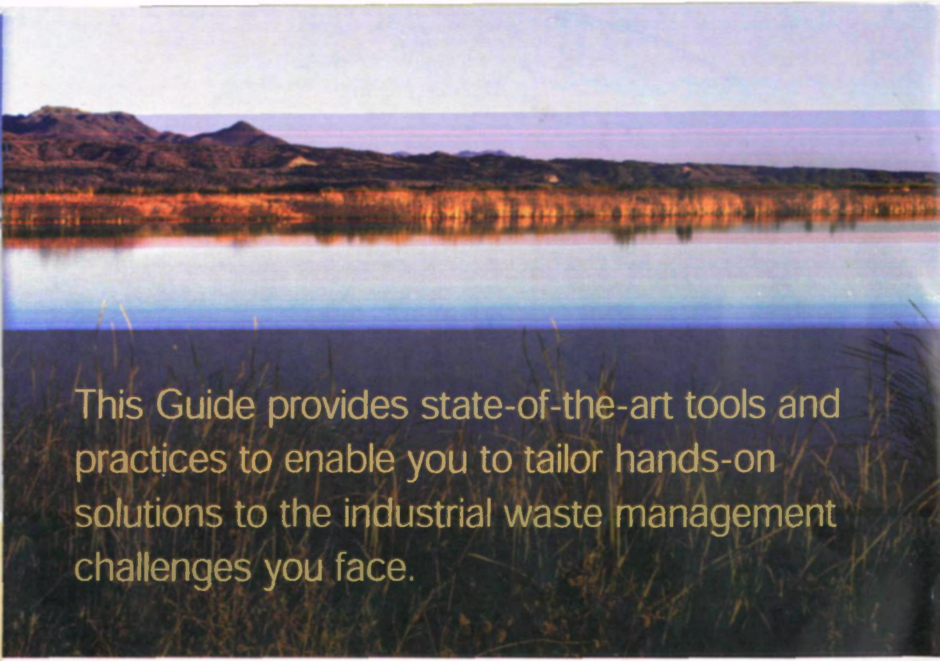
Guide for

Industrial Waste Management



This Guide provides state-of-the-art tools and practices to enable you to tailor hands-on solutions to the industrial waste management challenges you face.

WHAT'S AVAILABLE

- Quick reference to multimedia methods for handling and disposing of wastes from all types of industries
- Answers to your technical questions about siting, design, monitoring, operation, and closure of waste facilities
- Interactive, educational tools, including air and ground water risk assessment models, fact sheets, and a facility siting tool.
- Best management practices, from risk assessment and public participation to waste reduction, pollution prevention, and recycling

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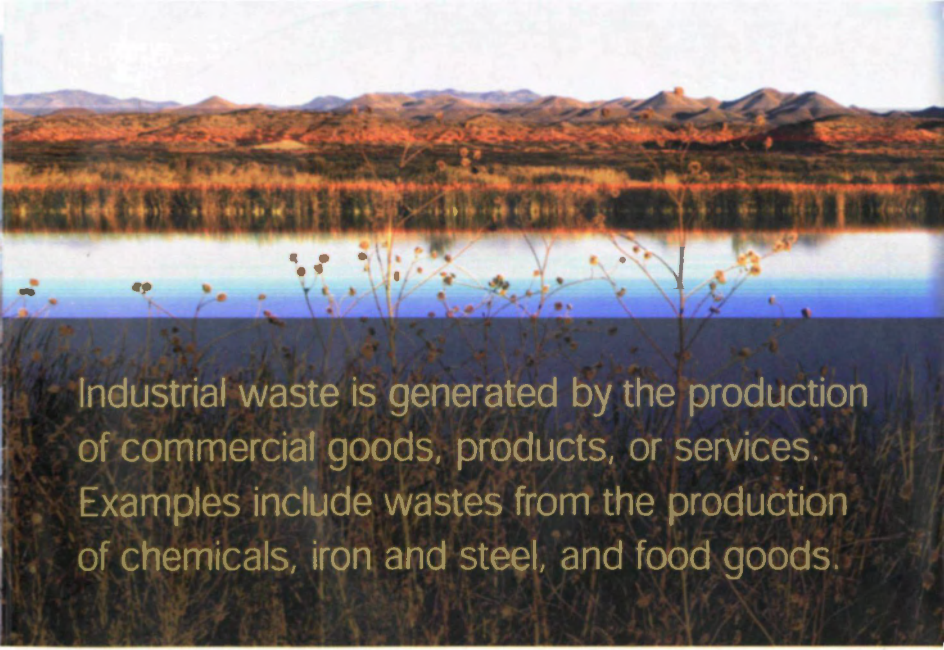

Industrial waste is generated by the production of commercial goods, products, or services. Examples include wastes from the production of chemicals, iron and steel, and food goods.

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Guidance for Data Quality Assessment

Practical Methods for Data Analysis

EPA QA/G-9

QA00 UPDATE

FOREWORD

This document is the 2000 (QA00) version of the *Guidance for Data Quality Assessment* which provides general guidance to organizations on assessing data quality criteria and performance specifications for decision making. The Environmental Protection Agency (EPA) has developed a process for performing Data Quality Assessment (DQA) Process for project managers and planners to determine whether the type, quantity, and quality of data needed to support Agency decisions has been achieved. This guidance is the culmination of experiences in the design and statistical analyses of environmental data in different Program Offices at the EPA. Many elements of prior guidance, statistics, and scientific planning have been incorporated into this document.

This document is distinctly different from other guidance documents; it is not intended to be read in a linear or continuous fashion. The intent of the document is for it to be used as a "tool-box" of useful techniques in assessing the quality of data. The overall structure of the document will enable the analyst to investigate many different problems using a systematic methodology.

This document is one of a series of quality management guidance documents that the EPA Quality Staff has prepared to assist users in implementing the Agency-wide Quality System. Other related documents include:

EPA QA/G-4	*Guidance for the Data Quality Objectives Process*
EPA QA/G-4D	*DEFT Software for the Data Quality Objectives Process*
EPA QA/G-4HW	*Guidance for the Data Quality Objectives Process for Hazardous Waste Site Investigations*
EPA QA/G-9D	*Data Quality Evaluation Statistical Toolbox (DataQUEST)*

This document is intended to be a "living document" that will be updated periodically to incorporate new topics and revisions or refinements to existing procedures. Comments received on this 2000 version will be considered for inclusion in subsequent versions. Please send your written comments on *Guidance for Data Quality Assessment* to:

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INTRODUCTION

0.1 PURPOSE AND OVERVIEW

Data Quality Assessment (DQA) is the scientific and statistical evaluation of data to determine if data obtained from environmental data operations are of the right type, quality, and quantity to support their intended use. This guidance demonstrates how to use DQA in evaluating environmental data sets and illustrates how to apply some graphical and statistical tools for performing DQA. The guidance focuses primarily on using DQA in environmental decision making; however, the tools presented for preliminary data review and verifying statistical assumptions are useful whenever environmental data are used, regardless of whether the data are used for decision making.

DQA is built on a fundamental premise: data *quality*, as a concept, is meaningful only when it relates to the *intended use* of the data. Data quality does not exist in a vacuum; one must know in what context a data set is to be used in order to establish a relevant yardstick for judging whether or not the data set is adequate. By using the DQA, one can answer two fundamental questions:

1. Can the decision (or estimate) be made with the desired confidence, given the quality of the data set?

2. How well can the sampling design be expected to perform over a wide range of possible outcomes? If the same sampling design strategy is used again for a similar study, would the data be expected to support the same intended use with the desired level of confidence, particularly if the measurement results turned out to be higher or lower than those observed in the current study?

The first question addresses the data user's immediate needs. For example, if the data provide evidence strongly in favor of one course of action over another, then the decision maker can proceed knowing that the decision will be supported by unambiguous data. If, however, the data do not show sufficiently strong evidence to favor one alternative, then the data analysis alerts the decision maker to this uncertainty. The decision maker now is in a position to make an informed choice about how to proceed (such as collect more or different data before making the decision, or proceed with the decision despite the relatively high, but acceptable, probability of drawing an erroneous conclusion).

The second question addresses the data user's potential future needs. For example, if investigators decide to use a certain sampling design at a different location from where the design was first used, they should determine how well the design can be expected to perform given that the outcomes and environmental conditions of this sampling event will be different from those of the original event. Because environmental conditions will vary from one location or time to another, the adequacy of the sampling design approach should be evaluated over a broad range of possible outcomes and conditions.

0.2 DQA AND THE DATA LIFE CYCLE

The data life cycle (depicted in Figure 0-1) comprises three steps: planning, implementation, and assessment. During the planning phase, the Data Quality Objectives (DQO) Process (or some other systematic planning procedure) is used to define quantitative and qualitative criteria for determining when, where, and how many samples (measurements) to collect and a desired level of confidence. This information, along with the sampling methods, analytical procedures, and appropriate quality assurance (QA) and quality control (QC) procedures, are documented in the QA Project Plan. Data are then collected following the QA Project Plan specifications. DQA completes the data life cycle by providing the assessment needed to determine if the planning objectives were achieved. During the assessment phase, the data are validated and verified to ensure that the sampling and analysis protocols specified in the QA Project Plan were followed, and that the measurement systems performed in accordance with the criteria specified in the QA Project Plan. DQA then proceeds using the validated data set to determine if the quality of the data is satisfactory.

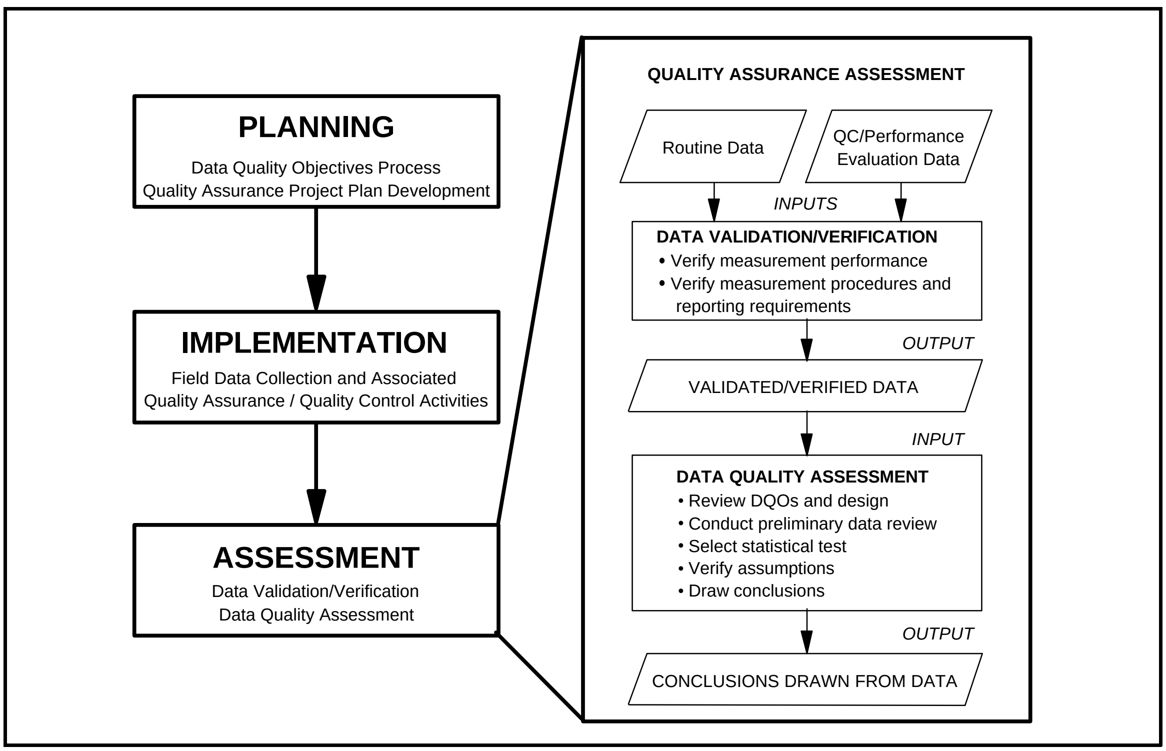


Figure 0-1. DQA in the Context of the Data Life Cycle

0.3 THE 5 STEPS OF THE DQA

The DQA involves five steps that begin with a review of the planning documentation and end with an answer to the question posed during the planning phase of the study. These steps roughly parallel the actions of an environmental statistician when analyzing a set of data. The five steps, which are described in detail in the remaining chapters of this guidance, are briefly summarized as follows:

1. ***Review the Data Quality Objectives (DQOs) and Sampling Design:*** Review the DQO outputs to assure that they are still applicable. If DQOs have not been developed, specify DQOs before evaluating the data (e.g., for environmental decisions, define the statistical hypothesis and specify tolerable limits on decision errors; for estimation problems, define an acceptable confidence or probability interval width). Review the sampling design and data collection documentation for consistency with the DQOs.

