CHAPTER 4
Remedial Design and Remedial Action

4.1. Introduction. During the RD/RA phase, engineers develop detailed designs for remedial actions, construct remediation systems, and operate and monitor sites with long-term remedies in place. The term remedial system is defined here in a broad sense; it includes removal actions and capping as well as more active treatment systems.

4.1.1. A number of statistical approaches that are applicable for prior stages of a project's life cycle are also applicable for the RD/RA. This Chapter will address environmental statistical applications for the RD/RA that have not been highlighted for the PA, SI, or RI/FS. In this Chapter, we consider adaptive sampling plans for removal actions and groundwater monitoring and trend analysis.

4.1.2. Although groundwater is most commonly subject to long-term monitoring, the same tools can be used to monitor and optimize remedial systems for other environmental media or demonstrate achievement of site closure criteria.

4.2. Comparisons to ACLs and MCLs. Confirmation sampling is often performed for the RD/RA and would typically entail one-sample statistical tests. These would be the same types of tests that would be conducted during the SI and RI, only the nature of the decision limits would differ (e.g., the decision limits for the RD/RA would be "cleanup goals" rather than the risk-based screening concentrations as in the SI).

4.2.1. As an example, consider data collected at a landfill. If a statistically significant difference is observed between upgradient and downgradient concentrations, a compliance monitoring program must be put into place. According to RCRA regulations, analysis of Appendix IX list constituents is required. Assuming that a release is confirmed, the facility must demonstrate that the release does not present a health or environmental risk. Generally, this entails comparing analytical results to fixed threshold values, called Alternate Concentration Limits (ACLs), which are often established in a jurisdiction-specific fashion. An alternative approach is to compare site data to MCLs. In the first case, tolerance or confidence intervals are recommended. In the second case, the tolerance limit is the preferred method.

4.2.2. An appropriate one-sample statistical test is to determine whether contamination exceeds the decision limit (e.g., an MCL). For example, if a set of measured contaminant concentrations is normal, a one-sample *t*-test could be used to compare the mean concentration to the decision limit. However, a reliable comparison using a one-sample test will not be possible if the data set is small (e.g., consists of only three points). If normality of the data set can be assumed, a conservative approach would consist of calculating an UTL and comparing it to the decision limit. If the UTL were less than the decision limit, there would be strong evidence that site contamination does not exceed the decision limit. *However, do not conclude that there is a contami-*

nation problem when the UTL exceeds the decision limit. To avoid false positives, when the UTL exceeds the decision limit, additional data should be collected to do an appropriate one-sample statistical test.

4.2.3. The confidence limit approach is used for comparisons to ACLs based on background data, whereas the tolerance limit approach is used when the comparison criteria are health-based and the comparisons are in relation to MCLs or health-based ACLs. The tolerance limit approach is more conservative than the confidence limit approach in that the UTL must be less than the MCL. However, Gibbons (1994) has pointed out the following.

4.2.4. Because at most four independent samples will be available during semiannual monitoring, the 95% confidence, 95% coverage tolerance limit is approximately five standard deviation units above the mean concentration. In light of this, even if all four semiannual measurements for a given compliance are well below the MCL, the tolerance limit will invariably exceed the MCL or health-based ACL and never-ending corrective action will be required.

4.2.5. Thus, special care must be taken in the design of compliance monitoring programs to ensure that the facility is not caught in the kind of regulatory trap described above.

4.2.6. In addition to one-sample statistical tests, multi-sample statistical tests can be appropriate for the RD/RA to perform comparisons with background values. Since long-term monitoring is commonly performed for groundwater during the RD/RA, Figures 4-1 through 4-5 summarize the types of one-sample and two-sample statistical tests that would be used for groundwater monitoring.

Section I
Groundwater Monitoring and Optimization Trend Analysis

4.3. Introduction. Monitoring remedial systems have significant, long-term costs. It is not difficult to anticipate that, over the course of 10 to 20 years, substantial economic resources available for environmental programs at military installations will be in long-term monitoring of sites actively under remediation or sites that require long-term monitoring. Project planners should ensure that these monitoring systems are optimized, and that they provide the necessary information at the least possible cost. Likewise, where active remediation is ongoing, optimization is important to minimize economic impacts to the facility. While optimization is desirable, compliance is mandatory, and at most installations, groundwater monitoring is required under various permits or consent agreements. This section reviews various methods of assessing groundwater systems over time with a view to both detection and compliance, and optimization.

4.4. Detection and Compliance Monitoring. Detection monitoring is a means of identifying whether a regulated hazardous waste site is releasing hazardous materials into the environment. Compliance monitoring entails the repetitive, periodic sampling and analysis of a select set of monitoring locations for compliance with a fixed set of standards or requirements. The standards to which analytical results are compared are generally specified in regulations, permits, or consent agreements.

4.4.1. In detection monitoring, the results of sampling and analysis from a location that has recorded a release are compared to measurements from an unaffected or background location. In the case of groundwater monitoring, this generally entails selecting one or more monitoring wells upgradient of the site and selecting a representative set of downgradient monitoring wells. If the difference between the two sets of results is statistically significant, the owner is usually required to begin compliance monitoring to investigate how the release is occurring and to remedy the situation. These statistics fall into the category of hypothesis tests, specifically two- or multiple-population tests, and are addressed in Appendices M and N.

4.4.2. The selection of the statistical approach is generally open to discussion with regulators and the final determination will depend upon many factors. In general terms, the simplest approach (consistent with the requirements of local jurisdictions) is the best approach. For example, for detection monitoring, a two-sample *t*-test could potentially be used to compare upgradient (background) to downgradient (site) contaminant concentrations. Under the best of circumstances, a straightforward, parametric *t*-test would suffice; however, in practical terms, it is rare that environmental data meet all of the conditions that would make such a straightforward approach viable. And, in fact, by the time Figure 4-2 was published in EPA 530-SW-89-026, the use of the *t*-test had been largely discredited for this application because it failed to adequately control false positives when multiple site and background comparisons are required. Clearly, as of the time of its publication, the 1989 guidance recommended the use of ANOVA techniques (essentially a generalization of the two-sample *t*-test), and, to a lesser extent, alternatives such as tolerance intervals, prediction intervals, and control charting. By 1992, with the publication of *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities—Addendum to Interim Final Guidance* (EPA 68-W0-0025), a somewhat different statistical approach was highlighted. Preferences had shifted further with the use of intervals and resampling strategies receiving much greater attention. By 1994, when Gibbons published *Statistical Methods for Groundwater Monitoring*, ANOVA techniques had largely fallen out of use, replaced by prediction intervals with resampling strategies that have become, in some cases, very complex. This statistical approach currently represents what might be called the state-of-the-art for groundwater.

