DETERMINING BACKGROUND CONCENTRATIONS IN SOIL

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STATEMENT OF PURPOSE

Background sampling is conducted to establish background concentrations for possible naturally occurring and/or site-related hazardous substances. Possible goals for establishing background concentrations at a contaminated site are to:

- Distinguish site-related contamination from naturally occurring or other non-site-related concentrations of hazardous substances;
- Establish remedial goals based on background concentrations of hazardous substances;
- Quantify the proportion of total risk that may be attributable to exposure to background concentrations of hazardous substances; and
- Determine cumulative risks associated with background and site-related hazardous substances.

The collection and analysis of background samples will yield a range of background concentrations for each hazardous substance. From this range, a single concentration value (or background statistic) may be determined for each hazardous substance.

The Alaska Department of Environmental Conservation (ADEC) developed this guidance document to provide the framework to determine that single background statistic. This document supercedes the previous edition of *Technical Guidance Document on Determination of Background Concentrations* dated September 17, 1998. Background concentrations determined using this guidance will comply with ADEC's oil and hazardous substance pollution control regulations in 18 Alaska Administrative Code (AAC) 75, 18 AAC 78, and with ADEC's risk assessment guidance.

Section I defines the types of background concentrations that are associated with a contaminated site. Once the type of background concentration is defined, the information in Section II can be used to plan collection of data of sufficient quality to establish a background concentration statistic. Section III provides the methods for calculating the statistic. Section IV presents considerations for the use of background concentrations, such as site characterization, cleanup, and risk assessment.

Changes from Previous Edition

The previous edition of this document recommended calculating an upper confidence limit (UCL) on the mean concentration in a background data set. The UCL statistical method is not included in this revised edition because that method generally performs poorly with environmental data sets, and recent guidance from the United States Environmental Protection Agency (EPA) and other states include new statistical methods for establishing background concentrations.

I. TYPES OF BACKGROUND CONCENTRATIONS

The first step in determining a single background statistic is to define the type of background concentration at a site. For the purposes of 18 AAC 75.300 to 75.396, *background concentration* is defined as the concentration of a hazardous substance that is consistently present and naturally occurring, or that is the result of human activities unrelated to a discharge or release from the site.

This definition can be divided into two classes:

- **Naturally occurring background concentrations** are ambient concentrations of a hazardous substance present in the environment, which have not been influenced by humans and which existed before any waste management or industrial activities occurred at a site. Because most organic compounds are not naturally occurring, the term *naturally occurring background concentrations* generally refers to inorganic metals that are commonly found in soil. However, some organic compounds associated with petroleum hydrocarbons may be present at naturally occurring concentrations because of natural events such as forest fires or decaying organic matter; and

- **Anthropogenic background concentrations** are concentrations of a hazardous substance present in the environment, which are caused by humans and which originate from off-site sources such as industry, automobiles, and agriculture. Anthropogenic concentrations generally result from indirect human activities that are unrelated to waste management and industrial activities at a site. Common examples of these indirect activities are deposition of hazardous substances from automobile and industrial emissions, and widespread use or application of hazardous substances such as pesticides. The key aspects of anthropogenic concentrations are that they are not specifically related to site activities and that they occur at uniformly low concentrations across a wide region.

These two classes of background concentrations have equal applicability. At any given site, naturally occurring and anthropogenic concentrations may be present.

Once the type of background concentration is defined, a sampling strategy can be developed to collect sufficient data that can be used to establish the background concentration statistic.

II. BACKGROUND SAMPLING DESIGN AND COLLECTION CRITERIA

The second step in determining a single background statistic is to acquire sufficient background data. If background data already exist for a project, and the sample quantity, location, and quality of data satisfy the objectives for determining background concentrations, then additional samples may not be necessary and the user may refer to Section III ("Analysis of Background Concentrations"). However, if existing data are inadequate for determining background concentrations, then additional background samples may be necessary. Examples of inadequate data are insufficient number of samples, inappropriate background sample locations, suspect data quality, data gaps in the existing data, and alterations to the surrounding lands near the site since the time of previous sample collection.

If additional background samples are required, then background sampling should be incorporated into the site-specific sampling and analysis plan (SAP) that addresses sampling methodology and quality assurance procedures, with particular attention paid to accomplishing additional objectives for establishing background concentrations. This section explains how data quality objectives (DQOs) and sampling methodology, which are integral to any project SAP, apply specifically to background data collection.