2. ***Conduct a Preliminary Data Review:*** Review QA reports, calculate basic statistics, and generate graphs of the data. Use this information to learn about the structure of the data and identify patterns, relationships, or potential anomalies.

3. ***Select the Statistical Test****:* Select the most appropriate procedure for summarizing and analyzing the data, based on the review of the DQOs, the sampling design, and the preliminary data review. Identify the key underlying assumptions that must hold for the statistical procedures to be valid.

4. ***Verify the Assumptions of the Statistical Test:*** Evaluate whether the underlying assumptions hold, or whether departures are acceptable, given the actual data and other information about the study.

5. ***Draw Conclusions from the Data:*** Perform the calculations required for the statistical test and document the inferences drawn as a result of these calculations. If the design is to be used again, evaluate the performance of the sampling design.

These five steps are presented in a linear sequence, but the DQA is by its very nature iterative. For example, if the preliminary data review reveals patterns or anomalies in the data set that are inconsistent with the DQOs, then some aspects of the study planning may have to be reconsidered in Step 1. Likewise, if the underlying assumptions of the statistical test are not supported by the data, then previous steps of the DQA may have to be revisited. The strength of the DQA is that it is designed to promote an understanding of how well the data satisfy their intended use by progressing in a logical and efficient manner.

Nevertheless, it should be emphasized that the DQA cannot *absolutely* prove that one has or has not achieved the DQOs set forth during the planning phase of a study. This situation occurs because a decision maker can never know the *true* value of the item of interest. Data collection only provides the investigators with an *estimate* of this, not its true value. Further, because analytical methods are not perfect, they too can only provide an estimate of the true value of an environmental sample. Because investigators make a decision based on estimated and not true values, they run the risk of making a wrong decision (decision error) about the item of interest.

0.4 INTENDED AUDIENCE

This guidance is written for a broad audience of potential data users, data analysts, and data generators. Data users (such as project managers, risk assessors, or principal investigators who are responsible for making decisions or producing estimates regarding environmental characteristics based on environmental data) should find this guidance useful for understanding and directing the technical work of others who produce and analyze data. Data analysts (such as quality assurance specialists, or any technical professional who is responsible for evaluating the quality of environmental data) should find this guidance to be a convenient compendium of basic assessment tools. Data generators (such as analytical chemists, field sampling specialists, or technical support staff responsible for collecting and analyzing environmental samples and reporting the resulting data values) should find this guidance useful for understanding how their work will be used and for providing a foundation for improving the efficiency and effectiveness of the data generation process.

0.5 ORGANIZATION

This guidance presents background information and statistical tools for performing DQA. Each chapter corresponds to a step in the DQA and begins with an overview of the activities to be performed for that step. Following the overviews in Chapters 1, 2, 3, and 4, specific graphical or statistical tools are described and step-by-step procedures are provided along with examples.

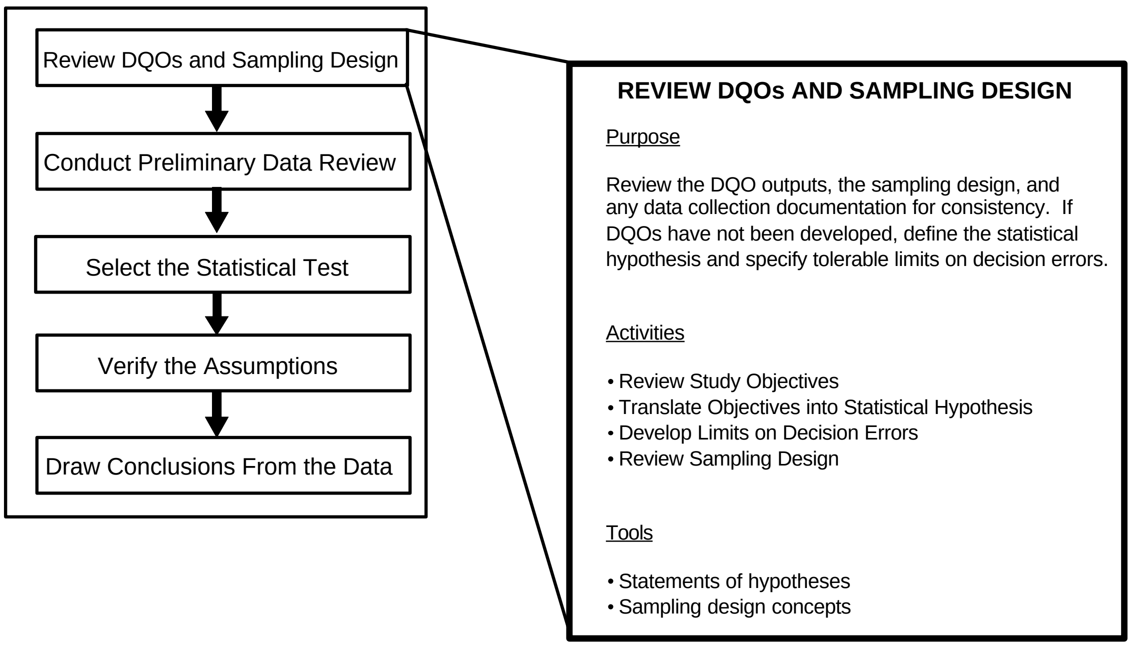
0.6 SUPPLEMENTAL SOURCES

Many of the graphical and statistical tools presented in this guidance are also implemented in a user-friendly, personal computer software program called *Data Quality Evaluation Statistical Tools (DataQUEST) (G-9D)* (EPA, 1996). DataQUEST simplifies the implementation of DQA by automating many of the recommended statistical tools. DataQUEST runs on most IBM-compatible personal computers using the DOS operating system; see the DataQUEST User's Guide for complete information on the minimum computer requirements.

CHAPTER 1

STEP 1: REVIEW DQOs AND THE SAMPLING DESIGN

THE DATA QUALITY ASSESSMENT PROCESS



Step 1: Review DQOs and Sampling Design

! Review the objectives of the study.
  - P If DQOs have not been developed, review Section 1.1.1 and define these objectives.
  - P If DQOs were developed, review the outputs from the DQO Process.

! Translate the data user's objectives into a statement of the primary statistical hypothesis.
  - P If DQOs have not been developed, review Sections 1.1.2 and 1.2, and Box 1-1, then develop a statement of the hypothesis based on the data user's objectives.
  - P If DQOs were developed, translate them into a statement of the primary hypothesis.

! Translate the data user's objectives into limits on Type I or Type II decision errors.
  - P If DQOs have not been developed, review Section 1.1.3 and document the data user's tolerable limits on decision errors.
  - P If DQOs were developed, confirm the limits on decision errors.

! Review the sampling design and note any special features or potential problems.
  - P Review the sampling design for any deviations (Sections 1.1.4 and 1.3).

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CHAPTER 1
STEP 1: REVIEW DQOs AND THE SAMPLING DESIGN

1.1 OVERVIEW AND ACTIVITIES

DQA begins by reviewing the key outputs from the planning phase of the data life cycle: the Data Quality Objectives (DQOs), the Quality Assurance (QA) Project Plan, and any associated documents. The DQOs provide the context for understanding the purpose of the data collection effort and establish the qualitative and quantitative criteria for assessing the quality of the data set for the intended use. The sampling design (documented in the QA Project Plan) provides important information about how to interpret the data. By studying the sampling design, the analyst can gain an understanding of the assumptions under which the design was developed, as well as the relationship between these assumptions and the DQOs. By reviewing the methods by which the samples were collected, measured, and reported, the analyst prepares for the preliminary data review and subsequent steps of DQA.

Careful planning improves the representativeness and overall quality of a sampling design, the effectiveness and efficiency with which the sampling and analysis plan is implemented, and the usefulness of subsequent DQA efforts. Given the benefits of planning, the Agency has developed the DQO Process which is a logical, systematic planning procedure based on the scientific method. The DQO Process emphasizes the planning and development of a sampling design to collect the right type, quality, and quantity of data needed to support the decision. Using both the DQO Process and the DQA will help to ensure that the decisions are supported by data of adequate quality; the DQO Process does so *prospectively* and the DQA does so *retrospectively*.

When DQOs have not been developed during the planning phase of the study, it is necessary to develop statements of the data user's objectives prior to conducting DQA. The primary purpose of stating the data user's objectives prior to analyzing the data is to establish appropriate criteria for evaluating the quality of the data with respect to their intended use. Analysts who are not familiar with the DQO Process should refer to the *Guidance for the Data Quality Objectives Process (QA/G-4)* (1994), a book on statistical decision

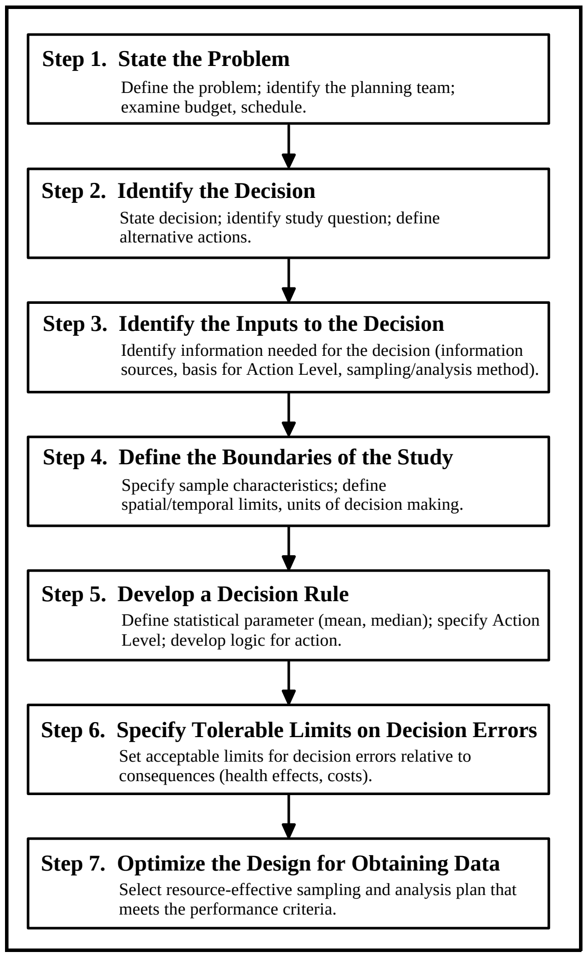

Figure 1-1. The Data Quality Objectives Process

making using tests of hypothesis, or consult a statistician. The seven steps of the DQO Process are illustrated in Figure 1.1.

The remainder of this chapter addresses recommended activities for performing this step of DQA and technical considerations that support these activities. The remainder of this section describes the recommended activities, the first three of which will differ depending on whether DQOs have already been developed for the study. Section 1.2 describes how to select the null and alternative hypothesis and Section 1.3 presents a brief overview of different types of sampling designs.

1.1.1 Review Study Objectives

In this activity, the objectives of the study are reviewed to provide context for analyzing the data. If a planning process has been implemented before the data are collected, then this step reduces to reviewing the documentation on the study objectives. If no planning process was used, the data user should:

- Develop a concise definition of the problem (DQO Process Step 1) and the decision (DQO Process Step 2) for which the data were collected. This should provide the fundamental reason for collecting the environmental data and identify all potential actions that could result from the data analysis.

- Identify if any essential information is missing (DQO Process Step 3). If so, either collect the missing information before proceeding, or select a different approach to resolving the decision.

- Specify the scale of decision making (any subpopulations of interest) and any boundaries on the study (DQO Process Step 4) based on the sampling design. The scale of decision making is the smallest area or time period to which the decision will apply. The sampling design and implementation may restrict how small or how large this scale of decision making can be.

1.1.2 Translate Objectives into Statistical Hypotheses

In this activity, the data user's objectives are used to develop a precise statement of the primary[1] hypotheses to be tested using environmental data. A statement of the primary statistical hypotheses includes a null hypothesis, which is a "baseline condition" that is presumed to be true in the absence of strong evidence to the contrary, and an alternative hypothesis, which bears the burden of proof. In other words, the baseline condition will be retained unless the alternative

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[1] Throughout this document, the term "primary hypotheses" refers to the statistical hypotheses that correspond to the data user's decision. Other statistical hypotheses can be formulated to formally test the *assumptions* that underlie the specific calculations used to test the primary hypotheses. See Chapter 3 for examples of assumptions underlying primary hypotheses and Chapter 4 for examples of how to test these underlying assumptions.

condition (the alternative hypothesis) is thought to be true due to the preponderance of evidence. In general, such hypotheses consist of the following elements:

- a population parameter of interest, which describes the feature of the environment that the data user is investigating;

- a numerical value to which the parameter will be compared, such as a regulatory or risk-based threshold or a similar parameter from another place (e.g., comparison to a reference site) or time (e.g., comparison to a prior time); and

- the relation (such as "is equal to" or "is greater than") that specifies precisely how the parameter will be compared to the numerical value.

