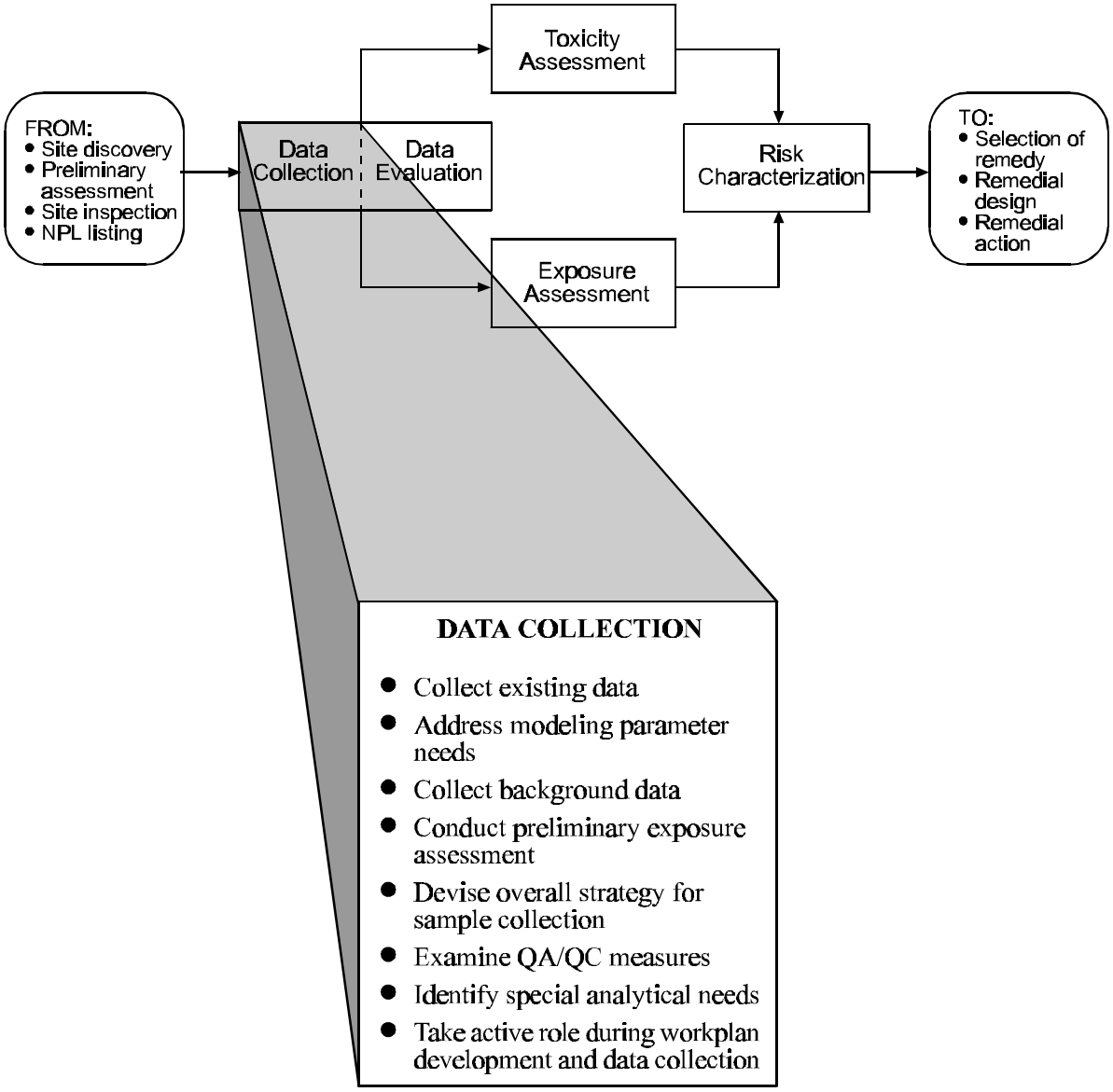
CHAPTER 4
DATA COLLECTION



CHAPTER 4

DATA COLLECTION

This chapter discusses procedures for acquiring reliable chemical release and exposure data for quantitative human health risk assessment at hazardous waste sites.[1] The chapter is intended to be a limited discussion of important sampling considerations with respect to risk assessment; it is not intended to be a complete guide on how to collect data or design sampling plans.

Following a general background section (Section 4.1), this chapter addresses the following eight important areas:

(1) review of available site information (Section 4.2);

(2) consideration of modeling parameter needs (Section 4.3);

(3) definition of background sampling needs (Section 4.4);

(4) preliminary identification of potential human exposure (Section 4.5);

(5) development of an overall strategy for sample collection (Section 4.6);

(6) definition of required QA/QC measures (Section 4.7);

(7) evaluation of the need for Special Analytical Services (Section 4.8); and

(8) activities during workplan development and data collection (Section 4.9).

4.1 BACKGROUND INFORMATION USEFUL FOR DATA COLLECTION

This section provides background information on the types of data needed for risk assessment, overall data needs of the RI/FS, reasons and steps for identifying risk assessment data needs early, use of the *Data Quality Objectives for Remedial Response Activities* (EPA 1987a,b, hereafter referred to as the DQO guidance), and other data concerns.

4.1.1 TYPES OF DATA

In general, the types of site data needed for a baseline risk assessment include the following:

- contaminant identities;

ACRONYMS FOR CHAPTER 4

CLP = Contract Laboratory Program
DQO = Data Quality Objectives
FIT = Field Investigation Team
FSP = Field Sampling Plan
HRS = Hazard Ranking System
IDL = Instrument Detection Limit
MDL = Method Detection Limit
PA/SI = Preliminary Assessment/Site Inspection
QA/QC = Quality Assurance/Quality Control
QAPjP = Quality Assurance Project Plan
RAS = Routine Analytical Services
RI/FS = Remedial Investigation/Feasibility Study
SAP = Sampling and Analysis Plan
SAS = Special Analytical Services
SMO = Sample Management Office
SOW = Statement of Work
TAL = Target Analyte List
TCL = Target Compound List
TIC = Tentatively Identified Compound

DEFINITIONS FOR CHAPTER 4

Analytes. The chemicals for which a sample is analyzed.

Anthropogenic Background Levels. Concentrations of chemicals that are present in the environment due to human-made, non-site sources (e.g., industry, automobiles).

Contract Laboratory Program (CLP). Analytical program developed for Superfund waste site samples to fill the need for legally defensible analytical results supported by a high level of quality assurance and documentation.

Data Quality Objectives (DQOs). Qualitative and quantitative statements to ensure that data of known and documented quality are obtained during an RI/FS to support an Agency decision.

Field Sampling Plan (FSP). Provides guidance for all field work by defining in detail the sampling and data gathering methods to be used on a project.

Naturally Occurring Background Levels. Ambient concentrations of chemicals that are present in the environment and have not been influenced by humans (e.g., aluminum, manganese).

Quality Assurance Project Plan (QAPjP). Describes the policy, organization, functional activities, and quality assurance and quality control protocols necessary to achieve DQOs dictated by the intended use of the data (*RI/FS Guidance*).

Routine Analytical Services (RAS). The set of CLP analytical protocols that are used to analyze most Superfund site samples. These protocols are provided in the EPA Statements of Work for the CLP (*SOW for Inorganics*, *SOW for Organics*) and must be followed by every CLP laboratory.

Sampling and Analysis Plan (SAP). Consists of a Quality Assurance Project Plan (QAPjP) and a Field Sampling Plan (FSP).

Sample Management Office (SMO). EPA contractor providing management, operational, and administrative support to the CLP to facilitate optimal use of the program.

Special Analytical Services (SAS). Non-standardized analyses conducted under the CLP to meet user requirements that cannot be met using RAS, such as shorter analytical turnaround time, lower detection limits, and analysis of non-standard matrices or non-TCL compounds.

Statement of Work (SOW) for the CLP. A document that specifies the instrumentation, sample handling procedures, analytical parameters and procedures, required quantitation limits, quality control requirements, and report format to be used by CLP laboratories. The SOW also contains the TAL and TCL.

Target Analyte List (TAL). Developed by EPA for Superfund site sample analyses. The TAL is a list of 23 metals plus total cyanide routinely analyzed using RAS.

Target Compound List (TCL). Developed by EPA for Superfund site sample analyses. The TCL is a list of analytes (34 volatile organic chemicals, 65 semivolatile organic chemicals, 19 pesticides, 7 polychlorinated biphenyls, 23 metals, and total cyanide) routinely analyzed using RAS.

- contaminant concentrations in the key sources and media of interest;[2]
- characteristics of sources, especially information related to release potential; and
- characteristics of the environmental setting that may affect the fate, transport, and persistence of the contaminants.

Most of these data are obtained during the course of a remedial investigation/feasibility study (RI/FS). Other sources of information, such as preliminary assessment/site inspection (PA/SI) reports, also may be available.

4.1.2 DATA NEEDS AND THE RI/FS

The RI/FS has four primary data collection components:

(1) characterization of site conditions;
(2) determination of the nature of the wastes;
(3) risk assessment; and
(4) treatability testing.

The site and waste characterization components of the RI/FS are intended to determine characteristics of the site (e.g., ground-water movement, surface water and soil characteristics) and the nature and extent of contamination through sampling and analysis of sources and potentially contaminated media. Quantitative risk assessment, like site characterization, requires data on concentrations of contaminants in each of the source areas and media of concern. Risk assessment also requires information on other variables necessary for evaluating the fate, transport, and persistence of contaminants and estimating current and potential human exposure to these contaminants. Additional data might be required for environmental risk assessments (see EPA 1989a).

Data also are collected during the RI/FS to support the design of remedial alternatives. As discussed in the DQO guidance (EPA 1987a,b), such data include results of analyses of contaminated media "before and after" bench-scale treatability tests. This information usually is not appropriate for use in a baseline risk assessment because these media typically are assessed only for a few individual parameters potentially affected by the treatment being tested. Also, initial treatability testing may involve only a screening analysis that generally is not sensitive enough and does not have sufficient quality assurance/quality control (QA/QC) procedures for use in quantitative risk assessment.

4.1.3 EARLY IDENTIFICATION OF DATA NEEDS

Because the RI/FS and other site studies serve a number of different purposes (e.g., site and waste characterization, design of remedial alternatives), only a subset of this information generally is useful for risk assessment. To ensure that all risk assessment data needs will be met, it is important to identify those needs early in the RI/FS planning for a site. The earlier the requirements are identified, the better the chances are of developing an RI/FS that meets the risk assessment data collection needs.

