Chapter 4
Steps for Planning for the Acquisition of Useable Environmental Data in Baseline Risk Assessments

This chapter provides planning guidance to the RPM and risk assessor for designing an effective sampling plan and selecting suitable analytical methods to collect environmental analytical data for use in baseline risk assessments. It is important to understand that the variances inherent in both sampling and analytical designs combine to contribute to the overall level of uncertainty. The chapter also provides a number of charts and worksheets that should be useful in planning. It is important to remember that these are provided for guidance only. Each Region, or the staff at an individual site, may modify these for their use or develop their own materials.

The chapter has two sections. The first section of the chapter describes the process of selecting a sampling design strategy and developing a sampling plan to resolve the four fundamental risk assessment decisions presented in Chapter 2:

- What contamination is present and at what levels?
- Are site concentrations sufficiently different from background?
- Are all exposure pathways and exposure areas identified and examined?
- Are all exposure areas fully characterized?

A Sampling Design Selection Worksheet and a Soil Depth Sampling Worksheet are used as data collection and decision-making tools in this process. Guidance for evaluating alternative sampling strategies and designing statistical sampling plans is included.

The second section of the chapter provides guidance on selecting the methods for analyzing samples collected during the RI. A Method Selection Worksheet is used to compile the list of chemicals of potential concern and to determine analytical priorities so that the most suitable combination of methods is selected.

The risk assessor or RPM, in consultation with other technical experts, will probably complete several worksheets, representing different media, exposure pathways, potential sampling strategies, chemicals of potential concern, and analytical priorities. This is done to compile sufficient information to communicate basic risk assessment requirements to the RPM, and to ensure that these requirements are addressed in the sampling and analysis plan (SAP).

The selection of sampling plans and analytical methods should be based on the performance measures discussed in this chapter. These measures are assessed by data quality indicators that quantify attainment of the data quality objectives (DQOs) developed by the RPM for the total data collection and evaluation effort.

4.1 STRATEGIES FOR DESIGNING SAMPLING PLANS

This section provides guidance for evaluating alternative sampling strategies. Risk assessment may involve sampling many media at a site: groundwater, surface water, soil, sediment, industrial sludge, mine tailings, or air. The strategies for sampling different media often vary. For example, random stratified sampling may be the appropriate method for examination of soils at a site, but the positioning of groundwater monitoring wells is seldom done on a random basis. Sampling designs for soils and sediments are usually created to examine spatial distribution and heterogeneity of chemicals of concern. Groundwater sampling plans examine the

Acronyms

AA	atomic absorption
BNA	base/neutral/acid
CAS	Chemical Abstracts Service
CLP	Contract Laboratory Program
CV	coefficient of variation
CVAA	cold vapor atomic absorption
DQO	data quality objective
EMMI	Environmental Monitoring Methods Index
EMSL-LV	Environmental Monitoring Systems Laboratory - Las Vegas
EPA	U.S. Environmental Protection Agency
GC	gas chromatography
GFAA	graphite furnace atomic absorption
GIS	Geographic Information System
GPC	gel permeation chromatography
ICP	inductively coupled plasma
MDL	method detection limit
MDRD	minimum detectable relative difference
MS	mass spectrometry
PA/SI	primary assessment/site inspection
PCB	polychlorinated biphenyl
QA	quality assurance
QC	quality control
RAS	routine analytical services
RI	remedial investigation
RME	reasonable maximum exposure
RPM	remedial project manager
SAP	sampling and analysis plan
VOA	volatile organics
XRF	X-ray fluorescence

extent of a plume containing the chemical of concern, and also often examine seasonal or temporal variability in chemical concentrations. Exhibit 41 summarizes the relative variation in spatial and temporal properties for different types of measurement.

The terms stratum and strata are used frequently in this section. A stratum is usually a physically defined layer or area; it can also be a conceptual grouping of data or site characteristics that is used in statistical analysis.

Sampling guidance in this section is focused on determining the spatial extent and variability of the concentration of chemicals of potential concern. Therefore, it applies most directly to soils and sediments. Some EPA Regions have developed sampling guidances for groundwater, and the RPM and risk assessor should consult these whenever available.

