that is, false negatives) and false positive results due to spatial variability are completely eliminated.

[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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***A Summary of Changes section appears at the end of this standard**

1.9 Finally, it should be noted that the statistical methods described here are not the only valid methods for analysis of groundwater monitoring data. They are, however, currently the most useful from the perspective of balancing site-wide false positive and false negative rates at nominal levels. A more complete review of this topic and the associated literature is presented by Gibbons (**1**).[2]

1.10 The values stated in ~~both inch-pound and~~ SI units are to be regarded as ~~the standard. The values given in parentheses are for information only.~~standard. No other units of measurement are included in this standard.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.12 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

3. Terminology

~~3.1 *Definitions:*~~

~~3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.~~

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*Definitions of Terms from D653 that are used in this standard and are provided for the user.

3.2.1 *assessment monitoring program, n*—groundwater monitoring that is intended to determine the nature and extent of a potential site impact following a verified statistically significant exceedance of the detection monitoring program.

3.2.2 *combined Shewhart (CUSUM) control chart, n*—a statistical method for intra-well comparisons that is sensitive to both immediate and gradual releases.

3.2.3 *detection limit (DL), n*—the true concentration at which there is a specified level of confidence (for example, 99 % confidence) that the analyte is present in the sample (**2**).

3.2.4 *detection monitoring program, n*—groundwater monitoring that is intended to detect a potential impact from a facility by testing for statistically significant changes in geochemistry in a downgradient monitoring well relative to background levels.

3.2.5 *intra-well comparisons, n*—a comparison of one or more new monitoring measurements to statistics computed from a sample of historical measurements from that same well.

3.2.6 *inter-well comparisons, n*—a comparison of a new monitoring measurement to statistics computed from a sample of background measurements (for example, upgradient versus downgradient comparisons).

~~3.2.7 *prediction interval or limit, n*—a statistical estimate of the minimum or maximum concentration, or both, that will contain the next series of *k* measurements with a specified level of confidence (for example, 99 % confidence) based on a sample of *n* background measurements.~~

3.2.7 *quantification limit (QL), n*—the concentration at which quantitative determinations of an analyte's concentration in the sample can be reliably made during routine laboratory operating conditions (**3**).

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *false negative rate, n—in detection monitoring*, the rate at which the statistical procedure does not indicate possible contamination when contamination is present.

3.3.2 *false positive rate, n—in detection monitoring*, the rate at which the statistical procedure indicates possible contamination when none is present.

3.3.3 *nonparametric, adj*—a term referring to a statistical technique in which the distribution of the constituent in the population is unknown and is not restricted to be of a specified form.

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[2] The boldface numbers given in parentheses refer to a list of references at the end of the text.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.3.4 *nonparametric prediction limit, n*—the largest (or second largest) of *n* background samples. The confidence level associated with the nonparametric prediction limit is a function of *n* and ~~*k*~~*k.*~~.~~

3.3.5 *parametric, adj*—a term referring to a statistical technique in which the distribution of the constituent in the population is assumed to be known.

3.3.6 *prediction interval or limit, n*—a statistical estimate of the minimum or maximum concentration, or both, that will contain the next series of *k* measurements with a specified level of confidence (for example, 99 % confidence) based on a sample of *n* background measurements.

3.3.7 *verification resample, n*—in the event of an initial statistical exceedance, one (or more) new independent sample is collected and analyzed for that well and constituent which exceeded the original limit.

3.4 *Symbols:*

3.4.1 α—the false positive rate for an individual comparison (that is, one well and constituent).

3.4.2 α^*—the site-wide false positive rate covering all wells and constituents.

3.4.3 k—the number of future comparisons for a single monitoring event (for example, the number of downgradient monitoring wells multiplied by the number of constituents to be monitored) for which statistics are to be computed.

3.4.4 n—the number of background measurements.

3.4.5 σ^2—the true population variance of a constituent.

3.4.6 s—the sample-based standard deviation of a constituent computed from *n* background measurements.

3.4.7 s^2—the sample-based variance of a constituent computed from *n* background measurements.

3.4.8 μ—the true population mean of a constituent.

3.4.9 $\bar{x}$—the sample-based mean or average concentration of a constituent computed from *n* background measurements.