One of the earliest stages of the RI/FS at which risk assessment data needs can be addressed is the site scoping meeting. As discussed in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988a, hereafter referred to as RI/FS guidance), the scoping meeting is part of the initial planning phase of site remediation. It is at this meeting that the data needs of each of the RI/FS components (e.g., site and waste characterization) are addressed together. Scoping meeting attendees include the RPM, contractors conducting the RI/FS (including the baseline risk assessment), onsite personnel (e.g., for construction), and natural resource trustees (e.g., Department of Interior). The scoping meeting allows development of a comprehensive sampling and analysis plan (SAP) that will satisfy the needs of each RI/FS component while helping to ensure that time and budget constraints are met. Thus, in addition to aiding the effort to meet the risk assessment data needs, this meeting can help integrate these needs with other objectives of the RI/FS and thereby help make maximum use of available resources and avoid duplication of effort.

During scoping activities, the risk assessor should identify, at least in preliminary fashion, the type and duration of possible exposures (e.g., chronic, intermittent), potential exposure routes (e.g., ingestion of fish, ingestion of drinking water, inhalation of dust), and key exposure points (e.g., municipal wells, recreation areas) for each medium. The relative importance of the potential exposure routes and exposure points in determining risks should be discussed, as should the consequences of not studying them adequately. Section 4.5 and Chapter 6 provide guidance for identifying exposure pathways that may exist at hazardous waste sites. If potential exposure pathways are identified early in the RI/FS process, it will be easier to reach a decision on the number, type, and location of samples needed to assess exposure.

During the planning stages of the RI/FS, the risk assessor also should determine if non-routine (i.e., lower) quantitation limits are needed to adequately characterize risks at a site. Special Analytical Services (SAS) of the EPA Contract Laboratory Program (CLP) may be needed to achieve such lower quantitation limits. (See Section 4.8 for additional information concerning quantitation limits.)

4.1.4 USE OF THE DATA QUALITY OBJECTIVES (DQO) GUIDANCE

The DQO guidance (EPA 1987a,b) provides information on the review of site data and the determination of data quality needs for sampling (see the box below).

OVERVIEW OF DQO GUIDANCE

According to the DQO guidance (EPA 1987a and b), DQO are qualitative and quantitative statements established prior to data collection, which specify the quality of the data required to support Agency decisions during remedial response activities. The DQO for a particular site vary according to the end use of the data (i.e., whether the data are collected to support preliminary assessments/site inspections, remedial investigations/feasibility studies, remedial designs, or remedial actions).

The DQO process consists of three stages. In Stage 1 (Identify Decision Types), all available site information is compiled and analyzed in order to develop a conceptual model of the site that describes suspected sources, contaminant pathways, and potential receptors. The outcome of Stage 1 is a definition of the objectives of the site investigation and an identification of data gaps. Stage 2 (Identify Data Uses/Needs) involves specifying the data necessary to meet the objectives set in Stage 1, selecting the sampling approaches and the analytical options for the site, and evaluating multiple-option approaches to allow more timely or cost-effective data collection and evaluation. In Stage 3 (Design Data Collection Program), the methods to be used to obtain data of acceptable quality are specified in such products as the SAP or the workplan.

Use of this guidance will help ensure that all environmental data collected in support of RI/FS activities are of known and documented quality.

4.1.5 OTHER DATA CONCERNS

The simple existence of a data collection plan does not guarantee usable data. The risk assessor should plan an active role in oversight of data collection to ensure that relevant data have been obtained. (See Section 4.9 for more information on the active role that the risk assessor must play.)

After data have been collected, they should be carefully reviewed to identify reliable, accurate, and verifiable numbers that can be used to quantify risks. All analytical data must be evaluated to identify the chemicals of potential concern (i.e., those to be carried through the risk assessment). Chapter 5 discusses the criteria to be considered in selecting the subset of chemical data appropriate for baseline risk assessment. Data that do not meet the criteria are not included in the quantitative risk assessment; they can be discussed qualitatively in the risk assessment report, however, or may be the basis for further investigation.

4.2 REVIEW OF AVAILABLE SITE INFORMATION

Available site information must be reviewed to (1) determine basic site characteristics, (2) initially identify potential exposure pathways and exposure points, and (3) help determine data needs (including modeling needs). All available site information (i.e., information existing at the start of the RI/FS) should be reviewed in accordance with Stage 1 of the DQO process. Sources of available site information include:

- RI/FS scoping information;
- PA/SI data and Hazard Ranking System (HRS) documentation;
- listing site inspection (LSI) data (formally referred to as expanded site inspection, or ESI);
- photographs (e.g., EPA's Environmental Photographic Interpretation Center [EPIC]);
- records on removal actions taken at the site; and
- information on amounts of hazardous substances disposed (e.g., from site records).

If available, LSI (or ESI) data are especially useful because they represent fairly extensive site studies.

Based on a review of the existing data, the risk assessor should formulate a conceptual model of the site that identifies all potential or suspected sources of contamination, types and concentrations of contaminants detected at the site, potentially contaminated media, and potential exposure pathways, including receptors (see Exhibit 4-1). As

discussed previously, identification of potential exposure pathways, especially the exposure points, is a key element in the determination of data needs for the risk assessment. Details concerning development of a conceptual model for a site are provided in the DQO guidance (EPA 1987a,b) and the RI/FS guidance (EPA 1988a).

In most cases, site information available at the start of the RI/FS is insufficient to fully characterize the site and the potential exposure pathways. The conceptual model developed at this stage should be adequate to determine the remaining data needs. The remainder of this chapter addresses risk assessment data needs in detail.

4.3 ADDRESSING MODELING PARAMETER NEEDS

As discussed in detail in Chapter 6, contaminant release, transport, and fate models are often needed to supplement monitoring data when estimating exposure concentrations. Therefore, a preliminary site modeling strategy should be developed during RI/FS scoping to allow model input data requirements to be incorporated into the data collection requirements. This preliminary identification of models and other related data requirements will ensure that data for model calibration and validation are collected along with other physical and chemical data at the site. Exhibit 4-2 lists (by medium) several site-specific parameters often needed to incorporate fate and transport models in risk assessments.

Although default values for some modeling parameters are available, it is preferable to obtain site-specific values for as many input parameters as is feasible. If the model is not sensitive to a particular parameter for which a default value is available, then a default value may be used. Similarly, default values may be used if obtaining the site-specific model parameter would be too time consuming or expensive. For example, certain airborne dust emission models use a default value for the average wind speed at the site; this is done because representative measurements of wind speed at the site would involve significant amounts of time (i.e., samples would have to be collected over a large part of the year).

Some model parameters are needed only if the sampling conducted at a site is sufficient to support complex models. Such model parameters may not be necessary if only simple fate and transport models are used in the risk assessment.

4.4 DEFINING BACKGROUND SAMPLING NEEDS

Background sampling is conducted to distinguish site-related contamination from naturally occurring or other non-site-related levels of chemicals. The following subsections define the types of background contamination and provide guidance on the appropriate location and number of background samples.

4.4.1 TYPES OF BACKGROUND

There are two different types of background levels of chemicals:

(1) naturally occurring levels, which are ambient concentrations of chemicals present in the environment that have not been influenced by humans (e.g., aluminum, manganese); and

(2) anthropogenic levels, which are concentrations of chemicals that are present in the environment due to human-made, non-site sources (e.g., industry, automobiles).

Background can range from localized to ubiquitous. For example, pesticides -- most of which are not naturally occurring (anthropogenic) -- may be ubiquitous in certain areas (e.g., agricultural areas); salt runoff from roads during periods of snow may contribute high ubiquitous levels of sodium. Polycyclic aromatic hydrocarbons (PAHs) and lead are other examples of anthropogenic, ubiquitous chemicals, although these chemicals also may be present at naturally occurring levels in the environment due to natural sources (e.g., forest fires may be a source of PAHs, and lead is a natural component of soils in some areas).

EXHIBIT 4-1
ELEMENTS OF A CONCEPTUAL EVALUATION MODEL

	VARIABLES	HYPOTHESES TO BE TESTED
SOURCES	• CONTAMINANTS • CONCENTRATIONS • TIME • LOCATIONS	• SOURCE EXISTS • SOURCE CAN BE CONTAINED • SOURCE CAN BE REMOVED AND DISPOSED • SOURCE CAN BE TREATED
PATHWAYS	• MEDIA • RATES OF MIGRATION • TIME • LOSS AND GAIN FUNCTIONS	• PATHWAY EXISTS • PATHWAY CAN BE INTERRUPTED • PATHWAY CAN BE ELIMINATED
RECEPTORS	• TYPES • SENSITIVITIES • TIME • CONCENTRATIONS • NUMBERS	• RECEPTOR IS NOT IMPACTED BY MIGRATION OF CONTAMINANTS • RECEPTOR CAN BE RELOCATED • INSTITUTIONAL CONTROLS CAN BE APPLIED • RECEPTOR CAN BE PROTECTED

EXHIBIT 4-2

EXAMPLES OF MODELING PARAMETERS FOR WHICH INFORMATION MAY NEED TO BE OBTAINED DURING A SITE SAMPLING INVESTIGATION

Type of Modeling	Modeling Parameters[a]
Source Characteristics	Geometry, physical/chemical conditions, emission rate, emission strength, geography
Soil	Particle size, dry weight, pH, redox potential, mineral class, organic carbon and clay content, bulk density, soil porosity
Ground-water	Head measurements, hydraulic conductivity (pump and slug test results), saturated thickness of aquifer, hydraulic gradient, pH, redox potential, soil-water partitioning
Air	Prevailing wind direction, wind speeds, stability class, topography, depth of waste, contaminant concentration in soil and soil gas, fraction organic content of soils, silt content of soils, percent vegetation, bulk density of soil, soil porosity
Surface Water	Hardness, pH, redox potential, dissolved oxygen, salinity, temperature, conductivity, total suspended solids, flow rates, and depths for rivers/streams, estuary and embayment parameters such as tidal cycle, saltwater incursion extent, depth and area, lake parameters such as area, volume, depth, depth to thermocline
Sediment	Particle size distribution, organic content, pH, benthic oxygen conditions, water content
Biota	Dry weight, whole body, specific organ, and/or edible portion chemical concentrations, percent moisture, lipid content, size/age, life history stage

[a] These parameters are not necessarily limited to the type of modeling with which they are associated in this exhibit. For example, many of the parameters listed for surface water are also appropriate for sediments.