Examples of common sampling designs are given in Exhibit 42, and their overall applicability is shown in Exhibit 43. Schematic examples of some of the designs are illustrated in Exhibit 44.

The objective of the sampling plan is to determine a strategy that collects data representative of site conditions. The data must have acceptable levels of precision and accuracy, obtain minimum required levels of detection for chemicals of potential concern, and have acceptable probabilities of false positives and false negatives. Meeting these objectives involves optimizing the confidence in concentration estimates and the ability to detect differences between site and background levels. To accomplish these objectives, the RPM can optimize the number of samples, the sampling design, or the efficiency of statistical estimators (e.g., mean, standard deviation, and standard error).

Increasing the number of samples may increase initial costs, depending on whether fixed or field analytical methods are used for analysis, but it is necessary in

EXHIBIT 41. EXAMPLES OF SPATIALLY AND TEMPORALLY DEPENDENT VARIABLES

Measurement	Relative Variation in Measurements Attributable to:	
	Spatial	Temporal
Geophysical Measurements	Large	Small
Soil-Gas Measurements	Large	Large
Weather/Air Quality	Large	Large
Surface Water Quality	Usually Small	Usually Large
Physical Soil Properties	Large	Small
Soil Moisture	Large	Large
Soil Quality	Large	Small
Aquifer Properties	Large	Small
Groundwater Flow	Usually Large	Usually Small
Concentration of Groundwater Contaminants	Large	Large

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EXHIBIT 42. EXAMPLES OF SAMPLING DESIGNS

Design	Examples of Application
Judgmental/ Purposive	Monitoring Wells Hot Spots
Classical Random	Background Soil
Classical Stratified:	
Random	Drums at Surface
Systematic	Waste Piles
Cluster	Soil from Boreholes
Composite	Soil from Test Pits
Systematic:	
Random	Determine Concentrations of Chemicals of Potential Concern in Soil
Grid	Concentrations of Chemicals of Potential Concern. Surface Soil Characteristics
Search	Contaminant Hot Spots
Surrogate	Gas Detector Measurements
Phased	Extent of Contamination
Geostatistical	Distribution of Contamination

21-002-042

certain situations (see Section 4.1.2). The sampling design can often be improved by stratifying within a medium to reduce variability, or by selecting a different sampling approach, such as a geostatistical procedure termed "kriging." Improving the efficiency of the statistical estimators involves specifying the type of data distribution if parametric procedures are being used, or switching from nonparametric to parametric procedures if distributional assumptions can be made.

Exhibit 45 is a Sampling Design Selection Worksheet, structured to assist design selection for the most complex environmental situation, which is usually soil sampling. The worksheet contains the elements needed to support the decisions for RI sampling design to meet data requirements for risk assessment. The RPM and risk assessor may use this worksheet or use it as a model to create one specifically suited to their needs. The final site sampling plan must meet the data useability requirements of risk assessment. The final procedure for sampling design should be selected based on the specific reason for sampling (e.g., defining a boundary or obtaining an average over some surface or volume). The worksheet should be completed for each medium and exposure pathway at the site. Once completed, this initial set of worksheets can be modified to assess alternative sampling strategies. Completion of a set of worksheets (i.e., a worksheet for each medium and exposure pathway at a site, based on a single sampling strategy) specifies the total number of samples to be taken for an exposure pathway, and sample breakdown according to type (i.e., field samples, quality control samples, and background samples).

The remainder of this section is a step-by-step guide to completing the Sampling Design Selection Worksheet. Chemicals of potential concern listed on the Sampling Design Selection Worksheet should be the same as those used for the Method Selection Worksheet (Exhibit 52).

4.1.1 Completing the Sampling Design Selection Worksheet

☛ *Use of the Sampling Design Selection Worksheet will help the RPM or statistician determine an appropriate sampling design.*

Pathway, medium and design alternatives. Sampling procedures used in environmental sampling are either unbiased or biased. Classical and geostatistical models are unbiased in terms of sample evaluation and hypothesis testing. The classical model is based on random, or stratified random procedures, and the geostatistical model on optimizing co-variance. Systematic grid sampling can be utilized by either the classical or geostatistical model. Biased, or judgmental/ purposive, design requires the use of different approaches to planning and evaluation.