4. Summary of Guide

4.1 This guide is summarized in Fig. 1, which provides a flowchart illustrating the steps in developing a statistical monitoring plan. The monitoring plan is based either on background versus monitoring well comparisons (for example, upgradient versus downgradient comparisons or intra-well comparisons, or a combination of both). Fig. 1 illustrates the various decision points at which the general comparative strategy is selected (that is, upgradient background versus intra-well background) and how the statistical methods are to be selected based on site-specific considerations. The statistical methods include parametric and nonparametric prediction limits for background versus monitoring well comparisons and combined Shewhart-CUSUM control charts for intra-well comparisons. Note that the background database is intended to expand as new data become available during the course of monitoring.

5. Significance and Use

5.1 The principal use of this guide is in groundwater detection monitoring of hazardous and municipal solid waste disposal facilities. There is considerable variability in the way in which existing ~~Guide USEPA~~ regulation and guidance are interpreted and practiced. Often, much of current practice leads to statistical decision rules that lead to excessive false positive or false negative rates, or both. The significance of this proposed guide is that it jointly minimizes false positive and false negative rates at nominal levels without sacrificing one error for another (while maintaining acceptable statistical power to detect actual impacts to groundwater quality (**4**)).

5.2 Using this guide, an owner/operator or regulatory agency should be able to develop a statistical detection monitoring program that will not falsely detect contamination when it is absent and will not fail to detect contamination when it is present.

6. Procedure

NOTE 1—In the following, an overview of the general procedure is described with specific technical details described in Section 6.

6.1 *Detection Monitoring:*

6.1.1 *Upgradient Versus Downgradient Comparisons:*

6.1.1.1 Detection frequency ≥50 %.

6.1.1.2 If the constituent is normally distributed, compute a normal prediction limit (**5**) selecting the false positive rate based on number of wells, constituents, and verification resamples (**6**) adjusting estimates of sample mean and variance for nondetects.

6.1.1.3 If the constituent is lognormally distributed, compute a lognormal prediction limit (**7**).

6.1.1.4 If the constituent is neither normally nor lognormally distributed, compute a nonparametric prediction limit (**7**) unless background is insufficient to achieve a 5 % site-wide false positive rate. In this case, use a normal distribution until sufficient background data are available (**7**).

6.1.1.5 If the background detection frequency is greater than zero but less than 50 %.

6.1.1.6 Compute a nonparametric prediction limit and determine if the background sample size will provide adequate protection from false positives.

6.1.1.7 If insufficient data exist to provide a site-wide false positive rate of 5 %, more background data must be collected.