4.4.2 BACKGROUND SAMPLING LOCATIONS

Background samples are collected at or near the hazardous waste site in areas not influenced by site contamination. They are collected from each medium of concern in these offsite areas. That is, the locations of background samples must be areas that could not have received contamination from the site, but that do have the same basic characteristics as the medium of concern at the site.

Identifying background location requires knowing which direction is upgradient/upwind/ upstream. In general, the direction of water flow tends to be relatively constant, whereas the direction of air flow is constantly changing. Therefore, the determination of background locations for air monitoring requires constant and concurrent monitoring of factors such as wind direction.

4.4.3 BACKGROUND SAMPLE SIZE

In appropriate circumstances, statistics may be used to evaluate background sample data. Because the number of background samples collected is important for statistical hypothesis testing, at some sites a statistician should be consulted when determining background sample size. At all sites, the RPM should decide the level of statistical analysis applicable to a particular situation.

Often, rigorous statistical analyses are unnecessary because site- and non-site-related contamination clearly differ. For most sites, the issue will not be whether a difference in chemical concentrations can be demonstrated between contaminated and background areas, but rather that of establishing a reliable representation of the extent (in three dimensions) of a contaminated area. However, statistical analyses are required at some sites, making a basic understanding of statistics necessary. The following discussion outlines some basic statistical concepts in the context of background data evaluation for risk assessment. (A general statistics textbook should be reviewed for additional detail. Also, the box below lists EPA guidance that might be useful.)

STATISTICAL METHODS GUIDANCE

Statistical Methods for Evaluating Ground-water Monitoring Data from Hazardous Waste Facilities (EPA 1988b)

Surface Impoundment Clean Closure Guidance Manual (EPA 1988c)

Love Canal Emergency Declaration Area Habitability Study (EPA 1988d)

Soils Sampling Quality Assurance Guide (EPA 1989b)

A statistical test of a hypothesis is a rule used for deciding whether or not a statement (i.e., the null hypothesis) should be rejected in favor of a specified alternative statement (i.e., the alternative hypothesis). In the context of background contamination at hazardous waste sites, the null hypothesis can be expressed as "there is no difference between contaminant concentrations in background areas and onsite," and the alternative hypothesis can be expressed as "concentrations are higher onsite." This expression of the alternative hypothesis implies a one-tailed test of significance.

The number of background samples collected at a site should be sufficient to accept or reject the null hypothesis with a specified likelihood of error. In statistical hypothesis testing there are two types of error. The null hypothesis may be rejected when it is true (i.e., a Type I error), or not rejected when it is false (i.e., a Type II error). An example of a Type I error at a hazardous waste site would be to conclude that contaminant concentrations in onsite soil are higher than background soil concentrations when in fact they are not. The corresponding Type II error would be to conclude that onsite contaminant concentrations are not higher than background concentrations when in fact they are. A Type I error could result in unnecessary remediation, while a Type II error could result in a failure to clean up a site when such an action is necessary.

In customary notations, α (alpha) denotes the probability that a Type I error will occur, and β (beta) denotes the probability that a Type II error will occur. Most statistical comparisons refer to α, also known as the level of significance of the test. If $\alpha = 0.05$, there is a 5 percent (i.e., 1 in 20) chance that we will conclude that concentrations of contaminants are higher than background when they actually are not.

Equally critical considerations in determining the number of background samples are β and a concept called "power." The power of a statistical test has the value $1 - \beta$ and is defined as the likelihood that the test procedure detects a false null hypothesis. Power functions for commonly used statistical tests can be found in most general statistical textbooks. Power curves are a function of α (which normally is fixed at 0.05), sample size (i.e., the number of background and/or onsite samples), and the amount of variability in the data. Thus, if a 15 percent likelihood of failing to detect a false null hypothesis is desired (i.e., $\beta = 0.15$), enough background samples must be collected to ensure that the power of the test is at least 0.85.

A small number of background samples increases the likelihood of a Type II error. If an insufficient number of background samples is collected, fairly large differences between site and background concentrations may not be statistically significant, even though concentrations in the many site samples are higher than the few background samples. To guard against this situation, the statistical power associated with the comparison of background samples with site samples should be evaluated.

In general, when trying to detect small differences as statistically significant, the number of background samples should be similar to the number of onsite samples that will be used for the comparison(s) (e.g., the number of samples taken from one well). (Note that this does not mean that the background sample size must equal the total number of onsite samples.) Due to the inherent variability of air concentrations (see Section 4.6), background sample size for air needs to be relatively large.

4.4.4 COMPARING BACKGROUND SAMPLES TO SITE-RELATED CONTAMINATION

The medium sampled influences the kind of statistical comparisons that can be made with background data. For example, air monitoring stations and ground-water wells are normally positioned based on onsite factors and gradient considerations. Because of this purposive placement (see Section 4.6.1), several wells or monitors cannot be assumed to be a random sample from a single population and hence cannot be evaluated collectively (i.e., the sampling results cannot be combined). Therefore, the information from each well or air monitor should be compared individually with background.

Because there typically are many site-related, media-specific sampling location data to compare with background, there usually is a "multiple comparison problem" that must be addressed. In general, the probability of experiencing a Type I error in the entire set of statistical tests increases with the number of comparisons being made. If $\alpha = 0.05$, there is a 1 in 20 chance of a Type I error in any single test. If 20 comparisons are being made, it therefore is likely that at least one Type I error will occur among all 20 tests. *Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities* (EPA 1989c) is useful for designing sampling plans for comparing information from many fixed locations with background.

It may be useful at times to look at comparisons other than onsite versus background. For example, upgradient wells can be compared with downgradient wells. Also, there may be several areas within the site that should be compared for differences in site-related contaminant concentration. These areas of concern should be established before sampling takes place. If a more complicated comparison scheme is planned, a statistician should be consulted frequently to help distribute the sampling effort and design the analysis.

A statistically significant difference between background samples and site-related contamination should not, by itself, trigger a cleanup action. The remainder of this manual still must be applied so that the toxicological -- rather than simply the statistical -- significance of the contamination can be ascertained.

4.5 PRELIMINARY IDENTIFICATION OF POTENTIAL HUMAN EXPOSURE

A preliminary identification of potential human exposure provides much needed information for the SAP. This activity involves the identification of (1) media of concern, (2) areas of concern (i.e., general locations of the media to be sampled),[3] (3) types of chemicals expected at the site, and (4) potential routes of contaminant transport through the environment (e.g., inter-media transfer, food chain). This section provides general information on the preliminary identification of potential human exposure pathways, as well as specific information on the various media. (Also, see Chapter 6 for a detailed discussion of exposure assessment.)

4.5.1 GENERAL INFORMATION

Prior to discussing various specific exposure media, general information on the following is provided: media, types of chemicals, areas of concern, and routes of contaminant transport is addressed.

Media of concern (including biota). For risk assessment purposes, media of concern at a site are:

- any <u>currently contaminated</u> media to which individuals may be exposed or through which chemicals may be transported to potential receptors; and
- any <u>currently uncontaminated</u> media that may become contaminated in the future due to contaminant transport.

Several medium-specific factors in sampling may influence the risk assessment. For example, limitations in sampling the medium may limit the detailed evaluation of exposure pathways described in Chapter 6. To illustrate this, if soil samples are not collected at the surface of a site, then it may not be possible to accurately evaluate potential exposures involving direct contact with soils or exposures involving the release of contaminants from soils via wind erosion (with subsequent inhalation of airborne contaminants by exposed individuals). Therefore, based on the conceptual model of the site discussed previously, the risk assessor should make sure that appropriate samples are collected from each medium of concern.

Areas of concern. Areas of concern refer to the general sampling locations at or near the site. For large sites, areas of concern may be treated in the RI/FS as "operable units," and may include several media. Areas of concern also can be thought of as the locations of potentially exposed populations (e.g., nearest residents) or biota (e.g., wildlife feeding areas).

Areas of concern should be identified based on site-specific characteristics. These areas are chosen purposively by the investigators during the initial scoping meeting. Areas of concern should include areas of the site that:

(1) have different chemical types;

(2) have different anticipated concentrations or hot spots;

(3) are a release source of concern;

(4) differ from each other in terms of the anticipated spatial or temporal variability of contamination;

(5) must be sampled using different equipment; and/or

(6) are more or less costly to sample.

In some instances, the risk assessor may want to estimate concentrations that are representative of the site as a whole, in addition to each area of concern. In these cases, two conditions generally should be met in defining areas of concern: (1) the boundaries of the areas of concern should not

overlap and (2) all of the areas of concern together should account for the entire area of the site.

Depending on the exposure pathways that are being evaluated in the risk assessment, it may not be necessary to determine site-wide representative values. In this case, areas of concern do not have to account for the entire area of the site.

Types of chemicals. The types of chemicals expected at a hazardous waste site may dictate the site areas and media sampled. For example, certain chemicals (e.g., dioxins) that bioconcentrate in aquatic life also are likely to be present in the sediments. If such chemicals are expected at a particular site and humans are expected to ingest aquatic life, sampling of sediments and aquatic life for the chemicals may be particularly important.

Due to differences in the relative toxicities of different species of the same chemical (e.g., Cr^{+3} versus Cr^{+6}), the species should be noted when possible.

Routes of contaminant transport. In addition to medium-specific concerns, there may be several potential current and future routes of contaminant transport within a medium and between media at a site. For instance, discharge of ground water or surface runoff to surface water could occur. Therefore, when possible, samples should be collected based on routes of potential transport. For cases in which contamination has not yet reached points of human exposure but may be transported to those areas in the future, sampling between the contaminant source and the exposure locations should be conducted to help evaluate potential future concentrations to which individuals may be exposed (e.g., through modeling). (See Chapter 6 for additional discussion on contaminant transport.)

4.5.2 SOIL

Soil represents a medium of direct contact exposure and often is the main source of contaminants released into other media. As such, the number, location, and type of samples collected from soils will have a significant effect on the risk assessment. See the box on this page for guidance that provides additional detailed information concerning soil sampling, including information on sampling locations, general soil and vegetation conditions, and sampling equipment, strategies, and techniques. In addition to the general sampling considerations discussed previously, the following specific issues related to soil sampling are discussed below: the heterogeneous nature of soils, designation of hot spots, depth of samples, and fate and transport properties.