☛ *While other designs may be appropriate in many cases, stratified random or systematic sampling designs are always acceptable.*

- Classical model: The classical model uses either a random or stratified random sampling design. It is appropriate for use in sampling any medium to define the representative concentration value over the exposure area. It is not subject to judgmental biases, and produces known estimates and recognized statistical measures and guidelines. A stratified random design provides the RPM and risk assessor with great flexibility. If the nature and extent of the exposure areas are not yet well defined, a pilot random study can be conducted and the results included in the final design. The data can be averaged for any exposure area. The classical model is the basis for calculating

EXHIBIT 43. APPLICABILITY OF SAMPLING DESIGNS

Design	Objective of Sampling		
	Estimate Chemical Concentration Distribution	Evaluate Trends	Identify Hot Spots
Judgmental/ Purposive	No	Maybe	Maybe
Classical Random	Yes	Yes	No
Classical Stratified:			
Random	Yes	Yes	Maybe
Systematic	Maybe	Yes	Maybe
Cluster	Yes	No	No
Composite	Maybe	No	Maybe
Systematic:			
Random	Maybe	Yes	Maybe
Grid	No	Yes	Yes
Search	No	No	Yes
Surrogate	No	Yes	Maybe
Phased	No	Maybe	Yes
Geostatistical	Yes	Yes	Yes

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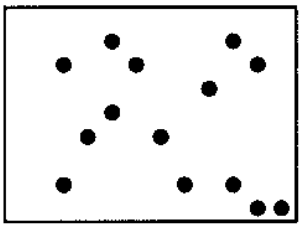
confidence levels, power, and minimum detectable relative differences (MDRDs).

- Geostatistical model: Geostatistical techniques are good for identifying hot spots and can be used for calculating reasonable maximum exposure (RME). These techniques require complex judgmental or purposive calculation procedures. Even with the use of available computer programs, a statistician should be consulted because different approaches to estimating key parameters can produce different estimates.

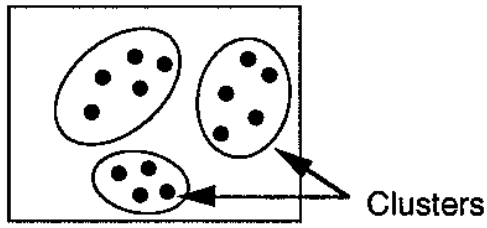
- Systematic grid sampling: Systematic grid sampling procedures are good for identifying unknown hot spots and also provide unbiased estimates of chemical occurrence and concentration (Gilbert 1987) useful in calculating the RME. Systematic sampling can be used in geostatistical or classical estimation models. Variance

EXHIBIT 44. COMMON SAMPLING DESIGNS

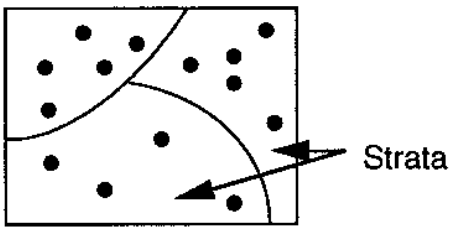
Simple Random Sampling



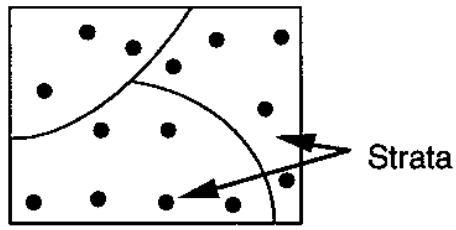
Cluster Sampling



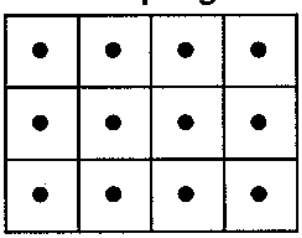
Stratified Random Sampling



Stratified Systematic Sampling



Systematic Grid Sampling



Systematic Random Sampling

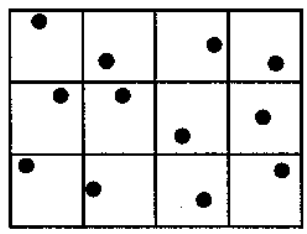


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EXHIBIT 45. HIERARCHICAL STRUCTURE OF SAMPLING DESIGN SELECTION WORKSHEET