To help the analyst decide what parameter value should be investigated, Table 1-1 compares the merits of the mean, upper proportion (percentile), and mean. If DQOs were developed, the statement of hypotheses already should be documented in the outputs of Step 6 of the DQO Process. If DQOs have not been developed, then the analyst should consult with the data user to develop hypotheses that address the data user's concerns. Section 1.2 describes in detail how to develop the statement of hypotheses and includes a list of common encountered hypotheses for environmental decisions.

1.1.3 Develop Limits on Decision Errors

The goal of this activity is to develop numerical probability limits that express the data user's tolerance for committing false rejection (Type I) or false acceptance (Type II) decision errors as a result of uncertainty in the data. A false rejection error occurs when the null hypothesis is rejected when it is true. A false acceptance decision error occurs when the null hypothesis is not rejected when it is false. These are the statistical definitions of false rejection and false acceptance decision errors. Other commonly used phrases include "level of significance" which is equal to the Type I Error (false rejection) and "complement of power" equal to the Type II Error (false acceptance). If tolerable decision error rates were not established prior to data collection, then the data user should:

- Specify the gray region where the consequences of a false acceptance decision error are relatively minor (DQO Process Step 6). The gray region is bounded on one side by the threshold value and on the other side by that parameter value where the consequences of making a false acceptance decision error begin to be significant. Establish this boundary by evaluating the consequences of not rejecting the null hypothesis when it is false and then place the edge of the gray region where these consequences are severe enough to set a limit on the magnitude of this false acceptance decision error. The gray region is the area between this parameter value and the threshold value.

  The width of the gray region represents one important aspect of the decision maker's concern for decision errors. A more narrow gray region implies a desire to detect

Table 1-1. Choosing a Parameter of Interest

Parameter	Points to Consider
Mean	1. Easy to calculate and estimate a confidence interval. 2. Useful when the standard has been based on consideration of health effects or long-term average exposure. 3. Useful when the data have little variation from sample to sample or season to season. 4. If the data have a large coefficient of variation (greater than about 1.5) testing the mean can require more samples than for testing an upper percentile in order to provide the same protection to human health and the environment. 5. Can have high false rejection rates with small sample sizes and highly skewed data, i.e., when the contamination levels are generally low with only occasional short periods of high contamination. 6. Not as powerful for testing attainment when there is a large proportion of less-than-detection-limit values. 7. Is adversely affected by outliers or errors in a few data values.
Upper Proportion (Percentile)	1. Requiring that an upper percentile be less than a standard can limit the occurrence of samples with high concentrations, depending on the selected percentile. 2. Unaffected by less-than-detection-limit values, as long as the detection limit is less than the cleanup standard. 3. If the health effects of the contaminant are acute, extreme concentrations are of concern and are best tested by ensuring that a large portion of the measurements are below a standard. 4. The proportion of the samples that must be below the standard must be chosen. 5. For highly variable or skewed data, can provide similar protection of human health and the environment with a smaller size than when testing the mean. 6. Is relatively unaffected by a small number of outliers.
Median	1. Has benefits over the mean because it is not as heavily influenced by outliers and highly variable data, and can be used with a large number of less-than-detection-limit values. 2. Has many of the positive features of the mean, in particular its usefulness of evaluating standards based on health effects and long-term average exposure. 3. For positively skewed data, the median is lower than the mean and therefore testing the median provides less protection for human health and the environment than testing the mean. 4. Retains some negative features of the mean in that testing the median will not limit the occurrence of extreme values.

conclusively the condition when the true parameter value is close to the threshold value ("close" relative to the variability in the data).

- Specify tolerable limits on the probability of committing false rejection and false acceptance decision errors (DQO Process Step 6) that reflect the decision maker's tolerable limits for making an incorrect decision. Select a possible value of the parameter; then, choose a probability limit based on an evaluation of the seriousness of the potential consequences of making the decision error if the true parameter value is located at that point. At a minimum, the decision maker should specify a false rejection decision error limit at the threshold value (α), and a false acceptance decision error limit at the other edge of the gray region (β).

An example of the gray region and limits on the probability of committing both false rejection and false acceptance decision errors are contained in Box 1-1.

If DQOs were developed for the study, the tolerable limits on decision errors will already have been developed. These values can be transferred directly as outputs for this activity. In this case, the action level is the threshold value; the false rejection error rate at the action level is the Type I error rate or α; and the false acceptance error rate at the other bound of the gray region is the Type II error rate or β.

1.1.4 Review Sampling Design

The goal of this activity is to familiarize the analyst with the main features of the sampling design that was used to generate the environmental data. The overall type of sampling design and the manner in which samples were collected or measurements were taken will place conditions and constraints on how the data must be used and interpreted. Section 1.3 provides additional information about several different types of sampling designs that are commonly used in environmental studies.

Review the sampling design documentation with the data user's objectives in mind. Look for design features that support or contradict those objectives. For example, if the data user is interested in making a decision about the mean level of contamination in an effluent stream over time, then composite samples may be an appropriate sampling approach. On the other hand, if the data user is looking for hot spots of contamination at a hazardous waste site, compositing should only be used with caution, to avoid "averaging away" hot spots. Also, look for potential problems in the implementation of the sampling design. For example, verify that each point in space (or time) had an equal probability of being selected for a simple random sampling design. Small deviations from a sampling plan may have minimal effect on the conclusions drawn from the data set. Significant or substantial deviations should be flagged and their potential effect carefully considered throughout the entire DQA.

Box 1-1: Example Applying the DQO Process Retrospectively

A waste incineration company was concerned that waste fly ash could contain hazardous levels of cadmium and should be disposed of in a RCRA landfill. As a result, eight composite samples each consisting of eight grab samples were taken from each load of waste. The TCLP leachate from these samples were then analyzed using a method specified in 40 CFR, Pt. 261, App. II. DQOs were not developed for this problem; therefore, study objectives (Sections 1.1.1 through 1.1.3) should be developed before the data are analyzed.

1.1.1 Review Study Objectives

P Develop a concise definition of the problem – The problem is defined above.

P Identify if any essential information is missing – It does not appear than any essential information is missing.

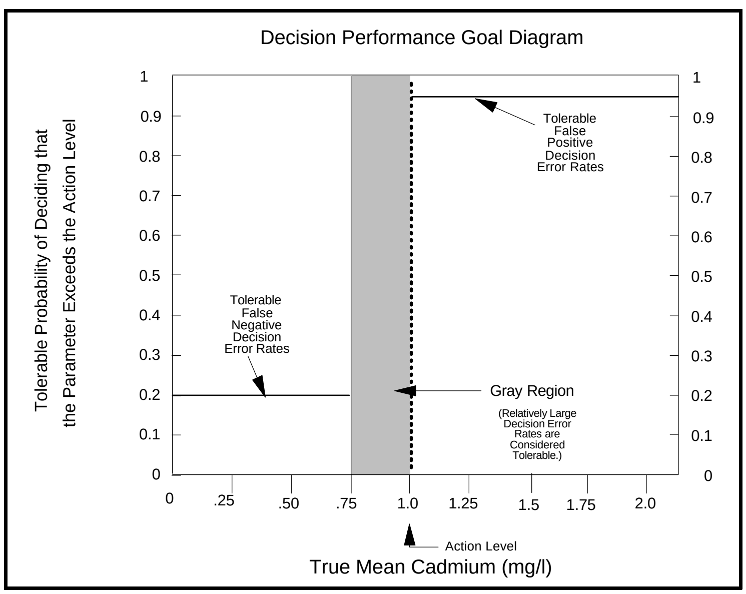
P Specify the scale of decision making – Each waste load is sampled separately and decisions need to be made for each load. Therefore, the scale of decision making is an individual load.

1.1.2 Translate Objectives into Statistical Hypotheses

Since composite samples were taken, the parameter of interest is the mean cadmium concentration. The RCRA regulatory standard for cadmium in TCLP leachate is 1.0 mg/L. Therefore, the two hypotheses are "mean cadmium $\geq$ 1.0 mg/L" and "mean cadmium < 1.0 mg/L."

There are two possible decision errors 1) to decide the waste is hazardous ("mean $\geq$ 1.0") when it truly is not ("mean < 1.0"), and 2) to decide the waste is not hazardous ("mean < 1.0") when it truly is ("mean $\geq$ 1.0"). The risk of deciding the fly ash is not hazardous when it truly is hazardous is more severe since potential consequences of this decision error include risk to human health and the environment. Therefore, this error will be labeled the false rejection error and the other error will be the false acceptance error. As a result of this decision, the null hypothesis will be that the waste is hazardous ("mean cadmium $\geq$ 1.0 mg/L") and the alternative hypothesis will be that the waste is not hazardous ("mean cadmium < 1.0 mg/L"). (See Section 1.2 for more information on developing the null and alternative hypotheses.)

1.1.3 Develop Limits on Decision Errors



P Specify the gray region – The consequence of a false acceptance decision error near the action level is unnecessary resource expenditure. The amount of data also influences the width of the gray region. Therefore, for now, a gray region was set from .75 to 1.0 mg/L. This region could be revised depending on the power of the hypothesis test.

P Specify tolerable limits on the probability of committing a decision error – Consequences of a false rejection error include risk to human health and environment. Another consequence for the landfill owners is the risk of fines and imprisonment. Therefore, the stringent limit of 0.05 was set on the probability of a false rejection decision error. Consequences of a false acceptance error include unnecessary expenditures so

1.2 DEVELOPING THE STATEMENT OF HYPOTHESES

The full statement of the statistical hypotheses has two major parts: the null hypothesis (H_0) and the alternative hypothesis (H_A). In both parts, a population parameter is compared to either a fixed value (for a one-sample test) or another population parameter (for a two-sample test). The population parameter is a quantitative characteristic of the population that the data user wants to estimate using the data. In other words, the parameter describes that feature of the population that the data user will evaluate when making the decision. Table 1-1 describes several common statistical parameters.

If the data user is interested in drawing inferences about only one population, then the null and alternative hypotheses will be stated in terms that relate the true value of the parameter to some fixed threshold value. A common example of this one-sample problem in environmental studies is when pollutant levels in an effluent stream are compared to a regulatory limit. If the data user is interested in comparing two populations, then the null and alternative hypotheses will be stated in terms that compare the true value of one population parameter to the corresponding true parameter value of the other population. A common example of this two-sample problem in environmental studies is when a potentially contaminated waste site is being compared to a reference area using samples collected from the respective areas. In this situation, the hypotheses often will be stated in terms of the difference between the two parameters.

The decision on what should constitute the null hypothesis and what should be the alternative is sometimes difficult to ascertain. In many cases, this problem does not arise because the null and alternative hypotheses are determined by specific regulation. However, when the null hypothesis is not specified by regulation, it is necessary to make this determination. The test of hypothesis procedure prescribes that the null hypothesis is only rejected in favor of the alternative, provided there is overwhelming evidence from the data that the null hypothesis is false. In other words, the null hypothesis is considered to be true unless the data show conclusively that this is not so. Therefore, it is sometimes useful to choose the null and alternative hypotheses in light of the consequences of possibly making an incorrect decision between the null and alternative hypotheses. The true condition that occurs with the more severe decision error (not what would be decided in error based on the data) should be defined as the null hypothesis. For example, consider the two decision errors: "decide a company does not comply with environmental regulations when it truly does" and "decide a company does comply with environmental regulations when it truly does not." If the first decision error is considered the more severe decision error, then the true condition of this error, "the company does comply with the regulations" should be defined as the null hypothesis. If the second decision error is considered the more severe decision error, then the true condition of this error, "the company does not comply with the regulations" should be defined as the null hypothesis.

An alternative method for defining the null hypothesis is based on historical information. If a large amount of information exists suggesting that one hypothesis is extremely likely, then this hypothesis should be defined as the alternative hypothesis. In this case, a large amount of data may not be necessary to provide overwhelming evidence that the other (null) hypothesis is false.

For example, if the waste from an incinerator was previously hazardous and the waste process has not changed, it may be more cost-effective to define the alternative hypothesis as "the waste is hazardous" and the null hypothesis as "the waste is not hazardous."

Consider a data user who wants to know whether the true mean concentration (μ) of atrazine in ground water at a hazardous waste site is greater than a fixed threshold value C. If the data user presumes from prior information that the true mean concentration is at least C due possibly to some contamination incident, then the data must provide compelling evidence to reject that presumption, and the hypotheses can be stated as follows:

Narrative Statement of Hypotheses	Statement of Hypotheses Using Standard Notation
<u>Null Hypothesis (Baseline Condition):</u> The true mean concentration of atrazine in ground water is greater than or equal to the threshold value C; versus	H_0: $\mu \geq C$; versus
<u>Alternative Hypothesis:</u> The true mean concentration of atrazine in ground water is less than the threshold value C.	H_A: $\mu < C$

On the other hand, if the data user presumes from prior information that the true mean concentration is less than C due possibly to the fact that the ground water has not been contaminated in the past, then the data must provide compelling evidence to reject that presumption, and the hypotheses can be stated as follows:

Narrative Statement of Hypotheses	Statement of Hypotheses Using Standard Notation
<u>Null Hypothesis (Baseline Condition):</u> The true mean concentration of atrazine in ground water is less than or equal to the threshold value C; versus	H_0: $\mu \leq C$; versus
<u>Alternative Hypothesis:</u> The true mean concentration of atrazine in ground water is greater than the threshold value C.	H_A: $\mu > C$

In stating the primary hypotheses, it is convenient to use standard statistical notation, as shown throughout this document. However, the logic underlying the hypothesis always corresponds to the decision of interest to the data user.