SOIL SAMPLING GUIDANCE

Test Methods for Evaluating Solid Waste (SW-846): Physical/Chemical Methods (EPA 1986a)

Field Manual for Grid Sampling of PCB Spill Sites to Verify Cleanups (EPA 1986b)

A Compendium of Superfund Field Operations Methods (EPA 1987c)

Soil Sampling Quality Assurance Guide (EPA Review Draft 1989b)

Heterogeneous nature of soils. One of the largest problems in sampling soil (or other solid materials) is that its generally heterogeneous nature makes collection of representative samples difficult (and compositing of samples virtually impossible -- see Section 4.6.3). Therefore, a large number of soil samples may be required to obtain sufficient data to calculate an exposure concentration. Composite samples sometimes are collected to obtain a more homogeneous sample of a particular area; however, as discussed in a later section, compositing samples also serves to mask contaminant hot spots (as well as areas of low contaminant concentration).

Designation of hot spots. Hot spots (i.e., areas of very high contaminant concentrations) may have a significant impact on direct contact exposures. The sampling plan should consider characterization of hot spots through extensive sampling, field screening, visual observations, or a combination of the above.

Depth of samples. Sample depth should be applicable for the exposure pathways and contaminant transport routes of concern and should be chosen purposively within that depth interval. If a depth interval is chosen purposively, a random procedure to select a sampling point may be established. Assessment of surface exposures will be more certain if samples are collected from the shallowest depth that can be practically obtained, rather than, for example, zero to two feet. Subsurface soil samples are important, however, if soil disturbance is likely or if leaching of chemicals to ground water is of concern, or if the site has current or potential agricultural uses.

Fate and transport properties. The sampling plan should consider physical and chemical characteristics of soil that are important for evaluating fate and transport. For example, soil samples being collected to identify potential sources of ground-water contamination must be able to support models that estimate both quantities of chemicals leaching to ground water and the time needed for chemicals to leach to and within the ground water.

4.5.3 GROUND WATER

Considerable expense and effort normally are required for the installation and development of monitoring wells and the collection of ground-water samples. Wells must not introduce foreign materials and must provide a representative hydraulic connection to the geologic formations of interest. In addition, ground-water samples need to be collected using an approach that adequately defines the contaminant plume with respect to potential exposure points. Existing potential exposure points (e.g., existing drinking water wells) should be sampled.

More detailed information concerning ground-water sampling considerations (e.g., sampling equipment, types, and techniques) can be found in the references in the box on this page. In addition to the general sampling considerations discussed previously in Section 4.5.1, those specific for ground water -- hydrogeologic properties, well location and depth, and filtered vs. unfiltered samples -- are discussed below.

GROUND-WATER SAMPLING GUIDANCE

Practical Guide to Ground-water Sampling (EPA 1985a)

A Compendium of Superfund Field Operations Methods (EPA 1987c)

Handbook: Ground Water (EPA 1987d)

Statistical Methods for Evaluating Ground Water from Hazardous Waste Facilities (EPA 1988b)

Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites (EPA 1988e)

Ground-water Sampling for Metals Analyses (EPA 1989d)

Hydrogeologic properties. The extent to which the hydrogeologic properties (e.g., hydraulic conductivity, porosity, bulk density, fraction organic carbon, productivity) of the aquifer(s) are characterized may have a significant effect on the risk assessment. The ability to estimate future exposure concentrations depends on the extent to which hydrogeologic properties needed to evaluate contaminant migration are quantified. Repetitive sampling of wells is necessary to obtain samples that are unaffected by drilling and well development and that accurately reflect hydrogeologic properties of the aquifer(s).

Well location and depth. The location of wells should be such that both the horizontal and vertical extent of contamination can be characterized. Separate water-bearing zones may have different aquifer classifications and uses and therefore may need to be evaluated separately in the risk assessment. In addition, sinking or floating layers of contamination may be present at different depths of the wells.

Filtered vs. unfiltered samples. Data from filtered and unfiltered ground-water samples are useful for evaluating chemical migration in ground

water, because comparison of chemical concentrations in unfiltered versus filtered samples can provide important information on the form in which a chemical exists in ground water. For instance, if the concentration of a chemical is much greater in unfiltered samples compared to filtered samples, it is likely that the majority of the chemical is sorbed onto particulate matter and not dissolved in the ground water. This information on the form of chemical (i.e., dissolved or suspended on particulate matter) is important to understanding chemical mobility within the aquifer.

If chemical analysis reveals significantly different concentrations in the filtered and unfiltered samples, try to determine whether there is a high concentration of suspended particles or if apparently high concentrations are due to sampling or well construction artifacts. Supplementary samples can be collected in a manner that will minimize the influence of these artifacts. In addition, consider the effects of the following.

- Filter size. A 0.45 um filter may screen out some potentially mobile particulates to which contaminants are absorbed and thus under-represent contaminant concentrations. (Recent research suggests that a 1.0 um may be a more appropriate filter size.)

- Pumping velocity. Pumping at too high a rate will entrain particulates (to which contaminants are absorbed) that would not normally be mobile; this could overestimate contaminant concentrations.

- Sample oxidation. After contact with air, many metals oxidize and form insoluble compounds that may be filtered out; this may underestimate inorganic chemical concentrations.

- Well construction materials. Corrosion may elevate some metal concentrations even in stainless steel wells.

If unfiltered water is of potable quality, data from unfiltered water samples should be used to estimate exposure (see Chapter 6). The RPM should ultimately decide the type of samples that are collected. If only one type of sample is collected (e.g., unfiltered), justification for not collecting the other type of sample (e.g., filtered) should be provided in the sampling plan.

4.5.4 SURFACE WATER AND SEDIMENT

Samples need to be collected from any nearby surface water body potentially receiving discharge from the site. Samples are needed at a sufficient number of sampling points to characterize exposure pathways, and at potential discharge points to the water body to determine if the site (or some other source) is contributing to surface water/sediment contamination. Some important considerations for surface water/sediment sampling that may affect the risk assessment for various types and portions of water bodies (i.e., lotic waters, lentic waters, estuaries, sediments) are discussed below. More detailed information concerning surface water and sediment sampling, such as selecting sampling locations and sampling equipment, types, and techniques, is provided in the references given in the references given in the box below.

SURFACE WATER AND SEDIMENT SAMPLING GUIDANCE

Procedures for Handling and Chemical Analysis of Sediment and Water Samples (EPA and COE 1981)

Sediment Sampling Quality Assurance User's Guide (EPA 1984)

Methods Manual for Bottom Sediment Sample Collection (EPA 1985b)

A Compendium of Superfund Field Operations Methods (EPA 1987c)

An Overview of Sediment Quality in the United States (EPA 1987e)

Proposed Guide for Sediment Collection, Storage, Characterization and Manipulation (The American Society for Testing and

Lotic waters. Lotic waters are fast-moving waters such as rivers and streams. Variations in mixing across the stream channel and downstream in rivers and streams can make it difficult to obtain representative samples. Although the selection of sampling points will be highly dependent on the exposure pathways of concern for a particular site, samples generally should be taken both toward the middle of the channel where the majority of the flow occurs and along the banks where flow is generally lower. Sampling locations should be downgradient of any possible contaminant sources such as tributaries or effluent outfalls. Any facilities (e.g., dams, wastewater treatment plants) upstream that affect flow volume or water quality should be considered during the timing of sampling. "Background" releases upstream could confound the interpretation of sampling results by diluting contaminants or by increasing contaminant loads. In general, sampling should begin downstream and proceed upstream.

Lentic waters. Lentic waters are slow-moving waters such as lakes, ponds, and impoundments. In general, lentic waters require more samples than lotic waters because of the relatively low degree of mixing of lentic waters. Thermal stratification is a major factor to be considered when sampling lakes. If the water body is stratified, samples from each layer should be obtained. Vertical composites of these layers then may be made, if appropriate. For small shallow ponds, only one or two sample locations (e.g., the intake and the deepest points) may be adequate depending on the exposure pathways of concern for the site. Periodic release of water should be considered when sampling impoundments, as this may affect chemical concentrations and stratification.

Estuaries. Contaminant concentrations in estuaries will depend on tidal flow and salinity-stratification, among other factors. To obtain a representative sample, sampling should be conducted through a tidal cycle by taking three sets of samples on a given day: (1) at low tide; (2) at high tide; and (3) at "half tide." Each layer of salinity should be sampled.

Sediments. Sediment samples should be collected in a manner that minimizes disturbance of the sediments and potential contamination of subsequent samples. Sampling in flowing waters should begin downstream and end upstream. Wading should be avoided. Sediments of different composition (i.e., mud, sand, rock) should not be composited. Again, it is important to obtain data that will support the evaluation of the potential exposure pathways of concern. For example, for pathways such as incidental ingestion, sampling of near-shore sediments may be important; however, for dermal absorption of sediment contaminants during recreational use such as swimming, samples from different points throughout the water body may be important. If ingestion of benthic (bottom-dwelling) species or surface water will be assessed during the risk assessment, sediment should be sampled so that characteristics needed for modeling (e.g., fraction of organic carbon, particle size distribution) can be determined (see Section 4.3).

4.5.5 AIR

Guidance for developing an air sampling plan for Superfund sites is provided in *Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis* (EPA 1989e). That document is Volume IV of a series of four technical guidance manuals called *Procedures for Conducting Air Pathway Analyses for Superfund Applications* (EPA 1989e-h). The other three volumes of the series include discussions of potential air pathways, air emission sources, and procedures for estimating potential source emission rates associated with both the baseline site evaluation and remedial activities at the site.

Air monitoring information, along with recommendations for proper selection and application of air dispersion models, is included in Volume IV. The section on air monitoring contained in this volume presents step-by-step procedures to develop, conduct, and evaluate the results of air concentration monitoring to characterize downwind exposure conditions from Superfund air emission sources. The first step addressed is the process of collecting and reviewing existing air monitoring information relevant to the specific site, including source, receptor, and environmental data. The second step involves determining the level of sophistication for the air monitoring program; the levels range from simple screening procedures to refined techniques.