4.4.3. The alternative approach of using control charts has not gone altogether out of favor, however. A control chart is a type of plot (using data from a particular monitoring well) of some function of concentration (e.g., the mean concentration) versus time. The various statistical tests previously discussed are based on one of two possible approaches for detection monitoring. With the exception of the control chart approach, each new downgradient result is compared to the history (or historical data set) of upgradient results. These types of comparisons are called interwell (literally, "*between well*") comparisons. A potential flaw in this approach is that it assumes the only variable that can make a difference between the upgradient and downgradient results is the intervening waste management unit. In reality, there are a number of other possible influences and, for this reason, intrawell (literally, "*within well*") comparisons are still considered quite useful in groundwater monitoring applications. The classic method of performing these *intrawell* comparisons is with control charting. The two types of control charts normally employed for these purposes are the Shewart and cumulative summation (CUSUM) control charts, which are often combined in normal use.

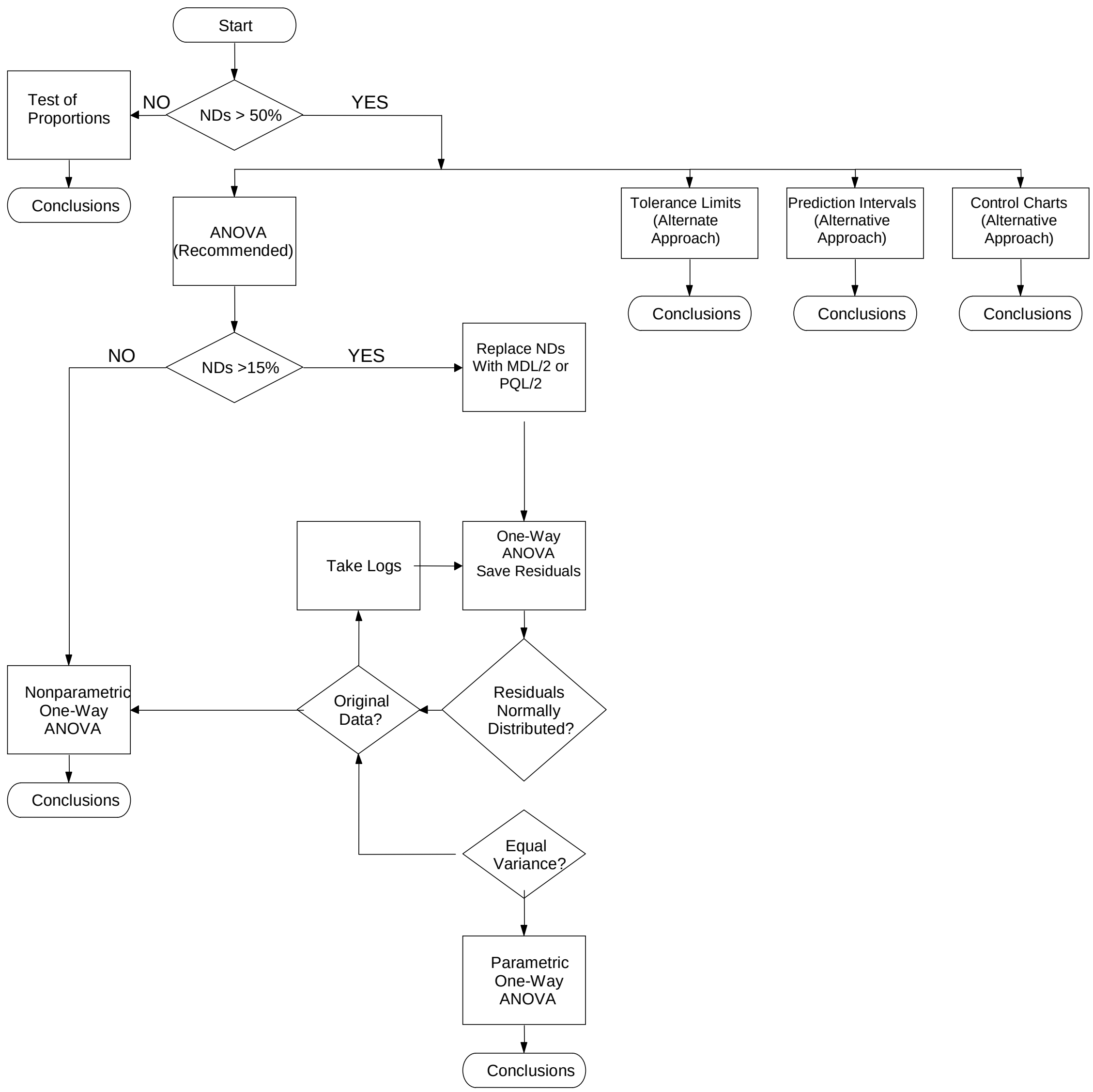

Figure 4-1. 1989 EPA decision tree for groundwater monitoring.