Table 1-2 summarizes common environmental decisions and the corresponding hypotheses. In Table 1-2, the parameter is denoted using the symbol "Θ," and the difference between two parameters is denoted using "Θ_1 - Θ_2" where Θ_1 represents the parameter of the first population and Θ_2 represents the parameter of the second population. The use of "Θ" is to avoid using the terms "population mean" or "population median" repeatedly because the structure of the hypothesis test remains the same regardless of the population parameter. The fixed threshold value is denoted "C," and the difference between two parameters is denoted "δ_0" (often the null hypothesis is defined such that $\delta_0 = 0$).

For the first problem in Table 1-2, only estimates of Θ that exceed C can cast doubt on the null hypothesis. This is called a one-tailed hypothesis test, because only parameter estimates on one side of the threshold value can lead to rejection of the null hypothesis. The second, fourth, and fifth rows of Table 1-2 are also examples of one-tailed hypothesis tests. The third and sixth rows of Table 1-2 are examples of two-tailed tests, because estimates falling both below and above the null-hypothesis parameter value can lead to rejection of the null hypothesis. Most hypotheses connected with environmental monitoring are one-tailed because high pollutant levels can harm humans or ecosystems.

1.3 DESIGNS FOR SAMPLING ENVIRONMENTAL MEDIA

Sampling designs provide the basis for how a set of samples may be analyzed. Different sampling designs require different analysis techniques and different assessment procedures. There are two primary types of sampling designs: authoritative (judgment) sampling and probability sampling. This section describes some of the most common sampling designs.

1.3.1 Authoritative Sampling

With authoritative (judgment) sampling, an expert having knowledge of the site (or process) designates where and when samples are to be taken. This type of sampling should only be considered when the objectives of the investigation are not of a statistical nature, for example, when the objective of a study is to identify specific locations of leaks, or when the study is focused solely on the sampling locations themselves. Generally, conclusions drawn from authoritative samples apply only to the individual samples and aggregation may result in severe bias and lead to highly erroneous conclusions. Judgmental sampling also precludes the use of the sample for any purpose other than the original one. Thus if the data may be used in further studies (e.g., for an estimate of variability in a later study), a probabilistic design should be used.

When the study objectives involve estimation or decision making, some form of probability sampling should be selected. As described below, this does not preclude use of the expert's knowledge of the site or process in designing a probability-based sampling plan; however,

Table 1-2. Commonly Used Statements of Statistical Hypotheses

Type of Decision	Null Hypothesis	Alternative Hypothesis
Compare environmental conditions to a fixed threshold value, such as a regulatory standard or acceptable risk level; presume that the true condition is less than the threshold value.	H_0: $\Theta \leq C$	H_A: $\Theta > C$
Compare environmental conditions to a fixed threshold value; presume that the true condition is greater than the threshold value.	H_0: $\Theta \geq C$	H_A: $\Theta < C$
Compare environmental conditions to a fixed threshold value; presume that the true condition is equal to the threshold value and the data user is concerned whenever conditions vary significantly from this value.	H_0: $\Theta = C$	H_A: $\Theta \neq C$
Compare environmental conditions associated with two different populations to a fixed threshold value (δ_0) such as a regulatory standard or acceptable risk level; presume that the true condition is less than the threshold value. If it is presumed that conditions associated with the two populations are the same, the threshold value is 0.	H_0: $\Theta_1 - \Theta_2 \leq \delta_0$ (H_0: $\Theta_1 - \Theta_2 \leq 0$)	H_A: $\Theta_1 - \Theta_2 > \delta_0$ (H_A: $\Theta_1 - \Theta_2 > 0$)
Compare environmental conditions associated with two different populations to a fixed threshold value (δ_0) such as a regulatory standard or acceptable risk level; presume that the true condition is greater than the threshold value. If it is presumed that conditions associated with the two populations are the same, the threshold value is 0.	H_0: $\Theta_1 - \Theta_2 \geq \delta_0$ (H_0: $\Theta_1 - \Theta_2 \geq 0$)	H_A: $\Theta_1 - \Theta_2 < \delta_0$ (H_A: $\Theta_1 - \Theta_2 < 0$)
Compare environmental conditions associated with two different populations to a fixed threshold value (δ_0) such as a regulatory standard or acceptable risk level; presume that the true condition is equal to the threshold value. If it is presumed that conditions associated with the two populations are the same, the threshold value is 0.	H_0: $\Theta_1 - \Theta_2 = \delta_0$ (H_0: $\Theta_1 - \Theta_2 = 0$)	H_A: $\Theta_1 - \Theta_2 \neq \delta_0$ (H_A: $\Theta_1 - \Theta_2 \neq 0$)

valid statistical inferences require that the plan incorporate some form of randomization in choosing the sampling locations or sampling times. For example, to determine maximum SO_2 emission from a boiler, the sampling plan would reasonably focus, or put most of the weight on, periods of maximum or near-maximum boiler operation. Similarly, if a residential lot is being evaluated for contamination, then the sampling plan can take into consideration prior knowledge of contaminated areas, by weighting such areas more heavily in the sample selection and data analysis.

1.3.2 Probability Sampling

Probability samples are samples in which every member of the target population (i.e., every potential sampling unit) has a known probability of being included in the sample. Probability samples can be of various types, but in some way, they all make use of randomization, which allows valid probability statements to be made about the quality of estimates or hypothesis tests that are derived from the resultant data.

One common misconception of probability sampling procedures is that these procedures preclude the use of important prior information. Indeed, just the opposite is true. An efficient sampling design is one that uses all available prior information to stratify the region and set appropriate probabilities of selection. Another common misconception is that using a probability sampling design means allowing the possibility that the sample points will not be distributed appropriately across the region. However, if there is no prior information regarding the areas most likely to be contaminated, a grid sampling scheme (a type of stratified design) is usually recommended to ensure that the sampling points are dispersed across the region.

1.3.2.1 Simple Random Sampling

The simplest type of probability sample is the simple random sample where every possible sampling unit in the target population has an equal chance of being selected. Simple random samples, like the other samples, can be either samples in time and/or space and are often appropriate at an early stage of an investigation in which little is known about systematic variation within the site or process. All of the sampling units should have equal volume or mass, and ideally be of the same shape if applicable. With a simple random sample, the term "random" should not be interpreted to mean haphazard; rather, it has the explicit meaning of equiprobable selection. Simple random samples are generally developed through use of a random number table or through computer generation of pseudo-random numbers.

1.3.2.2 Sequential Random Sampling

Usually, simple random samples have a fixed sample size, but some alternative approaches are available, such as sequential random sampling, where the sample sizes are not fixed *a priori*. Rather, a statistical test is performed after each specimen's analysis (or after some minimum number have been analyzed). This strategy could be applicable when sampling and/or analysis is quite expensive, when information concerning sampling and/or measurement variability is lacking, when the characteristics of interest are stable over the time frame of the sampling effort, or when the objective of the sampling effort is to test a single specific hypothesis.

1.3.2.3 Systematic Samples

In the case of spatial sampling, systematic sampling involves establishing a two-dimensional (or in some cases a three-dimensional) spatial grid and selecting a random starting location within one of the cells. Sampling points in the other cells are located in a deterministic way relative to that starting point. In addition, the orientation of the grid is sometimes chosen randomly and various types of systematic samples are possible. For example, points may be arranged in a pattern of squares (rectangular grid sampling) or a pattern of equilateral triangles (triangular grid sampling). The result of either approach is a simple pattern of equally spaced points at which sampling is to be performed.

Systematic sampling designs have several advantages over random sampling and some of the other types of probability sampling. They are generally easier to implement, for example. They are also preferred when one of the objectives is to locate "hot spots" within a site or otherwise map the pattern of concentrations over a site. On the other hand, they should be used with caution whenever there is a possibility of some type of cyclical pattern in the waste site or process. Such a situation, combined with the uniform pattern of sampling points, could very readily lead to biased results.

1.3.2.4 Stratified Samples

Another type of probability sample is the stratified random sample, in which the site or process is divided into two or more non-overlapping strata, sampling units are defined for each stratum, and separate simple random samples are employed to select the units in each stratum. (If a systematic sample were employed within each stratum, then the design would be referred to as a stratified systematic sample.) Strata should be defined so that physical samples within a stratum are more similar to each other than to samples from other strata. If so, a stratified random sample should result in more precise estimates of the overall population parameter than those that would be obtained from a simple random sample with the same number of sampling units.

Stratification is a way to incorporate prior knowledge and professional judgment into a probabilistic sampling design. Generally, units that are "alike" or anticipated to be "alike" are placed together in the same stratum. Units that are contiguous in space (e.g., similar depths) or time are often grouped together into the same stratum, but characteristics other than spatial or temporal proximity can also be employed. Media, terrain characteristics, concentration levels, previous cleanup attempts, and confounding contaminants can be used to create strata.

Advantages of stratified samples over random samples include their ability to ensure more uniform coverage of the entire target population and, as noted above, their potential for achieving greater precision in certain estimation problems. Even when imperfect information is used to form strata, the stratified random sample will generally be more cost-effective than a simple random sample. A stratified design can also be useful when there is interest in estimating or testing characteristics for subsets of the target population. Because different sampling rates can be used in different strata, one can oversample in strata containing those subareas of particular interest to ensure that they are represented in the sample. In general, statistical calculations for data generated via stratified samples are more complex than for random samples, and certain types of tests, for example, cannot be performed when stratified samples are employed. Therefore, a statistician should be consulted when stratified sampling is used.

1.3.2.5 Compositing Physical Samples

When analysis costs are large relative to sampling costs, cost-effective plans can sometimes be achieved by compositing physical samples or specimens prior to analysis, assuming that there are no safety hazards or potential biases (for example, the loss of volatile organic compounds from a matrix) associated with such compositing. For the same total cost, compositing in this situation would allow a larger number of sampling units to be selected than would be the case if compositing were not used. Composite samples reflect a physical rather than a mathematical mechanism for averaging. Therefore, compositing should generally be avoided if population parameters other than a mean are of interest (e.g., percentiles or standard deviations).

Composite sampling is also useful when the analyses of composited samples are to be used in a two-staged approach in which the composite-sample analyses are used solely as a screening mechanism to identify if additional, separate analyses need to be performed. This situation might occur during an early stage of a study that seeks to locate those areas that deserve increased attention due to potentially high levels of one or more contaminants.

1.3.2.6 Other Sampling Designs

Adaptive sampling involves taking a sample and using the resulting information to design the next stage of sampling. The process may continue through several additional rounds of sampling and analysis. A common application of adaptive sampling to environmental problems involves subdividing the region of interest into smaller units, taking a probability sample of these units, then sampling all units that border on any unit with a concentration level greater than some specified level C. This process is continued until all newly sampled units are below C. The field of adaptive sampling is currently undergoing active development and can be expected to have a significant impact on environmental sampling.

Ranked set sampling (RSS) uses the availability of an inexpensive surrogate measurement when it is correlated with the more expensive measurement of interest. The method exploits this correlation to obtain a sample which is more representative of the population that would be obtained by random sampling, thereby leading to more precise estimates of population parameters than what would be obtained by random sampling. RSS consists of creating n groups, each of size n (for a total of n^2 initial samples), then ranking the surrogate from largest to smallest within each group. One sample from each group is then selected according to a specified procedure and these n samples are analyzed for the more expensive measurement of interest.