Selection of a given level will depend on technical considerations (e.g., detection limits) and available resources. The third step on air monitoring is development of the air monitoring plan and includes determination of the type of air monitors, the number and location of monitors, the frequency and duration of monitoring, sampling and analysis procedures, and QA/QC procedures. Step four details the day-to-day activities related to conducting the air maintenance and calibration, and documentation of laboratory results and QA/QC procedures. The fifth and final step involves the procedures necessary to (1) summarize and evaluate the air monitoring results for validity, (2) summarize the statistics used, (3) determine site-related air concentrations (by comparison of upwind and downwind concentrations), and (4) estimate uncertainties in the results related to the monitoring equipment and program and the analytical techniques used in the laboratory.

Given the difficulties of collecting sufficient air samples to characterize both temporal and spatial variability of air concentrations, modeling -- along or in conjunction with monitoring -- is often used in the risk assessment. For the most efficient sampling program, the section in Volume IV on modeling should be used in conjunction with the section on monitoring.

Volume IV also contains a comprehensive bibliography of other sources of air monitoring and modeling guidance. Note, however, that while this volume contains an extensive discussion on planning and conducting air sampling, it does not provide details concerning particular monitoring equipment and techniques. The box on this page lists some sources of detailed information on air sampling. The following paragraphs address several specific aspects of air sampling: temporal and spatial considerations, emission sources, meteorological conditions.

Temporal and spatial considerations. The goal of air sampling at a site is to adequately characterize air-related contaminant exposures. At a minimum, sampling results should be adequate for predictive short-term and long-term modeling. When evaluating long-term inhalation exposures, sample results should be representative of the long-term average air concentrations at the long-term modeling. When evaluating long-term inhalation exposures, sample results should be representative of the long-term average air concentrations at the long-term exposure points. This requires an air sampling plan of sufficient temporal scale to encompass the range of meteorological and climatic conditions potentially affecting emissions, and of sufficient spatial scale to characterize associated air concentrations at potential exposure points. If acute or subchronic exposures resulting from episodes of unusually large emissions are of interest, sampling over a much smaller time scale would be needed.

AIR SAMPLING GUIDANCE

Technical Assistance Document for Sampling and Analysis of Toxic Organic Compounds in Ambient Air (EPA 1983)

A Compendium of Superfund Field Operations Methods (EPA 1987c)

Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis (EPA 1988f)

Emission sources. Selection of the appropriate type of air monitor will depend on the emission source(s) being investigated as well as the exposure routes to be evaluated. For example, if inhalation of dust is an exposure pathway of concern, then the monitoring equipment must be able to collect respirable dust samples.

Meteorological conditions. Site-specific meteorological conditions should be obtained (e.g., from the National Weather Service) or recorded during the air sampling program with sufficient detail and quality assurance to substantiate and explain the air sampling results. The review of these meteorological data can help indicate the sampling locations and frequencies. Meteorological characteristics also will be necessary if air modeling is to be conducted.

4.5.6 BIOTA

Organisms sampled for human health risk assessment purposes should be those that are likely to be consumed by humans. This may include animals such as commercial and game fish (e.g., salmon, trout, catfish), shellfish (e.g., oysters, clams, crayfish), fowl (e.g., pheasant, duck), and terrestrial mammals (e.g., rabbit, deer), as well as plants such as grains (e.g., wheat, corn), vegetables (e.g., spinach, carrots), and fruit (e.g., melons, strawberries). An effort should be made to sample species that are consumed most frequently by humans. Guidance for collecting biota samples is provided in the references given in the box below. The following paragraphs address the following special aspects of biota sampling: portion vs. whole sampling, temporal concerns, food preference, fish sampling, involvement by other agencies.

BIOTA SAMPLING GUIDANCE

Food and Drug Administration's *Pesticide Analytical Manual* (FDA 1977)

Cooperative Agreement on the Monitoring of Contaminants in Great Lakes Sport Fish for Human Health Purposes (EPA 1985c)

FDA's *Pesticides and Industrial Chemicals in Domestic Foods* (FDA 1986)

A Compendium of Superfund Field Operations Methods (EPA 1987c)

Guidance Manual for Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish (EPA 1989i)

Portion vs. whole sampling. If only human exposure is of concern, chemical concentrations should be measured only in edible portion(s) of the biota. For many fish species, estimates of concentrations in fillets (skin on or skin off) are the most appropriate measures of exposure concentrations. Whole body measurements may be needed, however, for certain species of fish and/or for environmental risk assessments. For example, for some species, especially small ones (e.g., smelt), whole body concentrations are most appropriate. (See *Risk Assessment Guidance for Superfund: Environmental Evaluation Manual* (EPA 1989a) for more information concerning biota sampling for environmental assessment.) The edible portion of an organism can vary with species and with the potentially exposed subpopulation.

Temporal concerns. Any conditions that may result in non-representative sampling, such as sampling during a species' migration or when plants are not in season, should be avoided.

Food preferences. At some sites, human subpopulations in the area may have different food consumption patterns that need to be evaluated. For example, some people commonly eat the hepatopancreas of shellfish. In these cases, organ concentrations would be most appropriate for estimating exposure. Another example of a less common food preference is consumption of relatively large quantities of seaweed and other less commonly eaten seafoods in some Asian communities.

Fish sampling. It is recommended that fish of "catchable" size be sampled instead of young, small fish because extremely young fish are not likely to be consumed. Older, larger fish also generally are more likely to have been exposed to site-specific contaminants for a long time, although for some species (e.g., salmon) the reverse is true. Both bottom-dwelling (benthic) and open-water species should be sampled if both are used as a food source.

Other agencies. Biota sampling may involve other federal agencies such as the Fish and Wildlife Service or the Department of Agriculture. The equivalent state agencies also may be involved. In such cases, these agencies should be involved early in the scoping process.

4.6 DEVELOPING AN OVERALL STRATEGY FOR SAMPLE COLLECTION

For each medium at a site, there are several strategies for collecting samples. The sampling strategies for a site must be appropriate for use in

a quantitative risk assessment; if inappropriate, even the strictest QA/QC procedures associated with the strategy will not ensure the usability of sample results. Generally, persons actually conducting the field investigation will determine the strategy. As discussed in Section 4.1, risk assessors also should be involved in discussions concerning the strategy. The following areas of major concern (from a risk assessment perspective) are discussed in this section: sample size, sampling location, types of samples, temporal and meteorological factors, field analyses, and cost of sampling. Many of these areas also are discussed for specific media in Section 4.5. See the box in the opposite column and Section 4.5 for more detailed guidance on sampling strategy.

4.6.1 DETERMINE SAMPLE SIZE

Typically, sample size and sample location (see Section 4.6.2) are determined at the same time. Therefore, much of the discussion in this subsection is also pertinent to determining sampling location. The discussion on statistics in Section 4.4 is useful for both sample size and location determinations.

A number of considerations are associated with determining an appropriate number of samples for a risk assessment. These considerations include the following four factors:

(1) number of areas of concern that will be sampled;

(2) statistical methods that are planned;

(3) statistical performance (i.e., variability power, and certainty) of the data that will be collected; and

(4) practical considerations of logistics and cost.

In short, many decisions must be made by the risk assessor related to the appropriate sample size for an investigation. A statistician cannot estimate an appropriate sample size without the supporting information provided by a risk assessor. The following paragraphs discuss these four factors as they relate to sample size determinations.

Areas of concern. A major factor that influences how many samples are appropriate is the number of areas of concern that are established prior to sampling. As discussed in the next subsection, if more areas of concern are identified, then more samples generally will be needed to characterize the site. If the total variability in chemical concentrations is reduced substantially by subdividing the site into areas of concern, then the statistical performance should improve and result in a more accurate assessment of the site.

SAMPLING STRATEGY GUIDANCE

Test Methods for Evaluating Solid Waste (SW-846): Physical/Chemical Methods (EPA 1986a)

Data Quality Objectives for Remedial Response Activities: Development Process (EPA 1987a)

Data Quality Objectives for Remedial Response Activities: Example Scenario: RI/FS Activities at a Site with Contaminated Soils and Ground Water (EPA 1987b)

Expanded Site Inspection (ESI) Transitional Guidance for FY 1988 (EPA 1987f)

Quality Assurance Field Operations Manual (EPA 1987g)

Statistical Methods for Evaluating the Attainment of Superfund Cleanup Standards: Volume 1, Soils and Solid Media (EPA 1988f)

Proposed Guidelines for Exposure-related Measurements (EPA 1988g)

Interim Report on Sampling Design Methodology (EPA 1988h)

Standard Handbook of Hazardous Waste Treatment and Disposal (Freeman 1989)

Soil Sampling Quality Assurance Guide (EPA

Statistical methods. A variety of statistical manipulations may need to be performed on the data used in the risk assessment. For example, there may be comparisons with background

concentrations, estimates of upper confidence limits on means, and determinations of the probability of identifying hot spots. Each of these analyses requires different calculations for determining a sample size that will yield a specified statistical performance. Some of the available guidance, such as the Ground-water Monitoring guidance (EPA 1986c), the RCRA Delisting guidance (EPA 1985d), and the Soils Cleanup Attainment guidance (EPA 1988f), address these strategies in detail.

Statistical performance (i.e., variability, power, and certainty). If samples will be taken from an area that is anticipated to have a high degree of variability in chemical concentrations, then many samples may be required to achieve a specified level of certainty and power. If contaminant concentrations in an area are highly variable and only a few samples can be obtained, then the risk assessor should anticipate (1) a great deal of uncertainty in estimating mean concentrations at the site, (2) difficulty in defining the distribution of the data (e.g., normal), and (3) upper confidence limits much higher than the mean. Identification of multiple areas of concern -- each with its own set of samples and descriptive statistics -- will help reduce the total variability if the areas of concern are defined so that they are very different in their contaminant concentration profiles. Risk assessors should discuss in the scoping meeting both the anticipated variability in the data and the desired power and certainty of the statistics that will be estimated from the data.

As discussed in Section 4.4.3, power is the likelihood of detecting a false null hypothesis. Power is particularly important when comparing site characteristics with background. For example, if a 10 percent difference in mean concentrations needs to be determined with 99 percent likelihood (i.e., power of 0.99), a very large number of samples will likely be needed (unless the site and background variabilities are extremely low). On the other hand, if the investigator is only interested in whether the onsite average conditions are 100 times larger than background or can accept a lower chance of detecting the difference if it exists (i.e., a lower power), then a smaller sample size could be accommodated.