Background Data Quality Objectives

Carefully constructed DQOs will clarify the project objectives, define the data that are desired, determine the appropriate conditions for collecting the data, and establish limits on interpreting the data. The DQO process involves seven steps, which are listed below. Explanations of how the steps apply specifically to background data collection are included:

1. State the Problem: Includes developing or refining the reason for collecting background samples.

2. Identify the Decision: Includes identifying the hazardous substances for which background samples are needed.

3. Identify Inputs into the Decision: Includes establishing the background sample types and depths that are needed.

4. Define Boundaries of the Study: Includes defining geographic boundaries for background samples.

5. Develop a Decision Rule: Includes determining the possible conclusions that will be drawn from the analysis of background data.

6. Specify the Limits on Decision Error: Includes identifying the possible errors in conclusions drawn from the background data and the consequences of those errors.

7. Optimize the Sampling Design: Includes developing alternatives for collection and analysis of background samples and selecting the most resource-effective design that satisfies the DQOs.

The process of defining DQOs will vary widely between projects. The above-referenced seven steps constitute a summary of the main points of the process. *Guidance for Data Quality Assessment, Practical Methods for Data Analysis,* (EPA 2000) provides a complete explanation of defining DQOs, and *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites* (EPA 2001) provides an example of defining DQOs in the context of establishing and using background concentrations in decision-making applications.

Background Sampling Methodology
Another integral part of any SAP is to define the sizes of sample sets and the methodology for collecting the samples, which includes establishing the number of background samples and the process for collecting them.

Sizes of background data sets will vary widely, and often there is no single solution because the DQOs of a particular project will dictate a range for the size of the respective sample set. For example, sometimes DQOs are defined in the form of a hypothesis test. In these cases, the size of the background sample set depends on the limits of tolerable error and power defined in the hypothesis test. On the other hand, a less specifically defined objective may be to determine whether site-related concentrations exceed background concentrations. In this case, the size of the background data set depends on how much statistical confidence is desired for the calculated result, considering the costs of collecting and analyzing additional background samples to achieve that level of confidence. A statistician can be consulted during development of the DQOs to assist in selecting an appropriate sample design and determining sample set size.

When the number of background samples is determined for a project, the rationale, location, and procedure for collection of those samples should be addressed. The following criteria should be considered:

- Background samples should be collected at or near the site in areas not influenced by site or non-site-related operational activities;

- Background samples should be collected from an area with dimensions similar to those of the site to minimize potential statistical variance between sample sets;

- Background sample locations should be upgradient of prevailing winds and site runoff to minimize the potential impact of dispersed or transported hazardous substances on the locations;

- Background samples should have physical soil characteristics similar to those of the regular site samples and should be collected from the same depth intervals, unless there is clear evidence of vertical mechanical mixing of site or background soils. In addition, background samples should be collected using the same soil sampling protocols as those used for the regular site samples. These procedures will minimize potential statistical variance between sample sets;

- Selection of more than one background area may be necessary when the site exhibits diverse physical, chemical, or biological characteristics;

- Background sample locations should account for the mobility of hazardous substances at the site, so that the sample locations are free from impacts by any site-related hazardous substance;

- Background samples may be discrete or composite samples. The choice depends on the DQOs for comparing site-related concentrations to background concentrations; and

- Use of statewide background data for site-specific background concentrations is generally unacceptable. However, background data from similar and nearby sites may be used if those data were collected using standard sampling protocol comparable to that of the site characterization sampling; if those data contain no anomalies or outliers for the hazardous substance; and if each reference site is located within the same physical geographic ("physiographic") region as that of the site under investigation.

Once sufficient background data are acquired, they may be analyzed using the methods presented in Section III.

III. ANALYSIS OF BACKGROUND CONCENTRATIONS

After background samples are collected and analyzed, a background concentration statistic may be calculated for each hazardous substance. The calculated statistic is a value that represents background concentrations for each hazardous substance. This value should be sufficiently robust to account for variability that naturally exists within the population of background concentrations. For this reason, the background concentration statistic can be considered an upper bound on background concentrations.

This section provides three methods for calculating the single background statistic for each hazardous substance. The methods are listed in the order of preference based on statistical confidence in the outcome.