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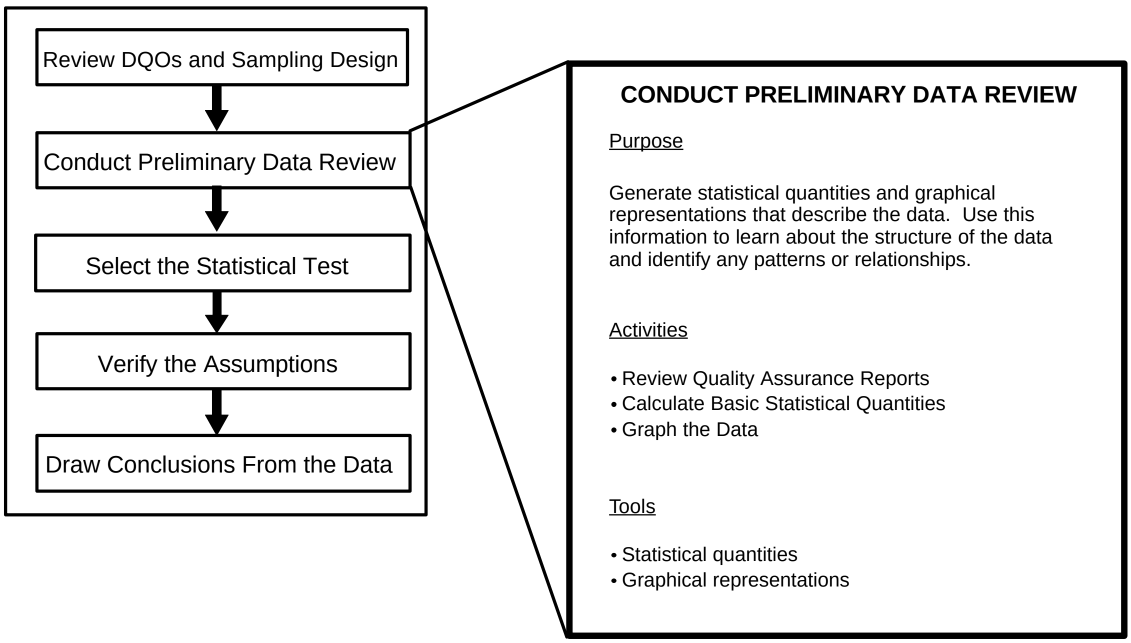
CHAPTER 2

STEP 2: CONDUCT A PRELIMINARY DATA REVIEW

THE DATA QUALITY ASSESSMENT PROCESS



Step 2: Conduct a Preliminary Data Review

! Review quality assurance reports.
  - P Look for problems or anomalies in the implementation of the sample collection and analysis procedures.
  - P Examine QC data for information to verify assumptions underlying the Data Quality Objectives, the Sampling and Analysis Plan, and the QA Project Plans.

! Calculate the statistical quantities.
  - P Consider calculating appropriate percentiles (Section 2.2.1)
  - P Select measures of central tendency (Section 2.2.2) and dispersion (Section 2.2.3).
  - P If the data involve two variables, calculate the correlation coefficient (Section 2.2.4).

! Display the data using graphical representations.
  - P Select graphical representations (Section 2.4) that illuminate the structure of the data set and highlight assumptions underlying the Data Quality Objectives, the Sampling and Analysis Plan, and the QA Project Plans.
  - P Use a variety of graphical representations that examine different features of the set.

Boxes

Figures

CHAPTER 2
STEP 2: CONDUCT A PRELIMINARY DATA REVIEW

2.1 OVERVIEW AND ACTIVITIES

In this step of DQA, the analyst conducts a preliminary evaluation of the data set, calculates some basic statistical quantities, and examines the data using graphical representations. A preliminary data review should be performed whenever data are used, regardless of whether they are used to support a decision, estimate a population parameter, or answer exploratory research questions. By reviewing the data both numerically and graphically, one can learn the "structure" of the data and thereby identify appropriate approaches and limitations for using the data. The DQA software *Data Quality Evaluation Statistical Tools (DataQUEST) (G-9D)* (EPA, 1996) will perform all of these functions as well as more sophisticated statistical tests.

There are two main elements of preliminary data review: (1) basic statistical quantities (summary statistics); and (2) graphical representations of the data. Statistical quantities are functions of the data that numerically describe the data set. Examples include a mean, median, percentile, range, and standard deviation. They can be used to provide a mental picture of the data and are useful for making inferences concerning the population from which the data were drawn. Graphical representations are used to identify patterns and relationships within the data, confirm or disprove hypotheses, and identify potential problems. For example, a normal probability plot may allow an analyst to quickly discard an assumption of normality and may identify potential outliers.

The preliminary data review step is designed to make the analyst familiar with the data. The review should identify anomalies that could indicate unexpected events that may influence the analysis of the data. The analyst may know what to look for based on the anticipated use of the data documented in the DQO Process, the QA Project Plan, and any associated documents. The results of the review are then used to select a procedure for testing a statistical hypotheses to support the data user's decision.

2.1.1 Review Quality Assurance Reports

The first activity in conducting a preliminary data review is to review any relevant QA reports that describe the data collection and reporting process as it actually was implemented. These QA reports provide valuable information about potential problems or anomalies in the data set. Specific items that may be helpful include:

- Data validation reports that document the sample collection, handling, analysis, data reduction, and reporting procedures used;

- Quality control reports from laboratories or field stations that document measurement system performance, including data from check samples, split samples, spiked samples, or any other internal QC measures; and

- Technical systems reviews, performance evaluation audits, and audits of data quality, including data from performance evaluation samples.

When reviewing QA reports, particular attention should be paid to information that can be used to check assumptions made in the DQO Process. Of great importance are apparent anomalies in recorded data, missing values, deviations from standard operating procedures, and the use of nonstandard data collection methodologies.

2.1.2 Calculate Basic Statistical Quantities

The goal of this activity is to summarize some basic quantitative characteristics of the data set using common statistical quantities. Some statistical quantities that are useful to the analyst include: number of observations; measures of central tendency, such as a mean, median, or mode; measures of dispersion, such as range, variance, standard deviation, coefficient of variation, or interquartile range; measures of relative standing, such as percentiles; measures of distribution symmetry or shape; and measures of association between two or more variables, such as correlation. These measures can then be used for description, communication, and to test hypothesis regarding the population from which the data were drawn. Section 2.2 provides detailed descriptions and examples of these statistical quantities.

The sample design may influence how the statistical quantities are computed. The formulas given in this chapter are for simple random sampling, simple random sampling with composite samples, and randomized systematic sampling. If a more complex design is used, such as a stratified design, then the formulas may need to be adjusted.

2.1.3 Graph the Data

The goal of this step is to identify patterns and trends in the data that might go unnoticed using purely numerical methods. Graphs can be used to identify these patterns and trends, to quickly confirm or disprove hypotheses, to discover new phenomena, to identify potential problems, and to suggest corrective measures. In addition, some graphical representations can be used to record and store data compactly or to convey information to others. Graphical representations include displays of individual data points, statistical quantities, temporal data, spatial data, and two or more variables. Since no single graphical representation will provide a complete picture of the data set, the analyst should choose different graphical techniques to illuminate different features of the data. Section 2.3 provides descriptions and examples of common graphical representations.

At a minimum, the analyst should choose a graphical representation of the individual data points and a graphical representation of the statistical quantities. If the data set has a spatial or temporal component, select graphical representations specific to temporal or spatial data in addition to those that do not. If the data set consists of more than one variable, treat each variable individually before developing graphical representations for the multiple variables. If the sampling plan or suggested analysis methods rely on any critical assumptions, consider whether a particular type of graph might shed light on the validity of that assumption. For example, if a small-sample study is strongly dependent on the assumption of normality, then a normal probability plot would be useful (Section 2.3.6).

The sampling design may influence what data may be included in each representation. Usually, the graphical representations should be applied to each complete unit of randomization separately or each unit of randomization should be represented with a different symbol. For example, the analyst could generate box plots for each stratum instead of generating one box plot with all the strata.

2.2 STATISTICAL QUANTITIES

2.2.1 Measures of Relative Standing

Sometimes the analyst is interested in knowing the relative position of one of several observations in relation to all of the observations. Percentiles are one such measure of relative standing that may also be useful for summarizing data. A percentile is the data value that is greater than or equal to a given percentage of the data values. Stated in mathematical terms, the p^{th} percentile is the data value that is greater than or equal to p% of the data values and is less than or equal to (1-p)% of the data values. Therefore, if 'x' is the p^{th} percentile, then p% of the values in the data set are less than or equal to x, and (100-p)% of the values are greater than or equal to x. A sample percentile may fall between a pair of observations. For example, the 75^{th} percentile of a data set of 10 observations is not uniquely defined. Therefore, there are several methods for computing sample percentiles, the most common of which is described in Box 2-1.

Important percentiles usually reviewed are the quartiles of the data, the 25^{th}, 50^{th}, and 75^{th} percentiles. The 50^{th} percentile is also called the sample median (Section 2.2.2), and the 25^{th} and 75^{th} percentile are used to estimate the dispersion of a data set (Section 2.2.3). Also important for environmental data are the 90^{th}, 95^{th}, and 99^{th} percentile where a decision maker would like to be sure that 90%, 95%, or 99% of the contamination levels are below a fixed risk level.

A quantile is similar in concept to a percentile; however, a percentile represents a percentage whereas a quantile represents a fraction. If 'x' is the p^{th} percentile, then at least p% of the values in the data set lie at or below x, and at least (100-p)% of the values lie at or above x, whereas if x is the p/100 quantile of the data, then the fraction p/100 of the data values lie at or below x and the fraction (1-p)/100 of the data values lie at or above x. For example, the .95 quantile has the property that .95 of the observations lie at or below x and .05 of the data lie at or above x. For the example in Box 2-1, 9 ppm would be the .95 quantile and 10 ppm would be the .99 quantile of the data.

Box 2-1: Directions for Calculating the Measure of Relative Standing (Percentiles) with an Example

Let $X_1, X_2, ..., X_n$ represent the n data points. To compute the p^{th} percentile, y(p), first list the data from smallest to largest and label these points $X_{(1)}, X_{(2)}, . . ., X_{(n)}$ (so that $X_{(1)}$ is the smallest, $X_{(2)}$ is the second smallest, and $X_{(n)}$ is the largest). Let t = p/100, and multiply the sample size n by t. Divide the result into the integer part and the fractional part, i.e., let nt = j + g where j is the integer part and g is the fraction part. Then the p^{th} percentile, y(p), is calculated by:

If g = 0, $y(p) = (X_{(j)} + X_{(j+1)})/2$

otherwise, $y(p) = X_{(j+1)}$

<u>Example</u>: The 90^{th} and 95^{th} percentile will be computed for the following 10 data points (ordered from smallest to largest) : 4, 4, 4, 5, 5, 6, 7, 7, 8, and 10 ppb.

For the 95th percentile, t = p/100 = 95/100= .95 and nt = (10)(.95) = 9.5 = 9 + .5. Therefore, j = 9 and g = .5. Because g = .5 $\neq$ 0, $y(95) = X_{(j+1)} = X_{(9+1)} = X_{(10)}$ = 10 ppm. Therefore, 10 ppm is the 95^{th} percentile of the above data.

For the 90^{th} percentile, t = p/100 = 90/100 = .9 and nt = (10)(.9) = 9. Therefore j = 9 and g = 0. Since g = 0, $y(90) = (X_{(9)} + X_{(10)}) / 2 = (8 + 10) / 2 = 9$ ppm.

2.2.2 Measures of Central Tendency

Measures of central tendency characterize the center of a sample of data points. The three most common estimates are the mean, median, and the mode. Directions for calculating these quantities are contained in Box 2-2; examples are provided in Box 2-3.

The most commonly used measure of the center of a sample is the sample mean, denoted by $\bar{X}$. This estimate of the center of a sample can be thought of as the "center of gravity" of the sample. The sample mean is an arithmetic average for simple sampling designs; however, for complex sampling designs, such as stratification, the sample mean is a weighted arithmetic average. The sample mean is influenced by extreme values (large or small) and nondetects (see Section 4.7).

The sample median ($\tilde{X}$) is the second most popular measure of the center of the data. This value falls directly in the middle of the data when the measurements are ranked in order from smallest to largest. This means that ½ of the data are smaller than the sample median and ½ of the data are larger than the sample median. The median is another name for the 50^{th} percentile (Section 2.2.1). The median is not influenced by extreme values and can easily be used in the case of censored data (nondetects).

The third method of measuring the center of the data is the mode. The sample mode is the value of the sample that occurs with the greatest frequency. Since this value may not always exist, or if it does it may not be unique, this value is the least commonly used. However, the mode is useful for qualitative data.

Box 2-2: Directions for Calculating the Measures of Central Tendency

Let X_1, X_2, ..., X_n represent the n data points.

Sample Mean: The sample mean $\bar{x}$ is the sum of all the data points divided by the total number of data points (n):

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Sample Median: The sample median ($\tilde{X}$) is the center of the data when the measurements are ranked in order from smallest to largest. To compute the sample median, list the data from smallest to largest and label these points $X_{(1)}$, $X_{(2)}$, . . ., $X_{(n)}$ (so that $X_{(1)}$ is the smallest, $X_{(2)}$ is the second smallest, and $X_{(n)}$ is the largest).

If the number of data points is odd, then $\tilde{X} = X_{([n+1]/2)}$

If the number of data points is even, then $\tilde{X} = \dfrac{X_{(n/2)} + X_{([n/2]+1)}}{2}$

Sample Mode: The mode is the value of the sample that occurs with the greatest frequency. The mode may not exist, or if it does, it may not be unique. To find the mode, count the number of times each value occurs. The sample mode is the value that occurs most frequently.