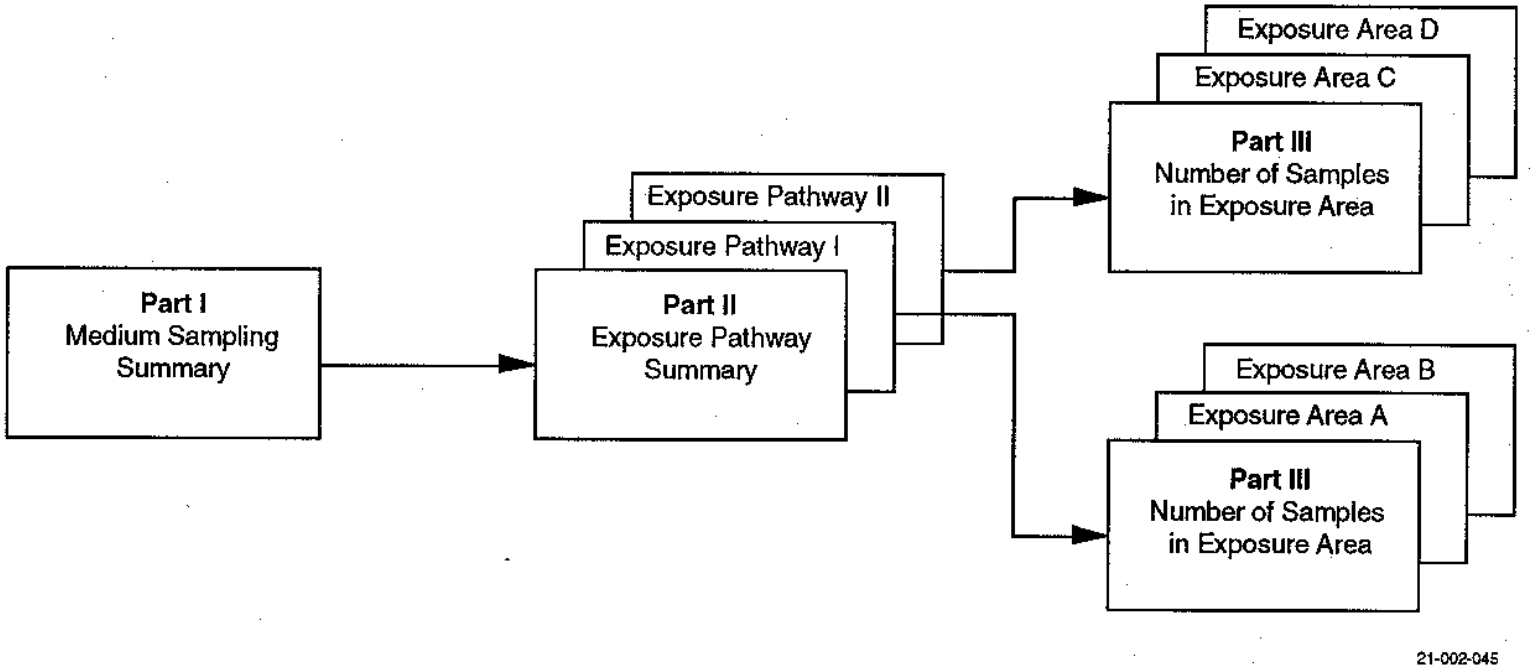

EXHIBIT 45. PART I: MEDIUM SAMPLING SUMMARY SAMPLING DESIGN SELECTION WORKSHEET (Cont'd)

A. Site Name _____ B. Base Map Code _____

C. Medium: Groundwater, Soil, Sediment, Surface Water, Air
Other (Specify) _____

D. Comments: _____

E. Medium/ Pathway Code	Exposure Pathway/ Exposure Area Name	F. Number of Samples from Part II					
		Judgmental/ Purposive	Back-ground	Statistical Design	Geo-metrical or Geo-statistical Design	QC	Row Total
	Column Totals:						
						G: Grand Total:	

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EXHIBIT 45. PART II: EXPOSURE PATHWAY SUMMARY SAMPLING DESIGN SELECTION WORKSHEET (Cont'd)