Method 1

Compute the background upper tolerance limit (UTL_B) for each hazardous substance detected in the background samples, as described in *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 2002). The UTL_B is a confidence limit on a percentile of the data, which means that the UTL_B estimates, with a certain degree of confidence, are an upper bound on a percentage of the data. In other words, the UTL_B provides an interval within which a percentage of the population (i.e., the concentration of a hazardous substance in soils) lies. In addition, the statistic includes a probability, or degree of confidence, that the interval actually contains that percentage of the population.

Example: Twenty-five background soil samples were collected at the XYZ site and analyzed for lead using field-portable X-ray fluorescence (XRF). Lead concentrations range from 6.5 milligrams per kilogram (mg/kg) to 10.2 mg/kg in those 25 samples. The calculated UTL_B for lead at the XYZ site is 10 mg/kg. This implies that 10 mg/kg of lead is the 95^{th} percentile of background lead concentrations with 95% confidence or certainty. Or, it is 95% certain that 95% of the background lead concentrations at the XYZ site are equal to or less than a value of 10 mg/kg. This is expressed as follows: *10 mg/kg of lead represents the 95% UTL_B with 95% confidence*.

The UTL_B statistic can be calculated regardless of the distribution of a sample set. There are two types of UTL_B statistics: the parametric UTL_B and the nonparametric UTL_B.

<u>Parametric UTL_B</u>

A parametric UTL_B can be calculated for those background sample sets that are normally distributed or that can be converted to a normal distribution.

A parametric method of data analysis requires a known distribution of a parameter (i.e., the mean concentration of a hazardous substance in soils) in a population (i.e., all concentrations of the same hazardous substance in soils). A parametric test evaluates a hypothesis regarding a parameter from a population.

A UTL_B for a normally distributed data set, or for a data set that can be converted to normality, is calculated using the following formula: $x + Ks$, where x is the mean of the data set, s is the standard deviation of the data set, and K is a tolerance coefficient based on critical values of the normal and chi-square distributions.

Appendix A contains a table of K values with 90%, 95%, and 99% confidence for the 90^{th}, 95^{th}, and 99^{th} percentile intervals.

Nonparametric UTL_B

A nonparametric UTL_B can be calculated when the distribution of the background sample set is unknown. This test compares the shapes and locations of distributions instead of a statistical parameter.

Derivation of a nonparametric UTL_B uses basic probability theory. Pages 5-10 and 5-11 of *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites* (EPA 2001) present a concise discussion of the process.

Example: Consider the XYZ site again, where 25 background samples were collected and analyzed for lead using field-portable XRF. Data from the 25 analytical results indicate that the background sample set for lead is not normally distributed. Using a nonparametric UTL_B, the *maximum concentration of lead* in the background data set represents:

The 90% upper tolerance limit for background lead concentrations with $1 - (0.90)^{25} = 0.928 \approx 92\%$ confidence.[1]

Notes Regarding Parametric and Nonparametric UTL_B

Tolerance limit tests are powerful in that they estimate a realistic upper bound on a population of background concentrations. However, these tests are sensitive to the size of the background sample set; therefore, sample sets of at least eight or nine data points

[1] The formula $1 - (0.90)^{25} = 0.928$ is based on the theory that a single random sample from a population has a probability of 0.1 (10%) of exceeding the 90^{th} percentile of the population (concentration of lead). The previous statement can be written mathematically in the form:

> $1 - (0.90)^1 = 1 - 0.90 = 0.1$, which means that there is a 10% chance (confidence) that the single random sample represents the 90% upper tolerance limit of the population.

Therefore, for n random samples, the probability that any one sample (or the maximum value from n random samples) exceeds the 90^{th} percentile of the population is: $1 - (0.90)^n$. Returning to the original example of 25 samples, the maximum concentration of lead in the background data set represents:

> The 90% upper tolerance limit with $1 - (0.90)^{25} = 0.928 \approx 92\%$ confidence.

Notice that the UTL_B is not the endpoint of the calculation as it was with a parametric UTL_B. In the case of a nonparametric UTL_B, the endpoint of the calculation is the degree of confidence that is obtained from the statistic. For this reason, a nonparametric UTL_B is less powerful than a parametric UTL_B. Consider the case of calculating a 95% UTL_B for lead at the XYZ site:

> The maximum concentration of lead in the background data set represents the 95% upper tolerance limit with $1 - (0.95)^{25} = 0.723 \approx 72\%$ confidence.