Box 2-3: Example Calculations of the Measures of Central Tendency

Using the directions in Box 2-2 and the following 10 data points (in ppm): 4, 5, 6, 7, 4, 10, 4, 5, 7, and 8, the following is an example of computing the sample mean, median, and mode.

Sample mean:

$$\bar{X} = \frac{4 + 5 + 6 + 7 + 4 + 10 + 4 + 5 + 7 + 8}{10} = \frac{60}{10} = 6 \; ppm$$

Therefore, the sample mean is 6 ppm.

Sample median: The ordered data are: 4, 4, 4, 5, 5, 6, 7, 7, 8, and 10. Since n=10 is even, the sample median is

$$\tilde{X} = \frac{X_{(10/2)} + X_{([10/2]+1)}}{2} = \frac{X_{(5)} + X_{(6)}}{2} = \frac{5 + 6}{2} = 5.5 \; ppm$$

Thus, the sample median is 5.5 ppm.

Sample mode: Computing the number of times each value occurs yields:

4 appears 3 times; 5 appears 2 times; 6 appears 1 time; 7 appears 2 times; 8 appears 1 time; and 10 appears 1 time.

Because the value of 4 ppm appears the most times, it is the mode of this data set.

2.2.3 Measures of Dispersion

Measures of central tendency are more meaningful if accompanied by information on how the data spread out from the center. Measures of dispersion in a data set include the range, variance, sample standard deviation, coefficient of variation, and the interquartile range. Directions for computing these measures are given in Box 2-4; examples are given in Box 2-5.

The easiest measure of dispersion to compute is the sample range. For small samples, the range is easy to interpret and may adequately represent the dispersion of the data. For large samples, the range is not very informative because it only considers (and therefore is greatly influenced) by extreme values.

The sample variance measures the dispersion from the mean of a data set. A large sample variance implies that there is a large spread among the data so that the data are not clustered around the mean. A small sample variance implies that there is little spread among the data so that most of the data are near the mean. The sample variance is affected by extreme values and by a large number of nondetects. The sample standard deviation is the square root of the sample variance and has the same unit of measure as the data.

The coefficient of variation (CV) is a unitless measure that allows the comparison of dispersion across several sets of data. The CV is often used in environmental applications because variability (expressed as a standard deviation) is often proportional to the mean.

When extreme values are present, the interquartile range may be more representative of the dispersion of the data than the standard deviation. This statistical quantity does not depend on extreme values and is therefore useful when the data include a large number of nondetects.

2.2.4 Measures of Association

Data often include measurements of several characteristics (variables) for each sample point and there may be interest in knowing the relationship or level of association between two or more of these variables. One of the most common measures of association is the correlation coefficient. The correlation coefficient measures the relationship between two variables, such as a linear relationship between two sets of measurements. However, the correlation coefficient does not imply cause and effect. The analyst may say that the correlation between two variables is high and the relationship is strong, but may not say that one variable causes the other variable to increase or decrease without further evidence and strong statistical controls.

2.2.4.1 Pearson's Correlation Coefficient

The Pearson correlation coefficient measures a linear relationship between two variables. A linear association implies that as one variable increases so does the other linearly, or as one

Box 2-4: Directions for Calculating the Measures of Dispersion

Let X_1, X_2, ..., X_n represent the n data points.

Sample Range: The sample range (R) is the difference between the largest value and the smallest value of the sample, i.e., R = maximum - minimum.

Sample Variance: To compute the sample variance (s^2), compute:

$$s^2 = \frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2}{n-1}$$

Sample Standard Deviation: The sample standard deviation (s) is the square root of the sample variance, i.e.,

$$s = \sqrt{s^2}$$

Coefficient of Variation: The coefficient of variation (CV) is the standard deviation divided by the sample mean (Section 2.2.2), i.e., CV = s/ $\bar{x}$. The CV is often expressed as a percentage.

Interquartile Range: Use the directions in Section 2.2.1 to compute the 25th and 75th percentiles of the data (y(25) and y(75) respectively). The interquartile range (IQR) is the difference between these values, i.e.,
IQR = y(75) - y(25).

Box 2-5: Example Calculations of the Measures of Dispersion

In this box, the directions in Box 2-4 and the following 10 data points (in ppm): 4, 5, 6, 7, 4, 10, 4, 5, 7, and 8, are used to calculate the measures of dispersion. From Box 2-2, $\bar{x}$ = 6 ppm.

Sample Range: R = maximum - minimum = 10 - 4 = 6 ppm

Sample Variance:

$$s^2 = \frac{[4^2 + 5^2 + ... + 7^2 + 8^2] - \frac{(4 + 5 + ... + 7 + 8)^2}{10}}{10 - 1} = \frac{396 - \frac{(60)^2}{10}}{9} = 4 \ ppm^2$$

Sample Standard Deviation: $s = \sqrt{s^2} = \sqrt{4} = 2 \ ppm$

Coefficient of Variation: $CV = s / \bar{X} = 2 ppm / 6 ppm = \frac{1}{3} = 33\%$

Interquartile Range: Using the directions in Section 2.2.1 to compute the 25th and 75th percentiles of the data (y(25) and y(75) respectively): y(25) = $X_{(2+1)}$ = $X_{(3)}$ = 4 ppm and y(75) = $X_{(7+1)}$ = $X_{(8)}$ = 7 ppm. The interquartile range (IQR) is the difference between these values: IQR = y(75) - y(25) = 7 - 4 = 3 ppm variable decreases the other increases linearly. Values of the correlation coefficient close to +1 (positive correlation) imply that as one variable increases so does the other, the reverse holds for values close to -1. A value of +1 implies a perfect positive linear correlation, i.e., all the data pairs lie on a straight line with a positive slope. A value of -1 implies perfect negative linear correlation. Values close to 0 imply little correlation between the variables. Directions and an example for calculating Pearson's correlation coefficient are contained in Box 2-6.

Box 2-6: Directions for Calculating Pearson's Correlation Coefficient with an Example

Let $X_1, X_2, ..., X_n$ represent one variable of the n data points and let $Y_1, Y_2, ..., Y_n$ represent a second variable of the n data points. The Pearson correlation coefficient, r, between X and Y is computed by:

$$r = \frac{\sum_{i=1}^{n} X_i Y_i - \frac{\sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n}}{\left[\left[\sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n} \right] \left[\sum_{i=1}^{n} Y_i^2 - \frac{(\sum_{i=1}^{n} Y_i)^2}{n} \right] \right]^{1/2}}$$

Example: Consider the following data set (in ppb): Sample 1 — arsenic (X) = 8.0, lead (Y) = 8.0; Sample 2 - arsenic = 6.0, lead = 7.0; Sample 3 - arsenic = 2.0, lead = 7.0; and Sample 4 - arsenic = 1.0, lead = 6.0.

$$\sum_{i=1}^{n} X_i = 10,\ \sum_{i=1}^{n} Y_i = 28,\ \sum_{i=1}^{n} X_i^2 = 105,\ \sum_{i=1}^{n} Y_i^2 = 198,\ \sum_{i=1}^{n} X_i Y_i = (8x8) + \ldots + (1x6) = 126.$$

and $$r = \frac{126 - \frac{(17)(28)}{4}}{\left[[105 - \frac{(17)(17)}{4}] \ [198 - \frac{(28)(28)}{4}] \right]^{1/2}} = 0.865$$

Since r is close to 1, there is a strong linear relationship between these two contaminants.

The correlation coefficient does not detect nonlinear relationships so it should be used only in conjunction with a scatter plot (Section 2.3.7.2). A scatter plot can be used to determine if the correlation coefficient is meaningful or if some measure of nonlinear relationships should be used. The correlation coefficient can be significantly changed by extreme values so a scatter plot should be used first to identify such values.

An important property of the correlation coefficient is that it is unaffected by changes in location of the data (adding or subtracting a constant from all of the X measurements and/or the Y measurements) and by changes in scale of the data and/or Y values by a positive constant). Thus linear transformations on the Xs and Ys do not affect the correlation of the measurements. This is reasonable since the correlation reflects the degree to which linearity between X and Y measurements occur and the degree of linearity is unaffected by changes in location or scale. For example, if a variable was temperature in Celsius, then the correlation should not change if Celsius was converted to Fahrenheit.

On the other hand, if nonlinear transformations of the X and/or Y measurements are made, then the Pearson correlation between the transformed values will differ from the correlation of the original measurements. For example, if X and Y, respectively, represent PCB and dioxin concentrations in soil, and x=log (X) and y=log(Y), then the Pearson correlations between X and Y, X and y x and Y, and x and y, will all be different, in general, since the logarithmic transformation is a nonlinear transformation.

Pearson's correlation may be sensitive to the presence of one or two extreme values, especially when sample sizes are small. Such values may result in a high correlation, suggesting a strong linear trend, when only moderate trend is present. This may happen, for instance, if a single (X,Y) pair has very high values for both X and Y while the remaining data values are uncorrelated. Extreme value may also lead to low correlations between X and Y, thus tending to mask a strong linear trend. This may happen if all the (X,Y) pairs except one (or two) tend to cluster tightly about a straight line, and the exceptional point has a very large X value paired with a moderate or small Y value (or vice versa). Because of the influences of extreme values, it is wise to use a scatter plot (Section 2.3.7.2) in conjunction with a correlation coefficient.

2.2.4.2 Spearman's Rank Correlation Coefficient

An alternative to the Pearson correlation is Spearman's rank correlation coefficient. It is calculated by first replacing each X value by its rank (i.e., 1 for the smallest X value, 2 for the second smallest, etc.) and each Y value by its rank. These pairs of ranks are then treated as the (X,Y) data and Spearman's rank correlation is calculated using the same formulae as for Pearson's correlation (Box 2-6). Directions and an example for calculating a correlation coefficient are contained in Box 2-7.

Since meaningful (i.e., monotonic increasing) transformations of the data will not later the ranks of the respective variables (e.g, the ranks for log (X) will be the same for the ranks for X), Spearman's correlation will not be altered by nonlinear increasing transformations of the Xs or the Ys. For instance, the Spearman correlation between PCB and dioxin concentrations (X and Y) in soil will be the same as the correlations between their logarithms (x and y). This desirable property and the fact that Spearman's correlation is less sensitive to extreme values than Pearson's correlation make Spearman's correlation an attractive alternative or complement of Pearson's correlation coefficient. There are some important theoretical differences between Pearson's and Spearman's correlation but a full discussion is beyond this guidance. In general, Pearson's correlation has a higher statistical power than Spearman's, although the latter has some more varied applications.

2.2.4.3 Serial Correlation Coefficient

When data are truly independent, the correlation between data points is zero. For a sequence of data points taken serially in time, or one-by-one in a row, the serial correlation

Box 2-7: Directions for Calculating Spearman's Correlation Coefficient with an Example

Let $X_1, X_2, ..., X_n$ represent a set of ranks of the n data points of one data set and let $Y_1, Y_2, ..., Y_n$ represent a set of ranks of a second variable of the n data points. The Spearman correlation coefficient, r, between X and Y is computed by:

$$r = \frac{\sum_{i=1}^{n} X_i Y_i - \frac{\sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n}}{\left[[\sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n}] \; [\sum_{i=1}^{n} Y_i^2 - \frac{(\sum_{i=1}^{n} Y_i)^2}{n}] \right]^{1/2}} \quad \textbf{(15)}$$

<u>Example</u>: Consider the following data set (in ppb): Sample 1 — arsenic (X) = 8.0, lead (Y) = 8.0; Sample 2 - arsenic = 6.0, lead = 7.0; Sample 3 - arsenic = 2.0, lead = 7.0; and Sample 4 - arsenic = 1.0, lead = 6.0.

Using Arsenic rank the data smallest to largest:

Sample No.	4	3	2	1
Arsenic	1.0	2.0	6.0	8.0
Lead	6.0	7.0	7.0	8.0

Convert the raw data to ranks, any ties being made an average of what ranks should have been assigned.

Sample No.	1	3	2	4	
Arsenic Rank	1	2	3	4	(X)
Lead Rank	1	2.5	2.5	4	(Y)

Note how 7.0 (two lead observations) was converted to the average rank (i.e., ranks 2 and 3, therefore 2.5 each).

$$\sum_{i=1}^{n} X_i = 10, \;\; \sum_{i=1}^{n} Y_i = 10, \;\; \sum_{i=1}^{n} X_i^2 = 30, \;\; \sum_{i=1}^{n} Y_i^2 = 29.5, \;\; \sum_{i=1}^{n} X_i Y_i = (1x1) + \ldots + (4x4) = 29.5.$$

and $$r = \frac{29.5 - \frac{(10)(10)}{4}}{\left[[30 - \frac{(10)(10)}{4}] \; [29.5 - \frac{(10)(10)}{4}] \right]^{1/2}} = 0.948$$

Since r is close to 1, there is a strong linear relationship between these two contaminants.

coefficient can be calculated by replacing the sequencing variable by the numbers 1 through n and calculating Pearon's correlation coefficient with z being the actual data values, and y being the numbers 1 through n. For example, for a sequence of data collected at a waste site along a straight transit line, the distances on the transit line of the data points are replaced by the numbers 1 through n, e.g., first 10-foot sample point = 1, the 20-foot sample point = 2, the 30-foot sample point = 3, etc., for samples taken at 10-foot intervals. Directions for the Serial correlation coefficient, along with an example, are given in Box 2-8.