H. Chemical of Potential Concern and CAS Number	I. Frequency of Occurrence	J. Estimation		K. CV	L. Background
		Arithmetic Mean	Maximum		

M. Code (CAS Number) of Chemical of Potential Concern Selected as Proxy _____

N. Reason for Defining New Stratum or Domain (Circle one)

1. Heterogeneous Chemical Distribution
2. Geological Stratum Controls
3. Historical Information Indicates Difference
4. Field Screening Indicates Difference
5. Exposure Variations
6. Other (specify) _____

O. Stratum or Exposure Area	P. Reason	Q. Number of Samples from Part III					
Name and Code		Judgmental/ Purposive	Back-ground	Statistical Design	Geo-metrical or Geo-statistical Design	QC	Row Total
	R. Total (Part I, Step F):						

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EXHIBIT 45. PART III: EXPOSURE AREA SUMMARY SAMPLING DESIGN SELECTION WORKSHEET (Cont'd)

O. Stratum or Exposure Area _____ Domain Code _____
E. Medium/Pathway Code _____ Pathway Code _____

S. Judgmental or Purposive Sampling
Comments: _____
_____

Use prior site information to place samples, or determine location and extent of contamination. Judgmental or purposive samples generally cannot be used to replace statistically located samples.

An exposure area and stratum MUST be sampled by at least TWO samples.

Number of Samples

T. Background Samples
Background samples must be taken for each medium relevant to each stratum/area. Zero background samples are not acceptable. See the discussion on page pp. 74-75.

Number of Background Samples

U. Statistical Samples
CV of proxy or chemical of potential concern _____
Minimum Detectable Relative Difference (MDRD) _____ (<40% if no other information exists)
Confidence Level _____ (>80%) Power of Test _____ (>90%)

Number of Samples
(See formula in Appendix IV)

V. Geometrical Samples
Hot spot radius _____ (Enter distance units) _____
Probability of hot spot prior to investigation _____ (0 to 100%)
Probability that NO hot spot exists after investigation _____ (enter only if >75%)
(see formula in Appendix IV)

W. Geostatistical Samples

Required number of samples to complete grid +
Number of short range samples

X. Quality Control Samples
Number of Duplicates (Minimum 1:20 environmental samples) _____
Number of Blanks (Minimum 1 per medium per day or 1 per sampling process, whichever is greater) _____

Y. Sample Total for Stratum
(Part II, Step U)

Judgmental/ Purposive	Back-ground	Statis-tical Design	Geo-metrical or Geo-statistical	QC	Row Total

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calculations required to estimate confidence limits on the average concentration are available (Caulcutt 1983). Systematic sampling is powerful for complete site or exposure area characterization when the exposure area is known to be heterogeneous.

Determining number of samples. Four factors need to be considered in determining the total number of samples required (see Exhibit 46):

- Exposure areas,
- Statistical performance objectives (based on site environmental samples),
- Quality assurance objectives (based on QC samples), and
- Background samples (based on MDRD).

EXHIBIT 46. FACTORS IN DETERMINING TOTAL NUMBER OF SAMPLES COLLECTED

Number of Exposure Areas That will be Sampled (p. 74)

- Media within exposure area
- Strata within exposure area medium

Number of Samples for Each Exposure Area Grouping Given Required Statistical Performance (p. 75)

- Confidence (1- α), where α is the probability of a type I error
- Power (1- β), where β is the probability of a type II error
- Minimum detectable relative difference

Number of Quality Control Samples (p. 76)

- Field duplicate (collocated)
- Field duplicate (split)
- Blank (trip, field, and equipment (rinsate))
- Field evaluation

Number of Background Samples (p. 74)

- Number of site samples collected
- Minimum detectable relative difference

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The number of environmental site samples is ultimately controlled by performance requirements, given the statistical sampling design. The relationship between number of samples and measures of performance depends upon the variability of the chemicals of potential concern, which is measured by the coefficient of variation. In other words, the relationship between the coefficient of variation for a chemical of potential concern and measures of performance is the basis for determining the number of samples necessary to provide useable data for risk assessment.