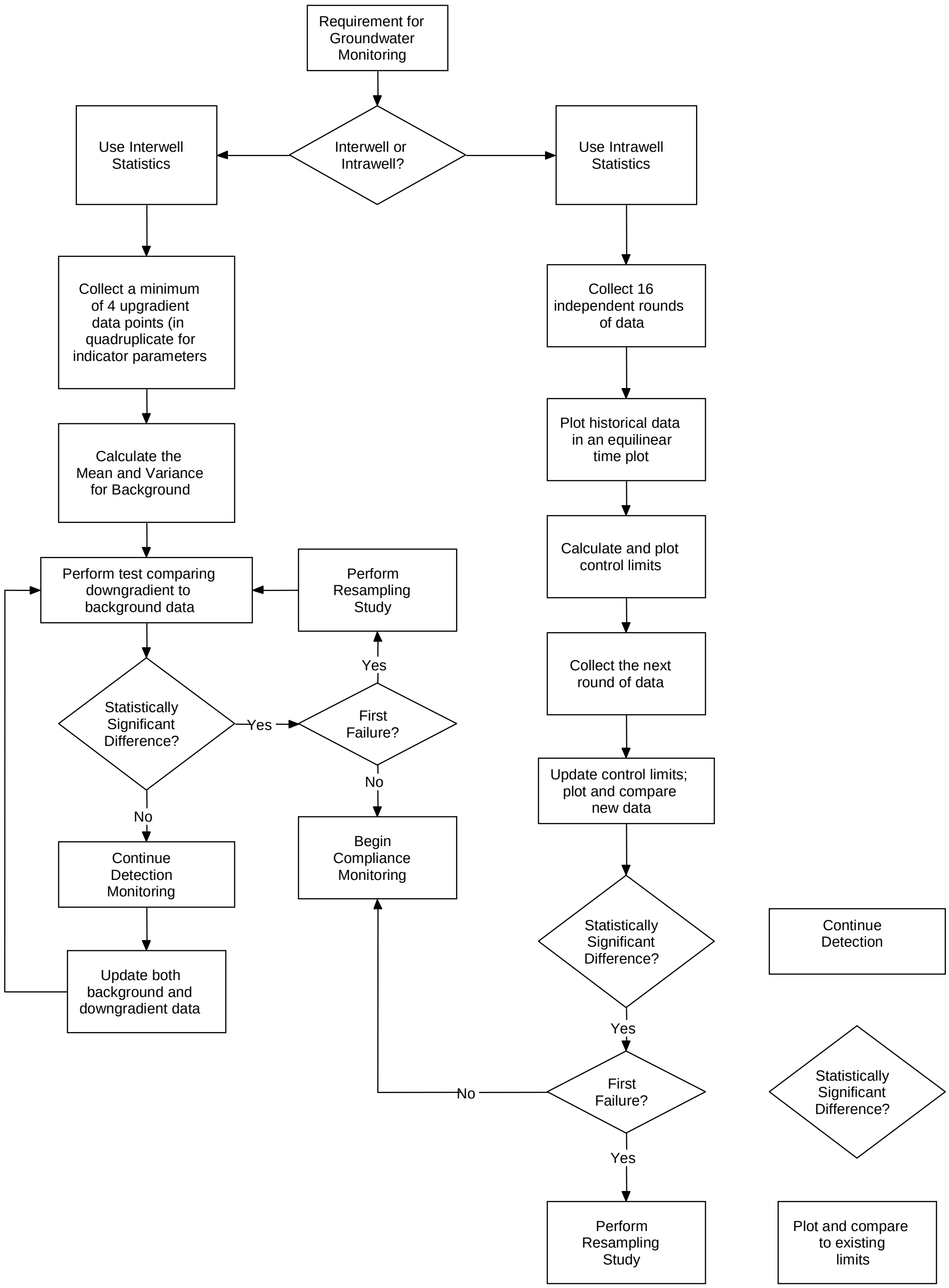

Figure 4-2. Statistical decision tree with options for groundwater monitoring—Part 1.

4.4.4. Figures 4-1 through 4-5 present flow charts showing the options available and guidance on option selection. However, the decision regarding the type of statistical analysis program to employ should be made as part of the DQO development process for the monitoring effort. It is strongly recommended that the Project Manager involve a statistician in this process.

4.4.5. Case study 1 provides an example in which multiple techniques are used to assess groundwater monitoring data. Case study 2 provides an example of using a combined Shewart/CUSUM method to identify a release at a site.

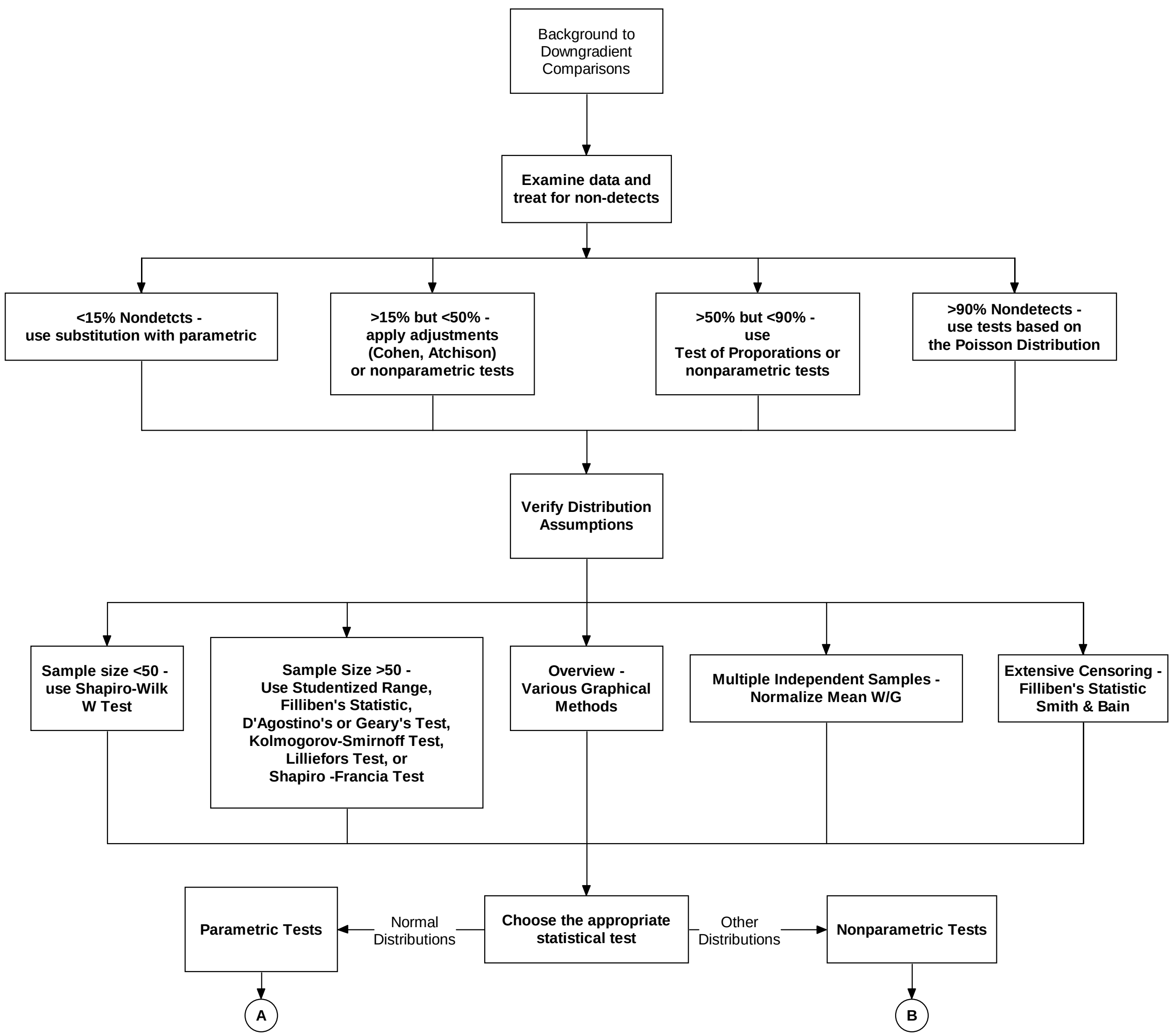

Figure 4-3. Statistical decision tree with options for groundwater monitoring—Part 2.