Box 2-8: Directions for Estimating the Serial Correlation Coefficient with a Example

Directions:

Let X_1, X_2, . . . , X_n represent the data values collected in sequence over equally spared periods of time. Label the periods of time 1, 2, ..., n to match the data values. Use the directions in Box 2-6 to calculate the Pearson's Correlation Coefficient between the data X and the time periods Y.

Example: The following are hourly readings from a discharge monitor. Notice how the actual 24-hour times are replaced by the numbers 1 through 13.

Time	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Reading	6.5	6.6	6.7	6.4	6.3	6.4	6.2	6.2	6.3	6.6	6.8	6.9	7.0
Time Periods	1	2	3	4	5	6	7	8	9	10	11	12	13

Using Box 2-6, with the readings being the X values and the Time Periods being the Y values gives a serial correlation coefficient of 0.432.

2.3 GRAPHICAL REPRESENTATIONS

2.3.1 Histogram/Frequency Plots

Two of the oldest methods for summarizing data distributions are the frequency plot (Figure 2-1) and the histogram (Figure 2-2). Both the histogram and the frequency plot use the same basic principles to display the data: dividing the data range into units, counting the number of points within the units, and displaying the data as the height or area within a bar graph. There are slight differences between the histogram and the frequency plot. In the frequency plot, the relative height of the bars represents the relative density of the data. In a histogram, the area within the bar represents the relative density of the data. The difference between the two plots becomes more distinct when unequal box sizes are used.

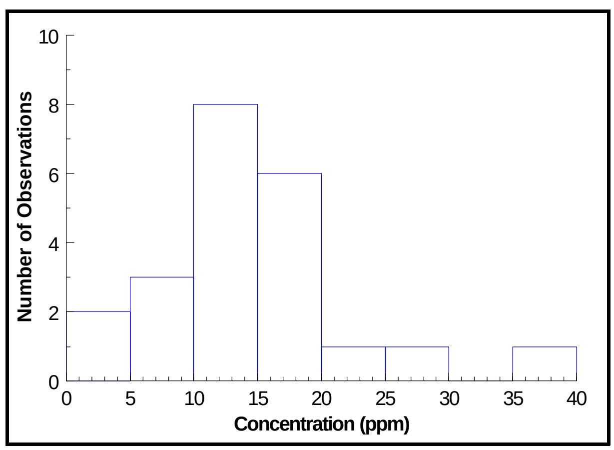


Figure 2-1. Example of a Frequency Plot

The histogram and frequency plot provide a means of assessing the symmetry and variability of the data. If the data are symmetric, then the structure of these plots will be symmetric around a central point such as a mean. The histogram and frequency plots will generally indicate if the data are skewed and the direction of the skewness.

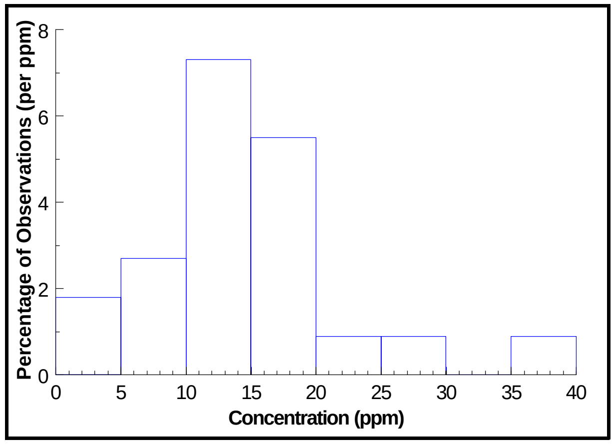


Figure 2-2. Example of a Histogram

Directions for generating a histogram and a frequency plot are contained in Box 2-9 and an example is contained in Box 2-10. When plotting a histogram for a continuous variable (e.g., concentration), it is necessary to decide on an endpoint convention; that is, what to do with cases that fall on the boundary of a box. With discrete variables, (e.g., family size) the intervals can be centered in between the variables. For the family size data, the intervals can span between 1.5 and 2.5, 2.5 and 3.5, and so on, so that the whole numbers that relate to the family size can be centered within the box. The visual impression conveyed by a histogram or a frequency plot can be quite sensitive to the choice of interval width. The choice of the number of intervals determines whether the histogram shows more detail for small sections of the data or whether the data will be displayed more simply as a smooth overview of the distribution.

Box 2-9: Directions for Generating a Histogram and a Frequency Plot

Let X_1, X_2, ..., X_n represent the n data points. To develop a histogram or a frequency plot:

STEP 1: Select intervals that cover the range of observations. If possible, these intervals should have equal widths. A rule of thumb is to have between 7 to 11 intervals. If necessary, specify an endpoint convention, i.e., what to do with cases that fall on interval endpoints.

STEP 2: Compute the number of observations within each interval. For a frequency plot with equal interval sizes, the number of observations represents the height of the boxes on the frequency plot.

STEP 3: Determine the horizontal axis based on the range of the data. The vertical axis for a frequency plot is the number of observations. The vertical axis of the histogram is based on percentages.

STEP 4: For a histogram, compute the percentage of observations within each interval by dividing the number of observations within each interval (Step 3) by the total number of observations.

STEP 5: For a histogram, select a common unit that corresponds to the x-axis. Compute the number of common units in each interval and divide the percentage of observations within each interval (Step 4) by this number. This step is only necessary when the intervals (Step 1) are not of equal widths.

STEP 6: Using boxes, plot the intervals against the results of Step 5 for a histogram or the intervals against the number of observations in an interval (Step 2) for a frequency plot.

Box 2-10: Example of Generating a Histogram and a Frequency Plot

Consider the following 22 samples of a contaminant concentration (in ppm): 17.7, 17.4, 22.8, 35.5, 28.6, 17.2 19.1, <4, 7.2, <4, 15.2, 14.7, 14.9, 10.9, 12.4, 12.4, 11.6, 14.7, 10.2, 5.2, 16.5, and 8.9.

STEP 1: This data spans 0 - 40 ppm. Equally sized intervals of 5 ppm will be used: 0 - 5 ppm; 5 - 10 ppm; etc. The endpoint convention will be that values are placed in the highest interval containing the value. For example, a value of 5 ppm will be placed in the interval 5 - 10 ppm instead of 0 - 5 ppm.

STEP 2: The table below shows the number of observations within each interval defined in Step 1.

STEP 3: The horizontal axis for the data is from 0 to 40 ppm. The vertical axis for the frequency plot is from 0 - 10 and the vertical axis for the histogram is from 0% - 10%.

STEP 4: There are 22 observations total, so the number observations shown in the table below will be divided by 22. The results are shown in column 3 of the table below.

STEP 5: A common unit for this data is 1 ppm. In each interval there are 5 common units so the percentage of observations (column 3 of the table below) should be divided by 5 (column 4).

STEP 6: The frequency plot is shown in Figure 2-1 and the histogram is shown in Figure 2-2.

Interval	# of Obs in Interval	% of Obs in Interval	% of Obs per ppm
0 - 5 ppm	2	9.10	1.8
5 - 10 ppm	3	13.60	2.7
10 - 15 ppm	8	36.36	7.3
15 - 20 ppm	6	27.27	5.5
20 - 25 ppm	1	4.55	0.9
25 - 30 ppm	1	4.55	0.9
30 - 35 ppm	0	0.00	0.0
35 - 40 ppm	1	4.55	0.9

2.3.2 Stem-and-Leaf Plot

The stem-and-leaf plot is used to show both the numerical values themselves and information about the distribution of the data. It is a useful method for storing data in a compact form while, at the same time, sorting the data from smallest to largest. A stem-and-leaf plot can be more useful in analyzing data than a histogram because it not only allows a visualization of the data distribution, but enables the data to be reconstructed and lists the observations in the order of magnitude. However, the stem-and-leaf plot is one of the more subjective visualization techniques because it requires the analyst to make some arbitrary choices regarding a partitioning of the data. Therefore, this technique may require some practice or trial and error before a useful plot can be created. As a result, the stem-and-leaf plot should only be used to develop a picture of the data and its characteristics. Directions for constructing a stem-and-leaf plot are given in Box 2-11 and an example is contained in Box 2-12.

Each observation in the stem-and-leaf plot consist of two parts: the stem of the observation and the leaf. The stem is generally made up of the leading digit of the numerical values while the leaf is made up of trailing digits in the order that corresponds to the order of magnitude from left to right. The stem is displayed on the vertical axis and the data points make

Box 2-11: Directions for Generating a Stem and Leaf Plot

Let X_1, X_2, ..., X_n represent the n data points. To develop a stem-and-leaf plot, complete the following steps:

STEP 1: Arrange the observations in ascending order. The ordered data is usually labeled (from smallest to largest) $X_{(1)}$, $X_{(2)}$, ..., $X_{(n)}$.

STEP 2: Choose either one or more of the leading digits to be the stem values. As an example, for the value 16, 1 could be used as the stem as it is the leading digit.

STEP 3: List the stem values from smallest to largest at the left (along a vertical axis). Enter the leaf (the remaining digits) values in order from lowest to highest to the right of the stem. Using the value 16 as an example, if the 1 is the stem then the 6 will be the leaf.

Box 2-12: Example of Generating a Stem and Leaf Plot

Consider the following 22 samples of trifluorine (in ppm): 17.7, 17.4, 22.8, 35.5, 28.6, 17.2 19.1, <4, 7.2, <4, 15.2, 14.7, 14.9, 10.9, 12.4, 12.4, 11.6, 14.7, 10.2, 5.2, 16.5, and 8.9.

STEP 1: Arrange the observations in ascending order: <4, <4, 5.2, 7.7, 8.9, 10.2, 10.9, 11.6, 12.4, 12.4, 14.7, 14.7, 14.9, 15.2, 16.5, 17.2, 17.4, 17.7, 19.1, 22.8, 28.6, 35.5.

STEP 2: Choose either one or more of the leading digits to be the stem values. For the above data, using the first digit as the stem does not provide enough detail for analysis. Therefore, the first digit will be used as a stem; however, each stem will have two rows, one for the leaves 0 - 4, the other for the leaves 5 - 9.

STEP 3: List the stem values at the left (along a vertical axis) from smallest to largest. Enter the leaf (the remaining digits) values in order from lowest to highest to the right of the stem. The first digit of the data was used as the stem values; however, each stem value has two leaf rows.

```
0 (0, 1, 2, 3, 4)    | <4   <4
0 (5, 6, 7, 8, 9)    | 5.2  7.7  8.9
1 (0, 1, 2, 3, 4)    | 0.2  0.9  1.6  2.4  2.4  4.7  4.7  4.9
1 (5, 6, 7, 8, 9)    | 5.2  6.5  7.2  7.4  7.7  9.1
2 (0, 1, 2, 3, 4)    | 2.8
2 (5, 6, 7, 8, 9)    | 8.6
3 (0, 1, 2, 3, 4)    |
3 (5, 6, 7, 8, 9)    | 5.5
```

Note: If nondetects are present, place them first in the ordered list, using a symbol such as <L. If multiple detection limits were used, place the nondetects in increasing order of detection limits, using symbols such as <L1, <L2, etc. If the first stem extends from zero to a value above the detection limit, then nondetects can be placed in this interval, as shown in the example above. Otherwise, special intervals dedicated to nondetects can be used.

up the magnitude from left to right. The stem is displayed on the vertical axis and the data points make up the leaves. Changing the stem can be accomplished by increasing or decreasing the digits that are used, dividing the groupings of one stem (i.e., all numbers which start with the numeral 6 can be divided into smaller groupings), or multiplying the data by a constant factor (i.e., multiply the data by 10 or 100). Nondetects can be placed in a single stem.

A stem-and-leaf plot roughly displays the distribution of the data. For example, the stem-and-leaf plot of normally distributed data is approximately bell shaped. Since the stem-and-leaf roughly displays the distribution of the data, the plot may be used to evaluate whether the data are skewed or symmetric. The top half of the stem-and-leaf plot will be a mirror image of the bottom half of the stem-and-leaf plot for symmetric data. Data that are skewed to the left will have the bulk of data in the top of the plot and less data spread out over the bottom of the plot.

2.3.3 Box and Whisker Plot

A box and whisker plot or box plot (Figure 2-3) is a schematic diagram useful for visualizing important statistical quantities of the data. Box plots are useful in situations where it is not necessary or feasible to portray all the details of a distribution. Directions for generating a box and whiskers plot are contained in Box 2-13, and an example is contained in Box 2-14.