> ☛ *If the natural variability of the chemicals of potential concern is large (e.g., greater than 30%), the major planning effort should be to collect more environmental samples.*

The number of samples can be calculated given a coefficient of variation, a required confidence level or certainty, a required statistical power, and an MDRD. Exhibit 47 illustrates the relationships between the number of samples required given typical values for the coefficient of variation and statistical performance objectives. Calculation formulas in Appendix IV facilitate the examination of effects beyond the examples cited.

4.1.2 Guidance for Completing the Sampling Design Selection Worksheet

This section provides step-by-step instructions for completing the Sampling Design Selection Worksheet shown in Exhibit 45.

Part I: Medium Sampling Summary

A. Enter the Superfund site name.

B. Enter a code that uniquely identifies a base map of the site or the exposure unit.

   All sampling events should be identified on a map or in a database such as a Geographical Information System (GIS).

C. Identify the medium to be sampled (e.g., soil, groundwater, industrial sludge, mine tailings, smelter slag, etc.).

D. Enter any comments required to describe the exposure area, and other information such as the RPM's name.

E. Enter a medium/pathway code that has been assigned for the risk investigation.

F. Specify the exposure pathway (e.g., ingestion of soil).

   Leave this entry blank for now, then enter the number of samples for each category that have been selected from Part II (Step R) of the worksheet when completed.

EXHIBIT 47. RELATIONSHIPS BETWEEN MEASURES OF STATISTICAL PERFORMANCE AND NUMBER OF SAMPLES REQUIRED

Coefficient of Variation (%)	Power (%)	Confidence Level (%)	Samples Required to Meet Minimum Detectable Relative Difference 5%	10%	20%
10	95	90	36	10	3
15	95	90	78	21	6
20	95	90	138	36	10
25	95	90	216	55	15
30	95	90	310	78	21
35	95	90	421	106	28

Note: Number of samples required in a one-sided one-sample t-test to achieve a minimum detectable relative difference at confidence level and power. CV based on geometric mean for transformed data.

Source: EPA 1989c.

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Sample types are broken out by sample type:

- Judgmental/Purposive,
- Background,
- Statistical design (e.g., stratified random sampling),
- Geometrical or geostatistical design (including hot spot sampling), and
- Quality control samples.

☛ *At least one broad spectrum analytical sample is required for risk assessment, and a minimum of two or three are recommended for each medium in an exposure pathway.*

G. Enter the grand total of all samples within a specific medium.

Part II: Exposure Pathway Summary

H. List the chemicals of potential concern and their CAS numbers.

List the known or suspected chemicals of potential concern based on historical data. This will generally be from the PA/SI.

I. List the frequency of occurrence (%).

The frequency of occurrence is the percent of samples in which the chemical of potential concern has been identified. This may be obtained from site-specific data or calculated from historial (PA/SI) data or fate and transport modeling.

J. Enter an estimate of the average (arithmetic mean) and maximum concentration of the chemical of potential concern.

Historical data or data from similar sites can be used to derive these values. More sampling will usually be necessary to determine statistically

significant differences if these values are close to background levels or to the levels of detection.

K. Estimate the coefficient of variation.

The coefficient of variation (CV) can be estimated from site-specific data or from data from similar sites. The number of samples necessary to produce useable data will generally increase as the CV increases. The definition of separate strata or domains should be investigated if a CV is above 50%. Exhibit 23 contains a listing of historical values for CVs that may be used as an estimate in the absence of site-specific data.

L. Estimate background concentration.

Background concentration estimates should be for each medium relevant to each strata/area. Site-specific data are preferred, but data from similar sites can be utilized.

M. Select a proxy chemical of potential concern.

Choose a proxy from the list of chemicals of potential concern to develop sampling plans. Note that a proxy that has the highest CV, lowest frequency of occurrence, or whose concentration at the site is closest to background levels will require the most samples.