The other statistical performance quantity besides power that may need to be specified is the certainty of the calculations. One minus the certainty is the significance level (i.e., α), or false positive rate (see also Section 4.4.3). The higher the desired certainty level (i.e., the lower the significance level), the greater the true difference must be to observe a statistical difference. In the case of upper confidence limits on estimates of mean concentrations, the higher the desired certainty level, the higher will be the upper confidence limit. This follows from the fact that in general, as certainty increases (i.e., α becomes smaller), the size of the confidence interval also increases.

Practical considerations. Finally, questions of practicality, logistics, sampling equipment, laboratory constraints, quality assurance, and cost influence the sample size that will be available for data analysis. After the ideal sample size has been determined using other factors, practical considerations can be introduced to modify the sample size if necessary.

4.6.2 ESTABLISH SAMPLING LOCATIONS

There are three general strategies for establishing sample locations: (1) purposive, (2) completely random, and (3) systematic. Various combinations of these general strategies are possible and acceptable.

Much of the discussion on statistics in the preceding subsection and in Section 4.4 is appropriate here. Typically, a statistician should be consulted when determining sampling location.

Purposive sampling. Although areas of concern are established purposively (e.g., with the intention of identifying contamination), the sampling locations within the areas of concern generally should not be sampled purposively if the data are to be used to provide defensible information for a risk assessment. Purposively identified sampling locations are not discouraged if the objective is site characterization, conducting a chemical inventory, or the evaluation of visually obvious contamination. The sampling results, however, may overestimate or underestimate the true conditions at the site depending on the strategies of the sampling team. Due to the bias associated with the samples, data from purposively

identified sampling locations generally should not be averaged, and distributions of these data generally should not be modeled and used to estimate other relevant statistics. After areas of concern have been established purposively, ground-water monitoring well locations, continuous air monitor locations, and soil sample locations should be determined randomly or systematically within the areas of concern.

Random sampling. Random sampling involves selecting sampling locations in an unbiased manner. Although the investigator may have chosen the area of concern purposively, the location of random sampling points within the area should be independent of the investigator (i.e., unbiased). In addition, the sampling points should be independent of each other; that is, it should not be possible to predict the location of one sampling point based on the location of others. Random sampling points can be established by choosing a series of pairs of random numbers that can be mapped onto a coordinate system that has been established for each area of concern.

Several positive features are associated with data collected in a random sampling program. First, the data can be averaged and used to estimate average concentrations for the area of concern (rather than simply an average of the samples that were acquired). Second, estimates of the uncertainty of the average and the distributional form of the concentration measurements are informative and simple to estimate when they are determined from data that were obtained randomly. Finally, if there is a trend or systematic behavior to the chemical concentrations (e.g., sampling is occurring along a chemical gradient), then random sampling is preferred because it reduces the likelihood that all of the high concentration locations are sampled to the exclusion of the low concentration locations.

Systematic sampling. Systematic sample locations are established across an area of concern by laying out a grid of sampling locations that follow a regular pattern. Systematic sampling ensures that the sampling effort across the area of concern is uniform and that samples are collected in each area. The sampling location grid should be determined by randomly identifying a single initial location from which the grid is constructed. If such a random component is not introduced, the sample is essentially purposive. The grid can be formed in several patterns including square, rectangular, triangular, or hexagonal, depending on the shape of the area. A square pattern is often the simplest to establish. Systematic sampling is preferable to other types of sampling if the objective is to search for small areas with elevated concentrations. Also, geostatistical characterizations -- as described in the DQO guidance (EPA 1987a,b) -- are best done with data collected from a systematic sample.

Disadvantages of systematic sampling include the need for special variance calculations in order to estimate confidence limits on the average concentration. The Soils Cleanup Attainment guidance (EPA 1988f) discusses these calculations in further detail.

4.6.3 DETERMINE TYPES OF SAMPLES

Another item of concern is the determination of the types of samples to be collected. Basically, two types of samples may be collected at a site: grab and composite.

Grab samples. Grab samples represent a single unique part of a medium collected at a specific location and time.

Composite samples. Composite samples -- sometimes referred to as continuous samples for air -- combine subsamples from different locations and/or times. As such, composite samples may dilute or otherwise misrepresent concentrations at specific points and, therefore, should be avoided as the only inputs to a risk assessment. For media such as soil, sediment, and ground water, composite samples generally may be used to assess the presence or absence of contamination; however, they may be used in risk assessment only to represent average concentrations (and thus exposures) at a site. For example, "hot spots" cannot be determined using composite samples. For surface water and air, composite samples may be useful if concentrations and exposures are expected to vary over time or space, as will often be the case in a large stream or river. Composites then can be used to estimate daily or monthly average concentrations, or to account for

stratification due to depth or varying flow rates across a stream.

4.6.4 CONSIDER TEMPORAL AND METEOROLOGICAL FACTORS

Temporal (time) and meteorological (weather) factors also must be considered when determining sampling strategies. The sampling design should account for fluctuations in chemical concentrations due to these factors because in general, the variability in sampling results increases with increasing complexity of these factors. When these factors are complex, specialized and detailed sampling designs are needed to maintain a constant and certain level of accuracy in the results. Countering this need, however, is the cost of the sampling. The following paragraphs address the interactions of the single sampling event, annual/seasonal sampling cycle, variability estimation, and the cost of sampling.

Single sampling event. Variability measures from a single sampling event will underestimate the overall variability of concentrations across an area of concern, which in turn will result in the underestimation of the confidence limits on the mean. The reason for this underestimation is that temporal variability is not included in an evaluation of the total environmental variability at the site.

Annual/seasonal sampling cycle. The ideal sampling strategy incorporates a full annual sampling cycle. If this strategy cannot be accommodated in the investigation, at least two sampling events should be considered. These sampling events should take place during opposite seasonal extremes. For example, sampling periods that may be considered extremes in temporal sampling include (1) high water/low water, (2) high recharge/low recharge, (3) windy/calm, and (4) high suspended solids/clear water. This type of sampling requires some prior knowledge of regional seasonal dynamics. In addition, a sampling team that can mobilize rapidly might be needed if the particular year of sampling is not typical and the extreme conditions occur at an unusual time. See the box on this page for examples of seasonal variability.

Variability estimation. The simple variance estimators that are often used in risk assessment require that the data are independent or uncorrelated. Certain types of repeated samples, however, (e.g., those from ground-water wells or air monitors) actually are time series data that might be correlated. In other words, the concentration of a contaminant in an aquifer measured at a well on a given day will depend, in part, on what the concentration in the aquifer was on the previous day. To reduce this dependence (e.g., due to seasonal variability), sampling of ground-water wells and air monitors should be either separated in time or the data should be evaluated using statistical models with variance estimators that can accommodate a correlation structure. Otherwise, if time series data that are correlated are treated as a random sample and used to calculate upper confidence limits on the mean, the confidence limits will be underestimated.

SEASONAL VARIABILITY

Regardless of the medium sampled, sample composition may vary depending on the time of year and weather conditions when the sample is collected. For example, rain storms may greatly alter soil composition and thus affect the types and concentrations of chemicals present on solid material; heavy precipitation and runoff from snowmelt may directly dilute chemical concentrations or change the types of chemicals present in surface water; heavy rain also may result in sediment loading to water bodies, which could increase contamination or affect the concentrations of other contaminants through adsorption and settling in the water column; if ground-water samples are collected from an area heavily dependent on ground water for irrigation, the composition of a sample collected during the summer growing season may greatly differ from the composition of a sample collected in the winter.

Ideally, samples of various media should be collected in a manner that accounts for time and weather factors. If seasonal fluctuations cannot be characterized in the investigations, details concerning meteorological, seasonal, and climatic conditions during sampling must be documented.

4.6.5 USE FIELD SCREENING ANALYSES

An important component of the overall sampling strategy is the use of field screening analyses. These types of analyses utilize instruments that range from relatively simple (e.g., hand-held organic vapor detectors) to more sophisticated (e.g., field gas chromatographs). (See *Field*

Screening Methods Catalog [EPA 1987h] for more information.) Typically, field screening is used to provide threshold indications of contamination. For example, on the basis of soil gas screening, the field investigation team may determine that contamination of a particular area is indicated and therefore detailed sampling is warranted. Although field screening results usually are not directly used in the risk assessment, they are useful for streamlining sampling and the overall RI/FS process.

4.6.6 CONSIDER TIME AND COST OF SAMPLING

Two primary constraints in sampling are time and cost. Time consuming or expensive sampling strategies for some media may prohibit multiple sampling points. For example, multiple ground-water wells and air monitors on a grid sampling pattern are seldom located within a single area of concern. However, multiple surface water and soil samples within each area of concern are easier to obtain. In the case of ground water and air, several areas of concern may have to be collapsed into a single area so that multiple samples will be available for estimating environmental variability or so that the dynamics of these media can be evaluated using accepted models of fate and transport.

In general, it is important to remember when developing the sampling strategy that detailed sampling must be balanced against the time and cost involved. The goal of RI/FS sampling is not exhaustive site characterization, but rather to provide sufficient information to form the basis for site remediation.

4.7 QA/QC MEASURES

This section presents an overview of the following quality assurance/quality control (QA/QC) considerations that are of particular importance for risk assessment sampling: sampling protocol, sampling devices, QC samples, collection procedures, and sample preservation. Note, however, that the purpose of this discussion is to provide background information; the risk assessor will not be responsible for most QA/QC evaluations.

The *Quality Assurance Field Operations Manual* (EPA 1987g) should be reviewed. In addition, the EPA Environmental Monitoring Support Laboratory in Las Vegas, Nevada, (EMSL-LV) currently is writing a guidance document concerning the development of quality assurance sample designs for Superfund site investigations. Regional QA/QC contacts (e.g., the regional Environmental Services Division) or EMSL-LV should be consulted if more information concerning QA/QC procedures for sampling is desired.

4.7.1 SAMPLING PROTOCOL

The sampling protocol for a risk assessment should include the following:

- objectives of the study;
- procedures for sample collection, preservation, handling, and transport; and
- analytical strategies that will be used.