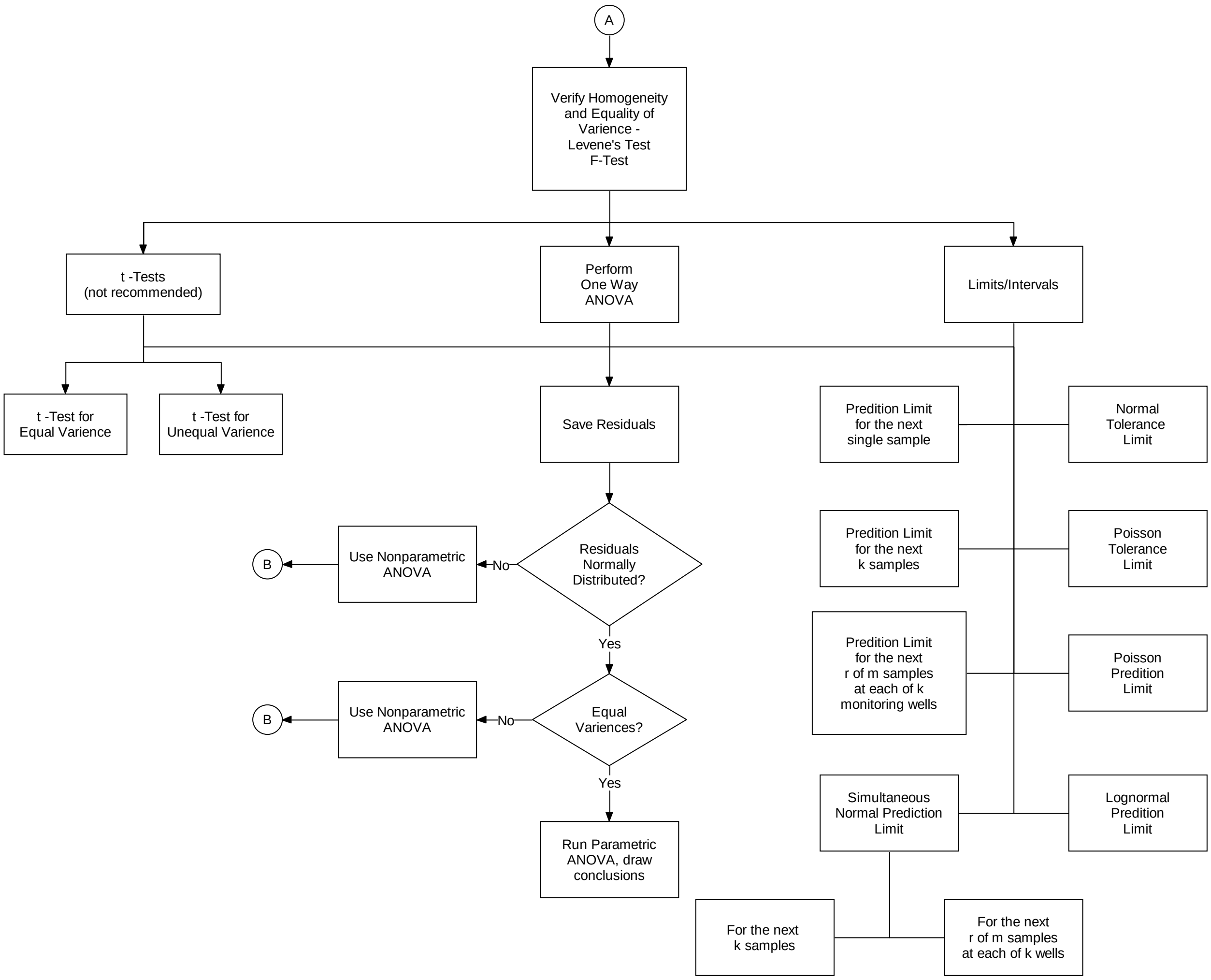

Figure 4-4. Statistical decision tree with options for groundwater monitoring—Part 3.