Development of a Statistical Detection Monitoring Plan

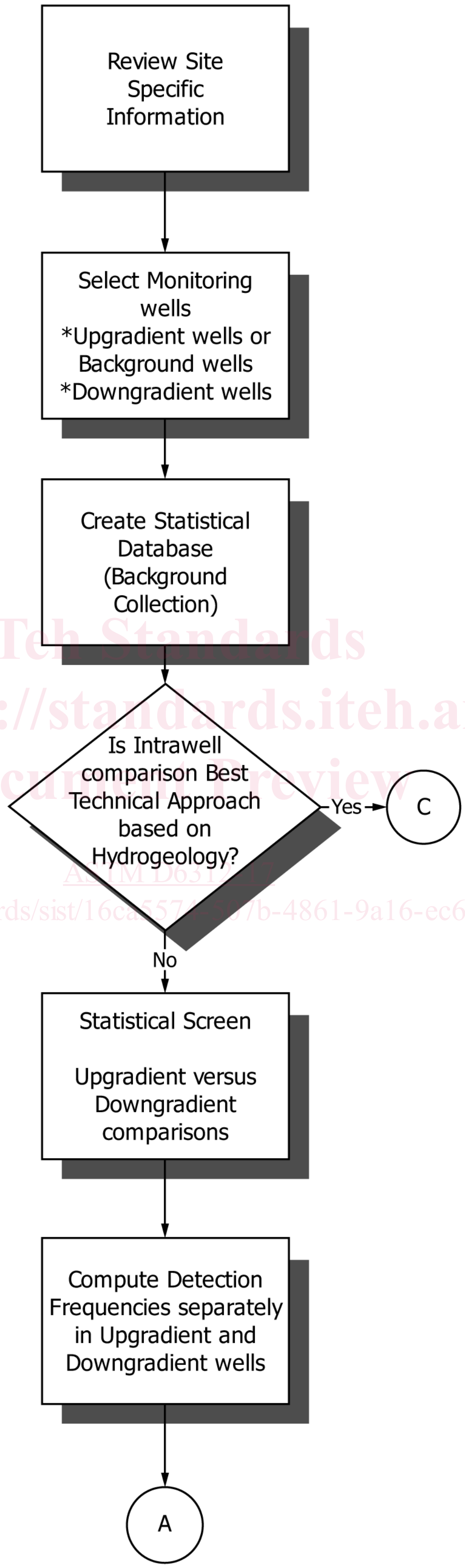

FIG. 1 Development of a Statistical Detection Monitoring Plan

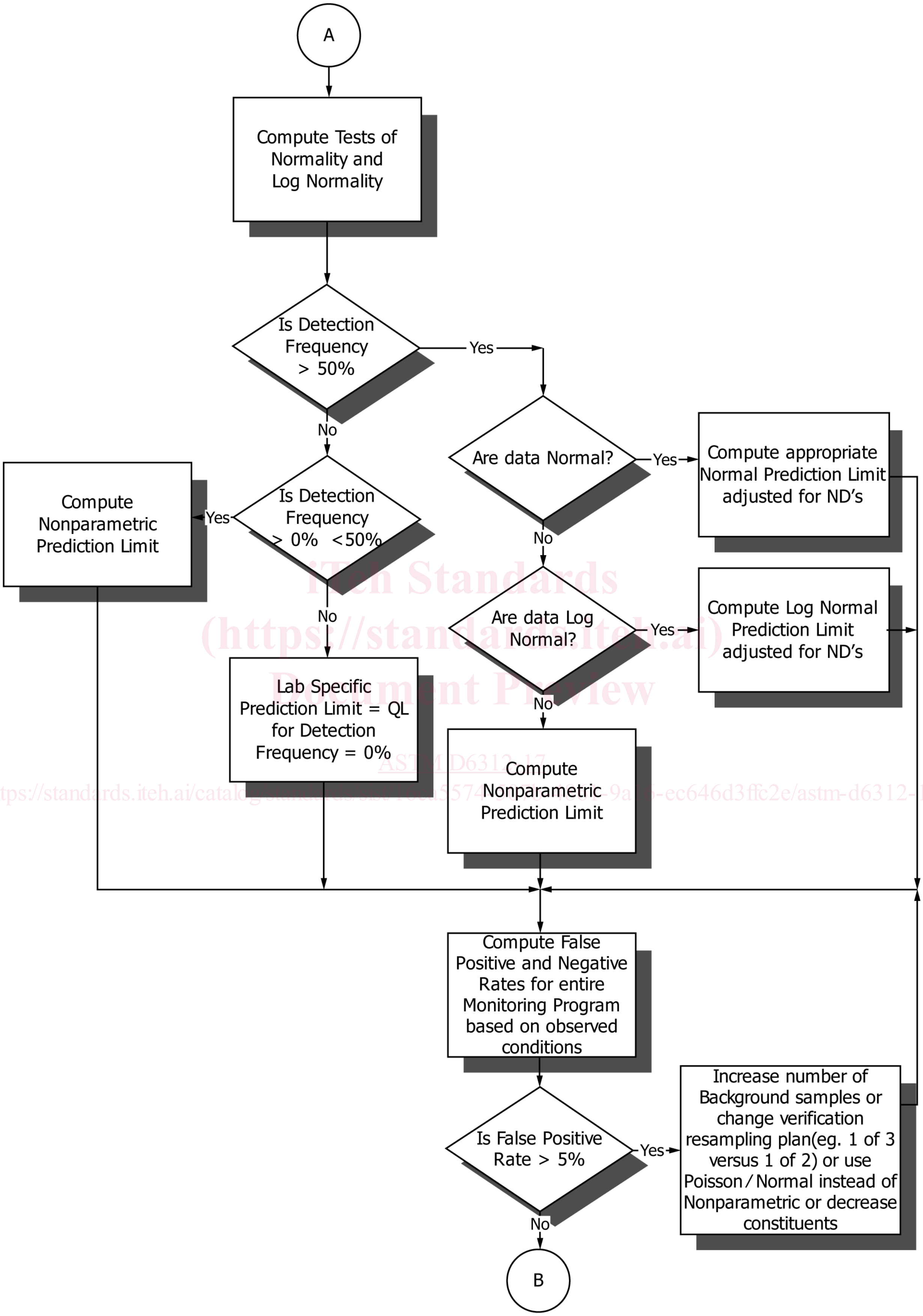

FIG. 1 *(continued)*

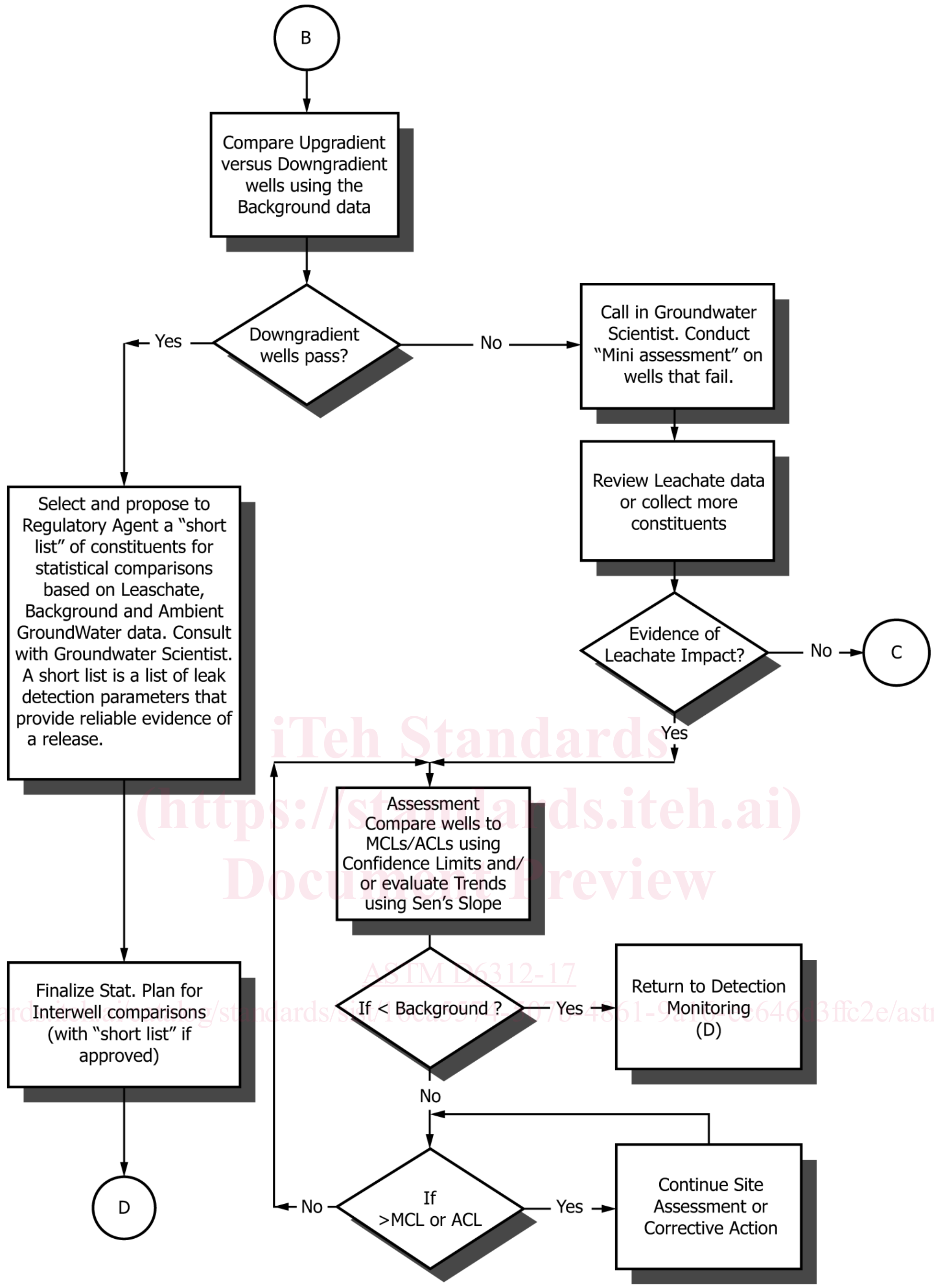

FIG. 1 *(continued)*

6.1.1.8 As an alternative to 6.1.1.7 use a Poisson prediction limit which can be computed from any available set of background measurements regardless of the detection frequency (see 3.3.4 of Ref (**4**)).

6.1.1.9 If the background detection frequency equals zero, use the laboratory-specific QL (recommended) or limits required by applicable regulatory agency (**8**).[4]

6.1.1.10 This only applies for those wells and constituents that have at least 13 background samples. Thirteen samples provide a 99 % confidence nonparametric prediction limit with one resample for a single well and constituent (see Table 1).

6.1.1.11 If less than 13 samples are available, more background data must be collected to use the nonparametric prediction limit.

6.1.1.12 An alternative would be to use a Poisson prediction limit that can be computed from four or more background measurements regardless of the detection frequency and can adjust for multiple wells and constituents.

[4] Note, if background detection frequency is zero, one should question whether the analyte is a useful indicator of contamination. If it is not, statistical testing of the constituent should not be performed.