Presenting the objectives of the RI sampling is particularly important because these objectives also will determine the focus of the risk assessment. There should be instructions on documenting conditions present during sampling (e.g., weather conditions, media conditions). Persons collecting samples must be adequately trained and experienced in sample collection. Test evaluations of the precision attained by persons involved in sample collection should be documented (i.e., the individual collecting a sample should do so in a manner that ensures that a homogeneous, valid sample is reproducibly obtained). The discussion of analytical strategies should specify quantitation limits to be achieved during analyses of each medium.

4.7.2 SAMPLING DEVICES

The devices used to collect, store, preserve, and transport samples must not alter the sample in any way (i.e., the sampling materials cannot be reactive, sorptive, able to leach analytes, or cause interferences with the laboratory analysis). For example, if the wrong materials are used to construct wells for the collection of ground-water samples, organic chemicals may be adsorbed to the well materials and not be present in the collected sample.

4.7.3 QC SAMPLES

Field QC samples (e.g., field blanks, trip blanks, duplicates, split samples) must be collected, stored, transported, and analyzed in a manner identical to those for site samples. The meaning and purpose of blank samples are discussed in detail in Chapter 5. Field duplicate samples are usually two samples collected simultaneously from the same sampling location and are used as measures of either the homogeneity of the medium sampled in a particular location or the precision in sampling. Split samples are usually one sample that is divided into equal fractions and sent to separate independent laboratories for analysis. These split samples are used to check precision and accuracy of laboratory analyses. Samples may also be split in the same laboratory, which can provide information on precision. The laboratory analyzing the samples should not be aware of the identity of the field QC samples (e.g., labels on QC samples should be identical to those on the site samples).

4.7.4 COLLECTION PROCEDURES

Collection procedures should not alter the medium sampled. The general environment surrounding the location of the sample should remain the same so that the collected samples are representative of the situation due to the site conditions, not due to conditions posed by the sampling equipment.

4.7.5 SAMPLE PRESERVATION

Until analysis by the laboratory, any chemicals in the samples must be maintained as close to the same concentrations and identities as in the environment from which they came. Therefore, special procedures may be needed to preserve the samples during the period between collection and analysis.

4.8 SPECIAL ANALYTICAL SERVICES

EPA's SAS, operated by the CLP, may be necessary for two main reasons: (1) the standard laboratory methods used by EPA's Routine Analytical Services (RAS) may not be appropriate (e.g., lower detection limits may be needed),[4] and (2) chemicals other than those on the target compound list (TCL; i.e., chemicals usually analyzed under the Superfund program) may be suspected at the site and therefore may need to be analyzed. A discussion on the RAS detection limits is provided in Chapter 5. Additional information on SAS can be found in the *User's Guide to the Contract Laboratory Program* (EPA 1988i).

In reviewing the historical data at a site, the risk assessor should determine if non-TCL chemicals are expected. As indicated above, non-TCL chemicals may require special sample collection and analytical procedures using SAS. Any such needs should be discussed at the scoping meeting. SAS is addressed in greater detail in Chapter 5.

4.9 TAKING AN ACTIVE ROLE DURING WORKPLAN DEVELOPMENT AND DATA COLLECTION

The risk assessor should be sure to take an active role during workplan development and data collection. This role involves three main steps:

(1) present risk assessment sampling needs at the scoping meeting;

(2) contribute to the workplan and review the Sampling and Analysis Plan; and

(3) conduct interim reviews of outputs of the field investigation.

See Chapter 9 for information on the role of the RPM during workplan development and data collection.

4.9.1 PRESENT RISK ASSESSMENT SAMPLING NEEDS AT SCOPING MEETING

At the scoping meeting, the uses of samples and data to be collected are identified, strategies for sampling and analysis are developed, DQOs are established, and priorities for sample collection are assigned based on the importance of

the data in meeting RI/FS objectives. One of the RI/FS objectives, of course, is the baseline risk assessment. Therefore, the risk assessment data needs and their fit with those of other RI/FS components are discussed. If certain risk assessment sampling needs are judged infeasible by the scoping meeting attendees, all persons involved with site investigation should be made aware of the potential effects of exclusion on the risk assessment.

4.9.2 CONTRIBUTE TO WORKPLAN AND REVIEW SAMPLING AND ANALYSIS PLAN

The outcome of the scoping meeting is the development of a workplan and a SAP. The workplan documents the decisions and evaluations made during the scoping process and presents anticipated future tasks, while the SAP specifies the sampling strategies, the numbers, types, and locations of samples, and the level of quality control. The SAP consists of a quality assurance project plan (QAPjP) and a field sampling plan (FSP). Elements of the workplan and the SAP are discussed in detail in Appendix B of the RI/FS guidance (EPA 1988a). Both the workplan and the SAP generally are written by the personnel who will be involved in the collection of the samples; however, these documents should be reviewed by all personnel who will be using the resulting sample data.

Review the workplan. The workplan should describe the tasks involved in conducting the risk assessment. It also should describe the development of a preliminary assessment of public health and environmental impacts at the site. The risk assessor should review the completed workplan to ensure that all feasible risk assessment sampling needs have been addressed as discussed in the scoping meeting. In particular, this review should focus on the descriptions of tasks related to:

- field investigation (e.g., source testing, media sampling), especially with respect to
  - -- background concentrations by medium,
  - -- quantification of present and future exposures, e.g.,
    - exposure pathways
    - present and potential future land use
    - media that are or may be contaminated
    - locations of actual and potential exposure
    - present concentrations at appropriate exposure points,
  - -- data needs for statistical analysis of the above, and
  - -- data needs for fate and transport models;
- sample analysis/validation, especially with respect to
  - -- chemicals of concern, and
  - -- analytical quantification levels;
- data evaluation; and
- assessment of risks.

In reviewing the above, the precise information necessary to satisfy the remainder of this guidance should be anticipated.

Review the SAP. The risk assessor should carefully review and evaluate all sections of the SAP to determine if data gaps identified in the workplan will be addressed adequately by the sampling program. Of particular importance is the presentation of the objectives. In the QAPjP component of the SAP, the risk assessor should pay particular attention to the QA/QC procedures associated with sampling (e.g., number of field blanks, number of duplicate samples -- see Section 4.8). The SAP should document the detailed, site-specific procedures that will be followed to ensure the quality of the resulting samples. Special considerations in reviewing the SAP are discussed in Section 4.1.3.

In reviewing the FSP, pay particular attention to the information on sample location and frequency, sampling equipment and procedures, and sample

handling and analysis. As discussed in Section 4.5, the sampling procedures should address:

- each medium of concern;
- background concentrations;
- all potential exposure points within each medium;
- migration to potential exposure points, including data for models;
- potential exposures based on possible future land uses;
- sufficient data to satisfy concerns about distributions of sampling data and statistics; and
- number and location of samples.

The analytical plans in the FSP should be reviewed to ensure that DQOs set during the scoping meeting will be met.

The SAP may be revised or amended several times during the site investigation. Therefore, a review of all proposed changes to the sampling and analysis plan that potentially may affect the data needs for risk assessment is necessary. Prior to any changes in the SAP during actual sampling, compliance of the changes with the objectives of the SAP must be checked. (If risk assessment objectives are not specified in the original SAP, they will not be considered when changes to an SAP are proposed.)

4.9.3 CONDUCT INTERIM REVIEWS OF FIELD INVESTIGATION OUTPUTS

All sampling results should be reviewed as soon as they are available to determine if the risk assessment data needs outlined in the workplan have been met by the sampling. Compare the actual number, types, and locations of samples collected with those planned in the SAP. Sampling locations frequently are changed in the field when access to a planned sampling location is obstructed. The number of samples collected may be altered if, for instance, there is an insufficient amount of a certain medium to collect the planned number of samples (e.g., if several wells are found to be dry).

If certain sampling needs have not been met, then the field investigators should be contacted to determine why these samples were not collected. If possible, the risk assessor should obtain samples to fill these data gaps. If time is critical, Special Analytical Services (see Section 4.7) may be used to shorten the analytical time. If this is not possible, then the risk assessor should evaluate all sampling results as discussed in Chapter 5, documenting the potential effect that these data gaps will have on the quantitative risk assessment. In general, the risk assessment should not be postponed due to these data gaps.

ENDNOTES FOR CHAPTER 4

1. Some information that is appropriate for the assessment of human health risks also may be suitable and necessary for an environmental evaluation of the site. Procedures for conducting an environmental evaluation of the hazardous waste site are outlined in the companion volume of this guidance, the Environmental Evaluation Manual (EPA 1989a), and are not discussed in this chapter.

2. The term "media" refers to both environmental media (e.g., soil) and biota (e.g., fish).

3. "Areas of Concern" within the context of this guidance should be differentiated from the same terminology used by the Great Lakes environmental community. This latter use is defined by the International Joint Commission as an area found to be exceeding the Great Lakes Water Quality Agreement objectives.

4. New routine services that provide lower detection limits are currently under development. Contact the headquarters Analytical Operations Branch for further information.

REFERENCES FOR CHAPTER 4

American Society of Testing and Materials (ASTM). Undated. A Proposed Guide for Sediment Collection, Storage, Characterization, and Manipulation. Draft. Available from G. Allen Burton, Dept of Biological Sciences, Wright State University, Dayton, Ohio 45435.

- Provides information concerning how to collect contaminated sediments, sediment spiking, dilution procedures, and QA/QC. Will probably be in the annual ASTM manual.

Environmental Protection Agency (EPA). 1981. Procedures for Handling and Chemical Analysis of Sediment and Water Samples. Great Lakes Laboratory.

Environmental Protection Agency (EPA). 1983. Technical Assistance Document for Sampling and Analysis of Toxic Organic Compounds in Ambient Air. Office of Research and Development.

- Provides guidance to persons involved in designing and implementing ambient air monitoring programs for toxic organic compounds. Includes guidance on selecting sampling/analytical methods, sampling strategy, QA procedures, and data format. Outlines policy issues.

Environmental Protection Agency (EPA). 1984. Sediment Sampling Quality Assurance User's Guide. Environmental Monitoring Support Laboratory. Las Vegas, NV. NTIS: PB-85-233-542.

- Overview of selected sediment models presented as a foundation for stratification of study of regions and selection of locations for sampling sites, methods of sampling, sampling preparation and analysis. Discussion of rivers, lakes, and estuaries.

Environmental Protection Agency (EPA). 1985a. Practical Guide to Ground-water Sampling. Environmental Research Laboratory. Ada, OK. EPA 600/2-85/104.

- Contains information on laboratory and field testing of sampling materials and procedures. Emphasizes minimizing errors in sampling and analysis.