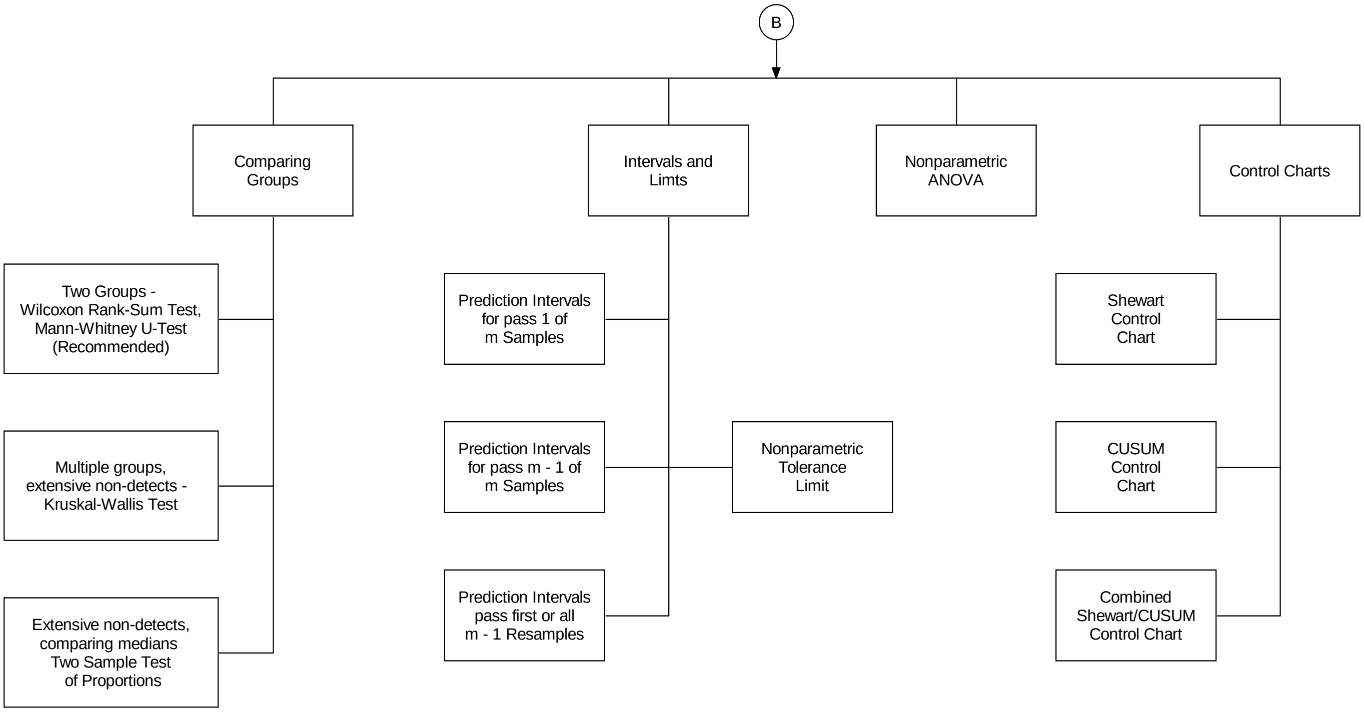

Figure 4-5. Statistical decision tree with options for groundwater monitoring—Part 4.

4.5. Case Study 1—Groundwater Monitoring. At a manufacturing facility in Virginia, a long-standing tetrachloroethene (PCE) plume is being hydrologically contained and treated with a combination of vapor extraction and groundwater pump-and-treat. The facility has been engaged in long-term monitoring for over 20 years and uses a variety of techniques to assess permit compliance. Sample statistics allow the facility to determine whether remediation at the site is causing reductions in PCE concentrations. Table 4-1 presents an example of summary statistics and testing results in a fashion that is easily understood for both compliance and detection monitoring.

4.5.1. For compliance monitoring at wells with known past contamination (MW1 to MW4), increasing or decreasing statistical trends were determined at the 90 and 95% level of confidence, respectively, as negotiated with state regulators at the site.

4.5.2. Trend analyses, control charts, and tolerance limits are being used for the four wells under the category "Comp" and for the three wells under the category "Trend." Typically, differing DQOs would be set for compliance and detection wells and only one set of statistical tests would be performed. However, the regulatory negotiations at this site mandated identical tests for both types of wells. (This example demonstrates an opportunity for improving past negotiated monitoring with regulators.)

4.5.3. Additionally, the number of detections greater than the "tolerance limit" is specified for each well. The 95% UTL is constructed from a set of background wells, also as determined in the site permit at time of negotiation with regulators. Because there is background contamination the following case study provides an example of using a combined Shewart/CUSUM method to identify a release at a site.

Table 4-1.
Groundwater Monitoring Data for Case Study 1

Identification				Descriptive Statistics				Trend Significance		Excursions?	
Class	**Well**	***n***	**Avg**	**Med**	***s***	***W***	**MK**	**95%**	**90%**	**Control Chart**	**Tolerance Limit**
Comp.	MW1	46	5595.0	5610.0	982.0	Yes	No	Up	Up	None	3
	MW2	44	62.3	67.2	21.5	Yes	No	Down	Down	None	None
	MW3	40	1295.0	1198.0	367.8	No	No	Down	Down	None	None
	MW4	47	133.8	133.7	22.3	Yes	No	Down	Down	None	None
Detect.	MW5	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW6	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW7	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW8	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW9	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW10	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW11	16	0.369	0.4	0.307	Yes	No	None	None	None	None
	MW12	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW13	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW14	16	0.0	0.0	0.0	N/A	N/A	None	None	None	None
	MW15	16	0.039	0.0	0.088	No	No	None	None	None	None

Notes:
Comp — Compliance
n — Number of samples
Avg — Sample mean
Med — Sample median
s — Sample standard deviation
W — Normal according to Shapiro-Wilk test at 95% confidence?
MK — Seasonality according to Mann-Kendall test at 95% confidence?

4.6. Case Study 2—Shewart/CUSUM Monitoring. A groundwater plume at a site is currently being addressed via pumping and treating large amounts of groundwater. The system is very costly, and the site owner wishes to change the system configuration. Project regulators want to know whether changing the system (in this case, shutting off the treatment system) will increase measured trichloroethene (TCE) values near the leading edge of the plume. A special type of compliance monitoring was initiated to determine whether concentrations after system shutdown exceeded a "trigger" level. Table 4-2 lists the eight most recent TCE measurements at monitoring well B-37 prior to altering the system.

4.6.1. The sample mean for these data ($\bar{x}$) is 4.3 parts per billion (ppb) and the sample standard deviation (s) is 1.1 ppb. These values are used in statistical tests for normality, which did not indicate the data set is non-normal. (A hypothesis of normality cannot be rejected at the 90% significance level using any of the Shapiro-Wilk, Anderson-Darling, Kolmogorov-Smirnov, or D'Agostino tests [See Appendix F].)

Table 4-2.
Eight Most Recent TCE Measurements in B-37

Well ID	Sample Date	Measured TCE Concentration (μg/L)
B-37	7-Jun-99	3.0
B-37	29-Nov-99	3.2
B-37	26-Jun-00	4.5
B-37	3-Jan-01	5.8
B-37	16-May-01	5.9
B-37	4-Oct-01	3.2
B-37	27-Mar-02	4.6
B-37	10-Dec-02	4.3

4.6.2. Table 4-3 lists the measured TCE concentrations in this well over eight monitoring periods after system shutdown in mid-December 2002, and the associated Shewart/CUSUM statistical parameters (see Appendix K). The Shewart/CUSUM calculations shown in the table are plotted in the Figure 4-6.