In this case, increasing the desired tolerance limit from 90% to 95% caused the confidence in the test to drop from 92% to 72%.

generally are needed to calculate a parametric UTL_B. A nonparametric UTL_B is even more sensitive to the size of the sample set. In general, at least 20 data points are necessary to derive a nonparametric UTL_B that is comparable in power to a parametric test.

Another note regarding UTL_B is how to handle potential outliers in a data set. Any data set, regardless of distribution, should be tested for outliers. However, outlier tests require normally distributed data for sample sets with fewer than 50 data points, and outlier tests for sample sets with fewer than 25 data points will not detect multiple outliers. Therefore, outlier tests often are difficult to apply in environmental applications. *Guidance for Data Quality Assessment, Practical Methods for Data Analysis,* (EPA 2000) should be consulted for a thorough discussion regarding determining and handling outliers in data sets.

Method 2

Compute the interquartile range (IQR) of the sample set to estimate a 95% confidence limit on the median of the background data set, as described in Oregon Department of Environmental Quality's *Soil Cleanup Manual* (1994). The following procedure should be used:

1. Arrange the data in numerical order from the lowest to highest sample result.

2. Establish the data set's median value.

3. Determine the data point that lies halfway between the median and maximum of the data set. This value is known as the *upper quartile*. When there is an even number of data points, calculate the upper quartile based on the average of the two data points that straddle the upper quartile.

4. Follow the same process with the median and minimum of the data set to determine the *lower quartile*.

5. Calculate the IQR by taking the difference of the upper quartile and lower quartile.

6. Calculate the 95% confidence limit on the median of the background data set by adding the median to two times the IQR.

The 95% confidence limit on the median of the background data works well when there are more than three data points in the background data set and fewer than a sufficient number of samples to calculate a UTL_B (generally fewer than nine). It is not necessary to know the distribution of the background data to use the IQR 95% confidence limit on the median statistic.

Method 3
For background data sets with three or fewer data points, the maximum value for each hazardous substance should be selected as the background concentration unless it is suspected that the maximum represents an anomaly within the background population.

IV. USE OF BACKGROUND CONCENTRATIONS

This guidance document presents the rationale and methodology for establishing background concentrations. Background concentrations derived using this guidance apply to site characterization, cleanup, and risk assessment. However, this guidance does not encompass all possibilities for calculating background concentrations. The project objectives, and the DQOs established to meet those objectives, will dictate how background concentrations should be established.

Furthermore, this document does not provide guidance for comparing site-related concentrations to background concentrations in soil. Methods for comparing site-related and background data concern site-specific DQOs that are developed when the scope of a project is outlined. Complete guidance on developing DQOs is found in EPA guidance documents, such as *Guidance for Data Quality Assessment, Practical Methods for Data Analysis,* (EPA 2000) and *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites* (EPA 2001), which are listed in the section entitled "Additional Guidance" on page 13. Additionally, this guidance document addresses only background concentrations in soil. Other environmental media, such as surface water, groundwater, air, and sediments, are influenced by various factors that are unique to each medium.

Site Characterization

The application of background concentrations to site-related contaminant concentrations will be project-specific. In general, the calculated background concentration statistic is a tool for comparing and distinguishing site-related concentrations of hazardous substances, but the method for comparison depends on the project design and DQOs.

Cleanup

Background concentrations may be used to establish remedial goals for hazardous substances at a cleanup site. In the most stringent case, site-related concentrations will be remediated to background concentrations. However, the application of background concentrations in a cleanup scenario is project-specific, and remedial goals may be established using factors other than, and in addition to, background concentrations of hazardous substances.

Risk Assessment

Background concentrations may be very useful in characterizing site risks. Most often, background concentrations are used to screen site data for selection of contaminants of potential concern (COPCs). However, if a contaminant is site-related and may be attributable to background sources, it should not be eliminated automatically from consideration as a COPC.

As stated in *Risk Assessment Procedures Manual* (ADEC 2000), inorganic contaminants present at concentrations equal to or below site-specific background levels may be eliminated from consideration. Naturally occurring contaminants that are below site-specific background levels but detected at levels exceeding risk-based standards should be discussed qualitatively in the risk characterization portion of a risk assessment.