N. Develop the reason for defining new strata or areas.

- Heterogeneous Chemical Distribution: If a chemical can be shown to have dissimilar distributions of concentration in different areas, then the areas should be subdivided. For example, hot spots may be considered separately.
- Geological Stratum Controls: Knowledge of local geologic conditions can be used to produce separate areas where similar statistical distributions are likely to exist. In particular, different "stratigraphic" layers may produce distinct strata.
- Historical Information: Historical information on production, discharge or storage of chemicals of potential concern can be used to identify separate areas.
- Field Screening: Field analytical results can be used to locate sub-populations that are mapped into exposure areas.
- Exposure Variations: Information or variations in behavior patterns, land use or receptor groups can be used to identify separate areas.
- Other reasons can be used to produce separate sampling areas, such as observed stress on vegetation, oily appearance of soils, or the existence of refuse, etc.

O. List the stratum or area name and code.

The stratum or area identifies sub-areas on the site base-map.

P. Annotate reason from Step N.

Q. List the number of samples estimated after completing Part III of this worksheet.

R. List the number of samples estimated after completing Part II and Part III of this worksheet.

Part III: Exposure Area Summary

S. Enter judgmental/purposive sampling comments.

A minimum of three to five judgmental or purposive samples must be used to sample a stratum or exposure area. Historical or prior site information can be used to locate sampling positions to determine the extent and magnitude of contamination. Chemical field screening, geophysics, vegetation stress, remote sensing, geology, etc. can also be used to guide judgmental sampling. Judgmental or purposive samples are not recommended for estimating average and maximum values within a stratum or domain area, but they can be used in geostatistical kriging estimations and can be included in calculating risk.

T. Identify background samples.

For statistical purposes, a sufficient number of background samples must be taken to determine the validity of the null hypothesis that there is no difference between mean values of concentration in the site and the background samples at the desired level of confidence. Early sampling and analysis of background samples will indicate the ease with which background levels can be discriminated, and allow modifications to be made to the SAP if necessary.

Background samples must be taken for each exposure pathway. As with QC samples, results from the background sample should be assessed early to see if background levels will severely impact the sampling design. The number of necessary background samples increases as the variability of the background values increases. Background samples should not be used in the estimation of average or maximum values within a stratum or exposure area, but they can be used in

kriging estimations. In those instances where background levels are close to on-site contamination levels, it may be necessary to collect as many background samples as site samples. Small numbers of background samples increase the probability of a type II, false negative error (i.e., that no difference exists between site and background when a difference does, in fact, exist). However, rigorous statistical analyses involving background samples may be unnecessary if site and non-site related contamination clearly differ.

☛ *Collect and analyze background samples prior to the final determination of the sampling design since the number of samples is significantly reduced if little background contamination is present.*

Background levels of contaminants vary by medium and the type of contamination. If a detectable background level of a contaminant occurs infrequently, the number of background samples analyzed might be kept small. Metals often have high rates of detection in background samples. Some pesticides, such as DDT, are anthropogenic and also have high rates of detection in particular matrices. Anthropogenic background levels are also found in sites near industries and urban areas. It is important to distinguish detection, or lack of detection, in a single sample from a false positive or false negative result. Results from single samples are different estimators than those from statistical parameters from pooled samples. Background sampling must be increased in the following situations:

- Contamination exists in more than one medium,
- Expected coefficients of variation in chemicals of concern are high and confirmed by actual data,
- Relative differences between site and background levels are small, and
- Site concentrations and concentrations of concern are low.

U. Identify statistical samples.

Samples should be systematically or randomly located. The number of samples can be calculated using the CV of the proxy variable, the required MDRD, the required confidence level and power of the test, and the appropriate statistical formula and appropriate charts.

For example, using the equation in Appendix IV:

> Where Z_α and Z_β are obtained from the normal distribution tables for significance levels α and β respectively; α is the probability of the false positive error rate, and β is the probability of the false negative error rate.
>
> Then, if α is 0.2 (20%) and the confidence level is 80% then Z_α is 0.842. If β is 0.05 (5%) then the power is 95% and Z_β is 1.648.
>
> If the MDRD is 20% and the CV is 30%, then $D = \frac{MDRD}{CV}$ which equals 0.666
> and n>15 samples are required.

V. Identify samples from geometrical design.

☛ *Systematic sampling supplemented by judgmental sampling is the best strategy for identifying hot spots.*

For example, using the equation in Appendix IV:

> Where R = 20 m
>
> and A = 37,160 m^2
>
> and X = 0.3 Probability that a hot spot is in the exposure area from "historical records" or from field screening or geophysical tests.
>
> and C = 0.2 The acceptable "walk away" probability that a hot spot exists after a sampling grid has been done.
>
> then:
>
> D = 2.7, R = 54.8 m, and
> n = 27,160/54.82 = 12.37
>
> Therefore 12 samples are required.