Table 4-3.
TCE Measurements and Shewart/CUSUM Calculations

Hypothetical Sampling Event	Sampling Period, i	TCE Concentration (μg/L)	z_i	z_{i-1}	S_i
Winter 2002	1	4.9	0.6	–0.4	0
Spring 2003	2	5.7	1.2	0.2	0.2
Summer 2003	3	6.0	1.4	0.4	0.7
Fall 2003	4	3.9	–0.4	–1.4	0.0
Winter 2003	5	9.8	4.8	3.8	3.8
Spring 2004	6	8.1	3.3	2.3	6.1
Summer 2004	7	7.5	2.8	1.8	8.0
Fall 2004	8	10.6	5.5	4.5	12.5

z_i = standardized result (or normalized concentration)
S_i = cumulative sum

4.6.3. The quantities z_i and S_i (discussed in Appendix K) were calculated to determine whether changing the system configuration resulted in an unacceptable change (i.e., increase) in the TCE concentration in Well B-37.

4.6.4. The first out-of-control event occurred in winter 2003 when the z_i of 4.8 exceeded the Shewart threshold of 4.5. In addition, although the normalized concentration z_i decreases after the fifth sampling event following the start of shutdown, S_i continues to increase beyond and remains greater than the threshold of 5.0 for this quantity through fall 2004.

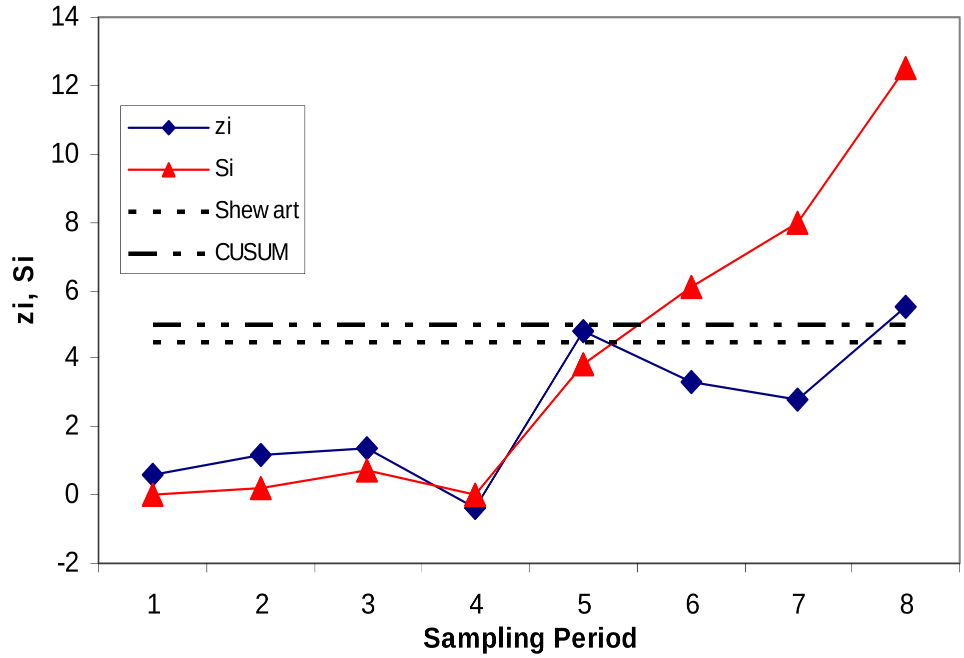

Figure 4-6. Shewart/CUSUM control chart, Well B-37.

4.6.5. The results of the testing showed that reconfiguring the system appeared to change the concentrations of TCE in this downgradient well at a statistically significant level. The reconfiguration was abandoned, and project planners began to reevaluate their understanding of groundwater movement at the site.

4.6.6. The Shewart/CUSUM method is commonly applied to landfills for detection monitoring, although it has obvious additional uses in other long-term monitoring applications. For instance, by looking for an insignificant change over time, a site stakeholder could suggest that monitoring at a natural attenuation site could be discontinued.

4.7. Optimization. The process of optimization is similar in many ways to the process of sensitivity analysis. In both cases, one makes planned adjustments to the system and looks for changes in the outcome. The process of optimization involves assessing whether or not a change made in the system results in a beneficial outcome—improving system performance, for example, by reducing cost, increasing efficiency, or shortening the time to completion. This can be accomplished by comparing data taken after the adjustments have been made to historical data for the process using a variety of hypothesis testing tools.

4.7.1. It is also possible to examine trends in the system after taking into account seasonal and other forms of cyclic correlation. For example, when a time plot is examined for trend after a system modification, one may find that the slope of the time plot line changes, indicating a change in system performance. A time series plot is a graph showing how a parameter (e.g., TCE concentration) changes over time. A trend is a statistically significant change upward or downward with a certain degree of confidence. Whether or not that change is significant and an assessment of the magnitude of its impact can be addressed using trend tests such as *Mann-Kendall* and *Sen's Slope Estimator.*[*]

4.7.2. Another example of system optimization is in addressing such issues as the monitored analyte list and the frequency of sampling, both of which have economic implications and can have regulatory implications as well. As a hypothetical extreme case for illustration, assume that a monitoring well network must be sampled four times each year; that there are 10 wells in the network; and that each well is monitored for 50 constituents, all of which must be non-detects.

4.7.3. The statistics underlying the determination of a detection limit (e.g., if normality is assumed and the detection limit is the "Type I detection limit" or "critical value" in Appendix C) are such that there is only a 1% probability of a false positive at the detection limit while, as the statistics employed are one-sided, there is a 50% probability of a false negative at the detection limit. Thus, in the course of a given year, based on probability alone, the facility could falsely report itself in violation an average of 20 times, while falsely reporting compliance 1000 times (on the average). In fact, it can be demonstrated that simply because of the inherent Type I error rate associated with any statistical test, where literally thousands of such comparisons may be required, whether at the detection limit or otherwise, the probability of a false conclusion of violation approaches unity. Thus, it is always in the best interest of the regulated facility to limit the number of analytes for which one tests to the smallest possible number. Every permit renewal period or 5-year review should be used as an opportunity to further limit the analyte list. Even hypothetically, one can see that this approach is inefficient (costly), and reaching the goal of all non-detect is an example of a poorly defined quality objective. Detection limits can differ across laboratories and over time, and, clearly, they are not related to risk management in any way.

4.7.4. Another approach currently under study is the use of statistics to establish predictable correlation between the analyte of interest and some parameter that is more readily or cost-effectively measured than the analyte of interest. This "harbinger" or "calibration" approach has its roots in the commonly accepted practice of monitoring for indicator parameters such as pH, conductivity, total organic carbon, and total organic halides in place of specific analytes. If a rig-

[*] Appendix P.

orous regression analysis of historical data suggests a quantitative linkage between the concentration of arsenic and magnesium at a given site, it should be possible to delete, or at least reduce the frequency of analysis, for one or the other analyte, particularly in the case where both analytes have historically displayed compliant behavior. It would also be useful in this type of situation if a functional relationship and the uncertainty associated with that relationship could be established.