Elimination of organic chemicals based on background analyses should be determined on a project-specific basis.

TERMS USED IN THIS DOCUMENT

Following are definitions of terms used in this document. These definitions were obtained from 18 Alaska Administrative Code 75.990 and 78, when available, and relevant United States Environmental Protection Agency guidance.

Background Concentration	Concentration of a hazardous substance that is consistently present in the environment or in the vicinity of a site and that is naturally present or is the result of human activities unrelated to a discharge or release at the site.
Confidence Limit of a Mean	An upper and/or lower bound on a mean value. The upper and lower bounds make up a confidence interval and form the range of values that have a specified probability of containing the mean value. For example, the 95% upper and lower confidence limits of a mean are the values within which the mean value will be found 95% of the time.
Data Quality Objective (DQO)	Used to define qualitative and quantitative criteria for determining when and where samples will be collected; the quantity of samples; and a desired level of confidence.
Hypothesis Test	A test that seeks to determine whether an assumption regarding a data set is true. The null hypothesis is the hypothesis that is to be tested, and the alternative hypothesis is the hypothesis that in some sense contradicts the null hypothesis.
Nonparametric	The underlying distribution of the data set is neither normal nor lognormal and may be considered *distribution-free*.
Normal Distribution	A symmetric distribution, with the pattern or distribution of values falling into a bell-shaped curve. The normal distribution is described by its mean value and variance.
Parametric	The underlying distribution of the data set is normal or lognormal. Normal and lognormal data sets can be described by two parameters: mean and variance.
Power	Describes the probability that a statistical test will not provide a false negative result; i.e., Type II error.
Risk Assessment	A determination of potential health effects including effects of containment exposure through inhalation, ingestion, dermal absorption, and other means, and the assessment of risk to

human health and the environment from contaminants remaining in the land, air, or water as a result of a release.

Robustness A characteristic of a test that means that the test has good performance for a wide variety of data distributions and that the performance will not be affected greatly by the presence of outliers.

Site An area that is contaminated, including areas contaminated by the migration of hazardous substances from a source area, regardless of property ownership.

Tolerable Error The level of error, or likelihood of a false positive or false negative, that is considered acceptable for a given statistical test.

Tolerance Limit A confidence limit on a percentile of the data set. An upper or lower tolerance limit provides an interval within which at least a certain proportion of the population lies.

ADDITIONAL GUIDANCE

For further guidance on the use of background data in risk assessment, refer to the following guidance documents:

- Alaska Department of Environmental Conservation, June 8, 2000, *Risk Assessment Procedures Manual*, Contaminated Sites Remediation Program, http://www.state.ak.us/dec/dspar/csites/guidance_cs.htm.
- United States Environmental Protection Agency (EPA), April 26, 2002, *Role of Background in the CERCLA Cleanup Program*, Office of Solid Waste and Emergency Response (OSWER), Washington, D.C., OSWER 9285.6-07P, http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gdhh.
- EPA, December 1989, *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual,* Part A, Office of Emergency and Remedial Response, Washington, D.C., EPA 540/1-89/002, http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gdhh.

For further guidance on establishing background concentrations in soils, refer to the following guidance documents:

- EPA, June 2001, *Guidance for Characterizing Background Chemicals in Soil at Superfund Sites,* external review draft, EPA-R-01-003, http://www.epa.gov/superfund/programs/risk/background.pdf.
- EPA, September 2002, *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*, EPA 540-R-01-003, http://www.epa.gov/superfund/programs/risk/background.pdf.
- Oregon Department of Environmental Quality, April 1994*, Soil Cleanup Manual*, Waste Management and Cleanup Division, Oregon Administrative Rule 340-122-045 and 046, http://www.deq.state.or.us/wmc/documents/soclean.pdf.

There are several other guidance documents regarding statistical procedures used to develop background concentrations. Some of the more pertinent documents and links to them are as follows:

- EPA, July 2000, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, http://www.epa.gov/quality/qs-docs/g9-final.pdf.
- Gibbons, R.D., 1994, *Statistical Methods for Groundwater Monitoring,* John Wiley & Sons, Inc., New York.
- Gilbert, R.O., 1987, *Statistical Methods for Environmental Pollution Monitoring,* Van Nostrand Reinhold, San Francisco.

APPENDIX A

TABLE OF K VALUES