Note that the requirements for 15 samples from a statistical sampling approach can be met in this example if the hot spot search is augmented by randomly locating two additional samples. The results for number of samples from U and V are not additive.

W. Identify samples from geostatistical design.

A geostatistical sampling pattern should be designed at the early stage of planning. A statistician should be consulted to develop the design.

X. Quality Control Samples

Generally, duplicates should be taken at a minimum of 1 duplicate for every 20 environmental samples (EPA 1989f). However, this frequency may be modified based on site conditions. For example, the number of duplicates and other QC samples may be set high for the beginning of site sampling, evaluated after several duplicates to determine routine measurement error, and subsequently adjusted according to observed performance. The information in Exhibit 48 shows that confidence in measurement error increases sharply when four or more pairs of duplicate samples are taken per medium. Critical samples are recommended for designation as duplicates in the QA sampling design.

EXHIBIT 48. NUMBER OF SAMPLES REQUIRED TO ACHIEVE GIVEN LEVELS OF CONFIDENCE, POWER, AND MDRD [1]

Confidence (1-α)	Power (1-ß)	MDRD	No. of Samples
90%	90%	10%	42
90%	90%	20%	12
80%[2]	90%[2]	20%	8
80%	80%	10%	19
80%	80%	20%	5
80%[2]	90%[2]	40%	3

[1] Values for number of samples are based on a CV of 25%.

[2] The minimum recommended performance measures for risk assessment are: confidence (80%) and power (90%).

Source: EPA 1989c.

Blanks provide an estimate of bias due to contamination introduced by sampling, transportation, carryover during field filtration, preservation, or storage. At least one field blank per medium should be collected each day, and at least one blank must be collected for each sampling process (EPA 1989f).

Examine results from duplicate and blank samples as early as possible in the sampling operation to ascertain if presumed sampling characteristics are accurate and discover areas where the sampling strategy requires modification. For a more detailed discussion of the types and use of QC samples see *A Rationale for the Assessment of Errors in the Sampling of Soils* (EPA 1990c).

Y. Calculate the sample total for stratum or exposure area (enter in Part II, Step U).

4.1.3 Specific Sampling Issues

Selection of performance measures. Quantitative data quality indicators based on performance objectives should be proposed for completeness, comparability, representativeness, precision, and accuracy during planning. Performance measures are specified as minimum limits for each stratum. Based on the coefficients of variation of the analyte concentrations, these limits will determine the numbers of samples required. The actual values or objectives are determined by the level of acceptable uncertainty, which includes that associated with hot spot identification. Recommended minimum criteria are specified in Exhibit 48 for statistical performance measures associated with the uncertainty in risk assessment: confidence level, power, and MDRD. Recommended minimum criteria for measurement error and completeness for critical samples are discussed in the following sections.

Setting minimum acceptable limits for confidence level, power, and minimum detectable relative difference. Confidence level, power, and MDRD are three measures of sampling design precision. These measures are ultimately determined by the coefficient of variation of chemical concentration and the number of samples. Each measure is briefly defined as follows:

- Confidence level: The confidence level is 100 minus α, where α is the **percent** probability of taking action when no action is required (false positive).
- Power: Power is 100 minus ß, where ß is the **percent** probability of not taking action when action is required (false negative).
- Minimum detectable relative difference: MDRD is the percent difference required between site and background concentration levels before the difference can be detected statistically.

The power and ability to detect differences between site concentration levels compared to background levels are critical for risk assessment. Given a CV, the required levels of confidence, power, and MDRD significantly affect the number of samples. Exhibit 48 illustrates the effect when the CV is equal to 25%.

It is important to note that the number of samples required to meet confidence and power requirements will be low if the acceptable MDRD is large; that is, if site contamination is easily discriminated from background levels.

Determining required precision of measurement error. Field duplicates and blanks are the major field QC samples of importance to the precision of measurement error. Duplicates provide an estimate of