4.7.5. To assess the viability of monitored natural attenuation as a remedial alternative, it is essential to demonstrate: i) degradation of VOCs from parent products through to mineralization; and ii) correlation between that degradation and appropriate geochemical conditions. An example of assessing the correlation of parameters at a site in Maryland is illustrated in Case Study 3. Correlation measures show how strongly variables (or parameters) are related, or change with each other.

4.8. Case Study 3—Trend Analysis and Correlation in Natural Attenuation Data.

4.8.1. The data used for a site in Maryland were organized along a single geographic line, from the suspected source to a groundwater discharge zone located along a creek bed. Location was displayed in feet from the center of the suspected source. The parent constituent was PCE. The primary geochemical indicators of interest (for purposes of this case study) were dissolved oxygen (DO) and oxidation-reduction potential (redox).

Table 4-4.
Attenuation Data

Distance from Source (feet)	PCE (μg/L)	DO (mg/L)	Redox (mV)
0	320	0	–210
50	1430	0	–220
100	960	0.2	–170
150	780	0.3	–140
200	570	0.6	–80
250	630	0.5	–30
300	580	0.8	10
350	340	1.1	40
400	430	1.4	70
450	130	1.7	90
500	12	3.5	120

4.8.2. The data for the three parameters of interest are presented in Table 4-4. The data were then plotted against distance from the origin (source) to identify trends over distance. A Mann-Kendall trend analysis showed that PCE concentration decreased over distance. Redox and DO are positively correlated to one another with a Pearson's r value of 0.84. Geochemical understanding of natural attenuation requires that redox and DO should be inversely correlated to

PCE concentration, and the Pearson's *r* values for DO and redox are –0.71 and –0.74, respectively. The results are displayed in the Figures 4-7 and 4-8. In summary, the results suggest that conditions for natural attenuation are present.

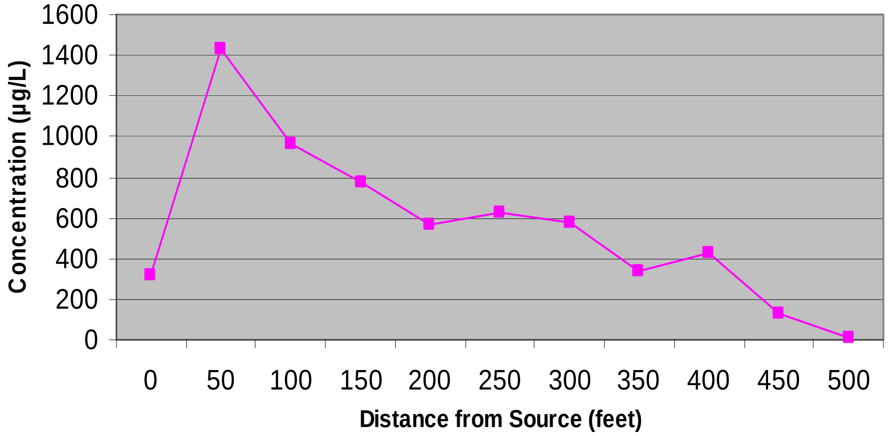

Figure 4-7. PCE concentration versus distance.

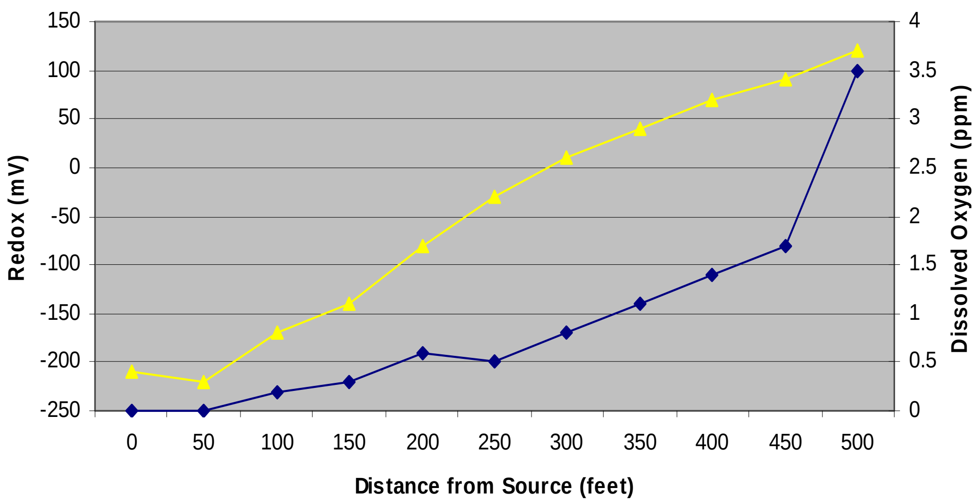

Figure 4-8. Geochemical parameters versus distance from source (yellow triangle—redox; blue diamond—dissolved oxygen).

Section II
Applying Cleanup Levels

4.9. Introduction. When derived in accordance with USEPA's risk assessment guidance, risk-based cleanup levels are intended to represent the average contaminant concentration within the exposure unit that can be left on the site following remediation (Schulz and Griffin, 2001). In contrast, a "not-to-exceed" cleanup level drives remediation solutions that involve treating or removing any and all media with contaminant concentrations that exceed the cleanup level. The result is that applying a not-to-exceed level may result in over-remediation.

4.9.1. Calculated using risk assessment principles, the cleanup goal concentration is usually defined as an exposure unit concentration that will meet the target risk level agreed to by the design team and regulatory authorities. Some sample concentrations exceeding the cleanup objective can remain in place as long as the overall exposure concentration, calculated to a predetermined level of certainty, meets the cleanup goal (and likewise the agreed upon risk level). Because of the uncertainty associated with estimating the true average concentration of a contaminant at a site, USEPA recommends use of the 95% one-sided, upper confidence limit of the arithmetic mean (95% UCL) of the sample data to represent the exposure unit concentration term in risk assessments (EPA 9285.7-09A and EPA OSWER 9285.6-10). Consequently, a risk-based cleanup level should generally be interpreted as the 95% UCL of the contaminant concentration within the exposure unit following remediation.