Environmental Protection Agency (EPA). 1985b. Methods Manual for Bottom Sediment Sample Collection. Great Lakes National Program Office. EPA 905/4-85/004.

- Provides guidance on survey planning, sample collection, document preparation, and quality assurance for sediment sampling surveys. Sample site selection, equipment/containers, collection field observation, preservation, handling custody procedures.

Environmental Protection Agency (EPA). 1985c. Cooperative Agreement on the Monitoring of Contaminants in Great Lakes Sport Fish for Human Health Purposes. Region V, Chicago, IL.

- Discusses sampling protocols and sample composition used for sport fish (chinook salmon, coho salmon, lake trout, and rainbow trout), maximum composite samples (5 fish) and length ranges which would be applicable to hazardous waste sites contaminating lakes or streams used for recreational fishing.

Environmental Protection Agency (EPA). 1985d. Petitions to Delist Hazardous Wastes Guidance Manual. Office of Solid Waste. EPA/530/SW-85/003.

Environmental Protection Agency (EPA). 1986a. Test Methods for Evaluating Solid Waste (SW-846): Physical/Chemical Methods. Office of Solid Waste.

- Provides analytical procedures to test solid waste to determine if it is a hazardous waste as defined under RCRA. Contains information for collecting solid waste samples and for determining reactivity, corrosivity, ignitability, composition of waste, and mobility of waste compounds.

Environmental Protection Agency (EPA). 1986b. Field Manual for Grid Sampling of PCB Spill Sites to Verify Cleanups. Office of Toxic Substances. EPA/560/5-86/017.

- Provides detailed, step-by-step guidance for using hexagonal grid sampling; includes sampling design, collection, QA/QC and reporting.

Environmental Protection Agency (EPA). 1986c. Resource Conservation and Recovery Act (RCRA) Ground-water Monitoring Technical Enforcement Guidance Document. Office of Waste Programs Enforcement.

- Contains a detailed presentation of the elements and procedures essential to the design and operation of ground-water monitoring systems that meet the goals of RCRA and its regulations. Includes appendices on statistical analysis and some geophysical techniques.

Environmental Protection Agency (EPA). 1987a. Data Quality Objectives for Remedial Response Activities: Development Process. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. EPA/540/G-87/003. (OSWER Directive 9335.0-7B).

- Identifies (1) the framework and process by which data quality objectives (DQOs; qualitative and quantitative statements that specify the quality of the data required to support Agency decisions during remedial response activities) are developed and (2) the individuals responsible for development of DQOs. Provides procedures for determining a quantifiable degree of certainty that can be used in making site-specific decisions. Provides a formal approach to integration of DQO development with sampling and analysis plan development. Attempts to improve the overall quality and cost effectiveness of data collection and analysis activities.

Environmental Protection Agency (EPA). 1987b. Data Quality Objectives for Remedial Response Activities: Example Scenario: RI/FS Activities at a Site with Contaminated Soils and Ground Water. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. EPA/540/G-87/004.

- Companion to EPA 1987a. Provides detailed examples of the process for development of data quality objectives (DQOs) for RI/FS activities under CERCLA.

Environmental Protection Agency (EPA). 1987c. A Compendium of Superfund Field Operations Methods. Office of Emergency and Remedial Response. EPA/540/P-87/001. (OSWER Directive 9355.0-14).

Environmental Protection Agency (EPA). 1987d. Handbook: Ground Water. Office of Research and Development. EPA/625/6-87/016.

- Resource document that brings together the available technical information in a form convenient for personnel involved in ground-water management. Also addresses minimization of uncertainties in order to make reliable predictions about contamination response to corrective or preventative measures.

Environmental Protection Agency (EPA). 1987e. An Overview of Sediment Quality in the United States. Office of Water Regulations and Standards.

- Good primer. Contains many references.

Environmental Protection Agency (EPA). 1987f. Expanded Site Inspection (ESI) Transitional Guidance for FY 1988. Office of Emergency and Remedial Response. (OSWER Directive 9345.1-.02).

- Provides reader with a consolidated ready reference of general methodologies and activities for conducting inspection work on sites being investigated for the NPL.

Environmental Protection Agency (EPA). 1987g. Quality Assurance Field Operations Manual. Office of Solid Waste and Emergency Response.

- Provides guidance for the selection and definition of field methods, sampling procedures, and custody responsibilities.

Environmental Protection Agency (EPA). 1987h. Field Screening Methods Catalog. Office of Emergency and Remedial Response.

- Provides a listing of methods to be used during field screening, and includes method descriptions, their application to particular sites, their limitations and uses, instrumentation requirements, detection limits, and precision and accuracy information.

Environmental Protection Agency (EPA). 1988a. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. Office of Emergency and Remedial Response. (OSWER Directive 9355.3-01).

- Provides the user (e.g., EPA personnel, state agencies, potentially responsible parties (PRPs), federal facility coordinators, and contractors assisting in RI/FS-related activities) with an overall understanding of the RI/FS process. Includes general information concerning scoping meetings, the development of conceptual models at the beginning of a site investigation, sampling, and analysis.

Environmental Protection Agency (EPA). 1988b. Statistical Methods for Evaluating Ground Water from Hazardous Waste Facilities. Office of Solid Waste.

- Specifies five different statistical methods that are appropriate for ground-water monitoring. Outlines sampling procedures and performance standards that are designed to help minimize the occurrence of Type I and Type II errors.

Environmental Protection Agency (EPA). 1988c. Surface Impoundment Clean Closure Guidance Manual. Office of Solid Waste.

Environmental Protection Agency (EPA). 1988d. Love Canal Emergency Declaration Area Habitability Study Report. Prepared by CH2M Hill and Life Systems for EPA Region II.

- Provides a formal comparison of samples with background as well as detailed discussions concerning problems associated with sampling to evaluate data.

Environmental Protection Agency (EPA). 1988e. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. Interim Final. Office of Emergency and Remedial Response. (OSWER Directive 9283.1-2).

- Provides guidance to develop, evaluate, and select ground-water remedial actions at Superfund sites, focusing on policy issues and establishing cleanup levels. Also includes discussion of data collection activities for characterization of contamination.

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- Provides statistical procedures that can be used in conjunction with attainment objectives defined by EPA to determine, with the desired confidence, whether a site does indeed attain a cleanup standard. It also provides guidance on sampling of soils to obtain baseline information onsite, monitor cleanup operations, and verify attainment of cleanup objectives.

Environmental Protection Agency (EPA). 1988g. Proposed Guidelines for Exposure-related Measurements. 53 Federal Register 48830 (December 2, 1988).

- Focuses on general principles of chemical measurements in various physical and biological media. Assists those who must recommend, conduct, or evaluate an exposure assessment.

Environmental Protection Agency (EPA). 1988h. Interim Report on Sampling Design Methodology. Environmental Monitoring Support Laboratory. Las Vegas, NV. EPA/600/X-88/408.

- Provide guidance concerning the statistical determination of the number of samples to be collected.

Environmental Protection Agency (EPA). 1988i. User's Guide to the Contract Laboratory Program. Office of Emergency and Remedial Response.

Environmental Protection Agency (EPA). 1989a. Risk Assessment Guidance for Superfund: Environmental Evaluation Manual. Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/001A. (OSWER Directive 9285.7-01).

Environmental Protection Agency (EPA). 1989b. Soil Sampling Quality Assurance Guide. Review Draft. Environmental Monitoring Support Laboratory. Las Vegas, NV.

- Replaces earlier edition: NTIS Pb-84-198-621. Includes DQO's, QAPP, information concerning the purpose of background sampling, selection of numbers of samples and sampling sites, error control, sample design, sample documentation.

Environmental Protection Agency (EPA). 1989c. Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities. Office of Solid Waste.

Environmental Protection Agency (EPA). 1989d. Ground-water Sampling for Metals Analyses. Office of Solid Waste and Emergency Response. EPA/540/4-89-001.

Environmental Protection Agency (EPA). 1989e. Air Superfund National Technical Guidance Series. Volume IV: Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis. Interim Final. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA/450/1-89/004.

- This volume discusses procedures for dispersion modeling and air monitoring for superfund air pathway analyses. Contains recommendations for proper selection and application of air dispersion models and procedures to develop, conduct, and

evaluate the results of air concentration monitoring to characterize downwind exposure conditions from Superfund air emission sources.

Environmental Protection Agency (EPA). 1989f. Air Superfund National Technical Guidance Series. Volume I: Application of Air Pathway Analyses for Superfund Activities. Interim Final. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA/450/1-89/001.

- Provides recommended procedures for the conduct of air pathway analyses (APAs) that meet the needs of the Superfund program. The procedures are intended for use by EPA remedial project managers, enforcement project managers, and air experts as well as by EPA Superfund contractors. The emphasis of this volume is to provide a recommended APA procedure relative to the remedial phase of the Superfund process.

Environmental Protection Agency (EPA). 1989g. Air Superfund National Technical Guidance Series. Volume II: Estimation of Baseline Air Emissions at Superfund Sites. Interim Final. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA/450/1-89/002.

- This volume provides information concerning procedures for developing baseline emissions from landfills and lagoons. Describes baseline emissions from both undisturbed sites and sites where media-disturbing activities are taking place. The procedures described for landfills may be applied to solid hazardous waste, and those for lagoons may be applied to liquid hazardous waste.

Environmental Protection Agency (EPA). 1989h. Air Superfund National Technical Guidance Series. Volume III: Estimation of Air Emissions from Cleanup Activities at Superfund Sites. Interim Final. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA/450/1-89/003.

- This volume provides technical guidance for estimating air emissions from remedial activities at NPL sites that may impact local air quality for both onsite workers at a site and the surrounding community while the remedial activities are occurring. Discusses methods to characterize air quality impacts during soil removal, incineration, and air stripping.

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Food and Drug Administration (FDA). 1986. Pesticides and Industrial Chemicals in Domestic Foods.

- Provides guidance for sampling designs for fishery products from the market.

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- Provides detailed information concerning sampling and monitoring of hazardous wastes at remedial action sites (Chapters 12 and 13).

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold. New York.

- Provides statistical analysis information by providing sampling plans, statistical tests, parameter estimation procedure techniques, and references to pertinent publications. The statistical techniques discussed are relatively simple, and examples, exercise, and case studies are provided to illustrate procedures.