4.9.2. However, *draft* USEPA guidance suggests specific situations in which application of the cleanup level as an area average may not be appropriate (USEPA, 2002) These include the following.

4.9.2.1. Exposure within the exposure unit is not random.

4.9.2.2. The cleanup level is based on acute rather than chronic exposure.

4.9.2.3. The cleanup level is not risk-based (i.e., it considers factors other than risk).

4.9.2.4. The quality of site characterization data is not optimal but it is not worth investing in additional sampling.

4.9.2.5. Given the site conditions (complexity, size, characterization, contaminant distribution), it is not cost-effective to do the necessary sampling and statistical analysis.

4.9.2.6. The community will not accept leaving soil with contaminant concentrations that exceed the cleanup level on the site.

4.9.3. If applying cleanup levels as an area average is appropriate, there are two basic approaches: i) using non-spatial statistical methods to determine a not-to-exceed concentration, and ii) using spatial statistical methods to iteratively re-calculate the UCL until the optimal "design line" for the remedial action is determined.

4.10. Determining Not-to-Exceed Concentrations Using Non-Spatial Statistics. Draft USEPA guidance (USEPA, 2002) defines the remedial action level (RAL) as the maximum concentration that may be left in place within an exposure unit such that the average concentration (or 95% UCL) within the exposure unit is at or below the cleanup level. Non-spatial techniques may be appropriate for calculating the RAL when there is no spatial correlation between contaminant concentrations, such as at a dump site where small, randomly located spots of high contaminant concentrations are interspersed with areas of lower concentrations. Non-spatial techniques are based on the mean and standard deviation of the sample contaminant concentration data and on how those metrics change as soils with high contaminant concentrations are replaced with post-remediation concentrations during remediation. The draft guidance describes two non-spatial statistical methods for calculating remedial action levels that ensure that post-remediation area average contaminant concentrations achieve cleanup levels: i) iterative truncation method, and ii) confidence response goal method. These methods are also reviewed in Schulz and Griffin (2001). Both methods can be applied in a spreadsheet calculation or programming language.

4.10.1. *Iterative Truncation Method*.

4.10.1.1. The iterative truncation method is based on the identifying and removing (truncating) high values in the sample concentration measurements (hot spots), replacing them with the post-remediation concentration (e.g., concentration in clean fill), and calculating the hypothetical post-remediation average concentration (95% UCL) in the exposure unit. Starting with the highest concentration in the data set, the process is repeated iteratively until the post-remediation 95% UCL is less than or equal to the cleanup level. The highest sample concentration remaining in the data set is designated the RAL.

4.10.1.2. This method is sensitive to the completeness of site characterization and the range of resultant sample concentrations. According to the draft USEPA guidance, to use this method with confidence, good site characterization through extensive, unbiased sampling is required and the resulting data must adequately represent random, long-term exposure to receptors. This method is not reliable when samples are not independently and randomly located.

4.10.2. *Confidence Response Goal Method*. Bowers et al. (1996) developed a method for calculating a confidence response goal (CRG), which, like the RAL, is a not-to-exceed level. This method can be applied at sites where there is a non-spatial, lognormal distribution of contamination (USEPA, 2002).

4.10.2.1. As described in the draft USEPA guidance, the basic premise of the method is that the CRG can be expressed as a function of the geometric mean and the geometric standard deviation of contaminant concentrations, and the desired reduction in exposure, which is defined as the ratio of average post-remediation concentration to the average pre-remediation concentration. The guidance provides a summary of the method, documents the equation for calculating the CRG, and refers the reader to the original paper (Bowers et al., 1996) for details on the derivation of the function.

4.10.2.2. The Schulz and Griffin (2001) review of the two non-spatial methods concludes that the CRG method is less sensitive than the iterative truncation method to changes in the highest sample concentrations and recommends the use of the CRG method when the contaminant distribution is lognormal.

4.10.3. *Using Spatial Statistical Methods to Determine "Design Line" for Remediation*. The distribution of contaminant concentrations may be spatially correlated at many sites where there is an original source or release that is subject to environmental fate and transport mechanisms. Contaminant concentrations in and around the original source or release may be higher than those at greater distances, or they may be higher where there is a mechanism of accumulation or an environmental "sink." Biased sampling is frequently applied in such cases because a high number of samples is desired in areas with high variance and uncertainty (for example, near the source area), and a lower number of samples is often sufficient to characterize areas with expected low variance and uncertainty. The concept of taking "step out" samples in the vicinity of sample locations where high contaminant concentrations are detected also introduces bias into the sampling plan. Geostatistical techniques are statistical procedures designed to process spatially correlated data (see Appendix R on Geostatistics). Unlike the non-spatial techniques, geostatistical techniques are well suited for evaluation of biased data sets.

4.10.3.1. The draft USEPA guidance presents an example of the determination of RALs using geostatistical techniques. The example has two simplifying features that can be found on many (but not all) sites: i) contamination that is surface only, and ii) the importance of a residential scenario. For this example, the steps for determining RALs are as follows.

4.10.3.1.1. Create an iso-concentration map of the site by modeling the spatial correlation underlying measured values.

4.10.3.1.2. Superimpose a grid of exposure units over the site and compute average contaminant concentrations in each exposure unit.

4.10.3.1.3. Identify zones that must be remediated to reduce average concentrations in all exposure units to the appropriate cleanup level. This is an iterative process, where the higher contaminant concentrations are replaced with post-remediation concentrations and average contaminant concentrations in each exposure unit are re-calculated. The final cutoff concentration is the RAL.

4.10.3.1.4. Use the original iso-concentration map to define zones with concentrations in excess of the RAL. The contoured zone is the area that requires remediation.

4.10.3.2. The draft guidance cautions against using geostatistical techniques if contaminant concentrations show a random, non-spatial pattern, or if the anticipated benefits from geostatistical analysis do not justify the costs. For example, even in cases of conservatively biased data, spatial statistical methods may not be warranted when non-spatial methods are determined to result in cleanup objectives that are both sufficiently conservative from the risk perspective and acceptable from the cleanup cost perspective. Additionally, conservatively biased, non-spatial methods may be needed from a practical view when adequate technical or computational resources are not available. Proponents of geostatistical techniques counter that presentating the site contamination and remediation results as spatial is a highly intuitive and visually powerful approach, and therefore enhances communication among the parties during risk management discussions. Available computational tools make it possible to find the point of diminishing returns where an increase in remediation has little effect on reducing risk in a cost-effective manner.