A box and whiskers plot is composed of a central box divided by a line and two lines extending out from the box called whiskers. The length of the central box indicates the spread of the bulk of the data (the central 50%) while the length of the whiskers show how stretched the tails of the distribution are. The width of the box has no particular meaning; the plot can be made quite narrow without affecting its visual impact. The sample median is displayed as a line through the box and the sample mean is displayed using a '+' sign. Any unusually small or large data points are displayed by a '*' on the plot. A box and whiskers plot can be used to assess the symmetry of the data. If the distribution is symmetrical, then the box is divided in two equal halves by the median, the whiskers will be the same length and the number of extreme data points will be distributed equally on either end of the plot.

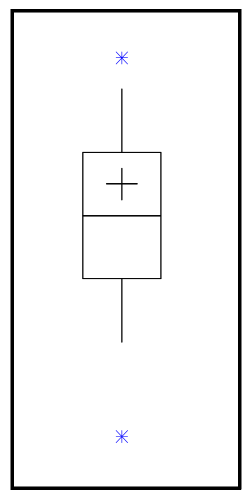


Figure 2-3. Example of a Box and Whisker Plot

2.3.4 Ranked Data Plot

A ranked data plot is a useful graphical representation that is easy to construct, easy to interpret, and makes no assumptions about a model for the data. The analyst does not have to make any arbitrary choices regarding the data to construct a ranked data plot (such as cell sizes for a histogram). In addition, a ranked data plot displays every data point; therefore, it is a graphical representation of the data instead of a summary of the data. Directions for developing a ranked data plot are given in Box 2-15 and an example is given in Box 2-16.

Box 2-13: Directions for Generating a Box and Whiskers Plot

STEP 1: Set the vertical scale of the plot based on the maximum and minimum values of the data set. Select a width for the box plot keeping in mind that the width is only a visualization tool. Label the width w; the horizontal scale then ranges from -½W to ½W.

STEP 2: Compute the upper quartile (Q(.75), the 75th percentile) and the lower quartile (Q(.25), the 25th percentile) using Box 2-1. Compute the sample mean and median using Box 2-2. Then, compute the interquartile range (IQR) where IQR = Q(.75) - Q(.25).

STEP 3: Draw a box through points (-½W, Q(.75)), (-½W, Q (.25)), (½W, Q(.25)) and (½W, Q(.75)). Draw a line from (½W, Q(.5)) to (-½W, Q(.5)) and mark point (0, $\bar{x}$) with (+).

STEP 4: Compute the upper end of the top whisker by finding the largest data value X less than Q(.75) + 1.5(Q(.75) - Q(.25)). Draw a line from (0, Q(.75)) to (0, X).

Compute the lower end of the bottom whisker by finding the smallest data value Y greater than Q(.25) - 1.5(Q(.75) - Q(.25)). Draw a line from (0, Q(.25)) to (0, Y).

STEP 5: For all points X* > X, place an asterisk (*) at the point (0, X*).

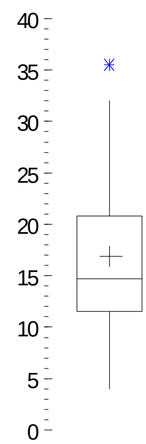
For all points Y* < Y, place an asterisk (*) at the point (0, Y*).

Box 2-14: Example of a Box and Whiskers Plot

Consider the following 22 samples of trifluorine (in ppm) listed in order from smallest to largest: 4.0, 6.1, 9.8, 10.7, 10.8, 11.5, 11.6, 12.4, 12.4, 14.6, 14.7, 14.7, 16.5, 17, 17.5, 20.6, 20.8, 25.7, 25.9, 26.5, 32.0, and 35.5.

STEP 1: The data ranges from 4.0 to 35.5 ppm. This is the range of the vertical axis. Arbitrarily, a width of 4 will be used for the horizontal axis.

STEP 2: Using the formulas in Box 2-2, the sample mean = 16.87 and the median = 14.70. Using Box 2-1, Q(.75) = 20.8 and Q(.25) = 11.5. Therefore, IQR = 20.8 - 11.5 = 9.3.



STEP 3: In the figure, a box has been drawn through points (-2, 20.8), (-2, 11.5), (2, 11.5), (2, 20.8). A line has been drawn from (-2 , 14.7) to (2, 14.7), and the point (0, 16.87) has been marked with a '+' sign.

STEP 4: Q(.75) + 1.5(9.3) = 34.75. The closest data value to this number, but less than it, is 32.0. Therefore, a line has been drawn in the figure from (0, 20.8) to (0, 32.0).

Q(.25) - 1.5(9.3) = -2.45. The closest data value to this number, but greater than it, is 4.0. Therefore, a line has been drawn in the figure from (0, 4) to (0, 11.5).

STEP 5: There is only 1 data value greater than 32.0 which is 35.5. Therefore, the point (0, 35.5) has been marked with an asterisk. There are no data values less than 4.0.

Box 2-15: Directions for Generating a Ranked Data Plot

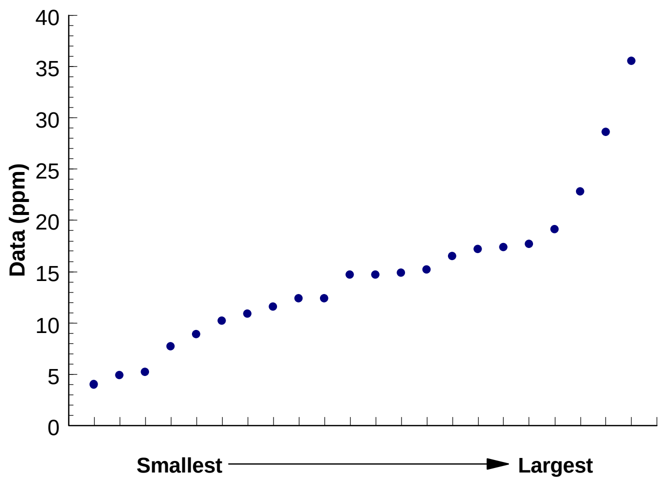
Let X_1, X_2, ..., X_n represent the n data points. Let $X_{(i)}$, for i=1 to n, be the data listed in order from smallest to largest so that $X_{(1)}$ (i = 1) is the smallest, $X_{(2)}$ (i = 2) is the second smallest, and $X_{(n)}$ (i = n) is the largest. To generate a ranked data plot, plot the ordered X values at equally spaced intervals along the horizontal axis.

Box 2-16: Example of Generating a Ranked Data Plot

Consider the following 22 samples of triflourine (in ppm): 17.7, 17.4, 22.8, 35.5, 28.6, 17.2 19.1, 4.9, 7.2, 4.0, 15.2, 14.7, 14.9, 10.9, 12.4, 12.4, 11.6, 14.7, 10.2, 5.2, 16.5, and 8.9. The data listed in order from smallest to largest $X_{(i)}$ along with the ordered number of the observation (i) are:

i	$X_{(i)}$	i	$X_{(i)}$
1	4.0	12	14.7
2	4.9	13	14.9
3	5.2	14	15.2
4	7.7	15	16.5
5	8.9	16	17.2
6	10.2	17	17.4
7	10.9	18	17.7
8	11.6	19	19.1
9	12.4	20	22.8
10	12.4	21	28.6
11	14.7	22	35.5

A ranked data plot of this data is a plot of the pairs (i, $X_{(i)}$). This plot is shown below:



A ranked data plot is a plot of the data from smallest to largest at evenly spaced intervals (Figure 2-4). This graphical representation is very similar to the quantile plot described in Section 2.3.5. A ranked data plot is marginally easier to generate than a quantile plot; however, a ranked data plot does not contain as much information as a quantile plot. Both plots can be used to determine the density of the data points and the skewness of the data; however, a quantile plot contains information on the quartiles of the data whereas a ranked data plot does not.

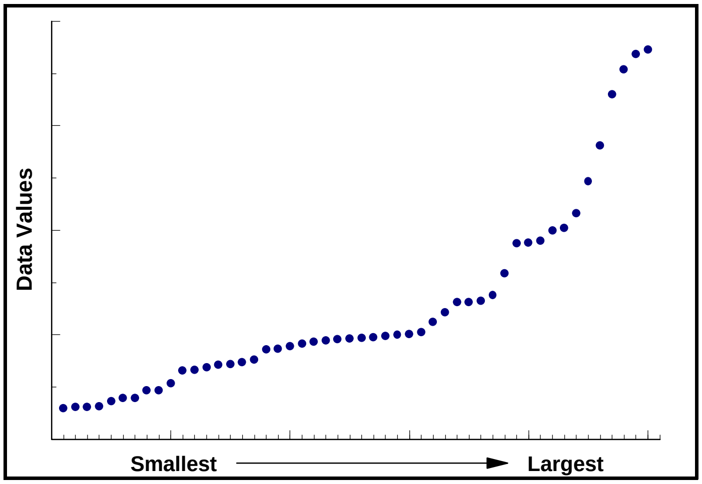


Figure 2-4. Example of a Ranked Data Plot

A ranked data plot can be used to determine the density of the data values, i.e., if all the data values are close to the center of the data with relatively few values in the tails or if there is a large amount of values in one tail with the rest evenly distributed. The density of the data is displayed through the slope of the graph. A large amount of data values has a flat slope, i.e., the graph rises slowly. A small amount of data values has a large slope, i.e., the graph rises quickly. Thus the analyst can determine where the data lie, either evenly distributed or in large clusters of points. In Figure 2-4, the data rises slowly up to a point where the slope increases and the graph rises relatively quickly. This means that there is a large amount of small data values and relatively few large data values.

A ranked data plot can be used to determine if the data are skewed or if they are symmetric. A ranked data plot of data that are skewed to the right extends more sharply at the top giving the graph a convex shape. A ranked data plot of data that are skewed to the left increases sharply near the bottom giving the graph a concave shape. If the data are symmetric, then the top portion of the graph will stretch to upper right corner in the same way the bottom portion of the graph stretches to lower left, creating a s-shape. Figure 2-4 shows a ranked data plot of data that are skewed to the right.

2.3.5 Quantile Plot

A quantile plot (Figure 2-5) is a graphical representation of the data that is easy to construct, easy to interpret, and makes no assumptions about a model for the data. The analyst does not have to make any arbitrary choices regarding the data to construct a quantile plot (such as cell sizes for a histogram). In addition, a quantile plot displays every data point; therefore, it is a graphical representation of the data instead of a summary of the data.

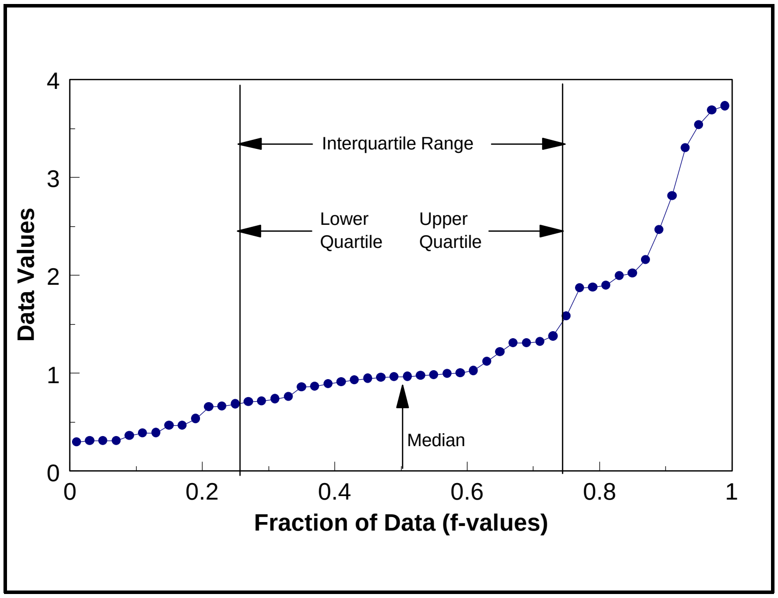


Figure 2-5. Example of a Quantile Plot of Skewed Data

A quantile plot is a graph of the quantiles (Section 2.2.1) of the data. The basic quantile plot is visually identical to a ranked data plot except its horizontal axis varies from 0.0 to 1.0, with each point plotted according to the fraction of the points it exceeds. This allows the addition of vertical lines indicating the quartiles or, any other quantiles of interest. Directions for developing a quantile plot are given in Box 2-17 and an example is given in Box 2-18.

A quantile plot can be used to read the quantile information such as the median, quartiles, and the interquartile range. In addition, the plot can be used to determine the density of the data points, e.g., are all the data values close to the center with relatively few values in the tails or are there a large amount of values in one tail with the rest evenly distributed? The density of the data is displayed through the slope of the graph. A large amount of data values has a flat slope, i.e., the graph rises slowly. A small amount of data values has a large slope, i.e., the graph rises quickly. A quantile plot can be used to determine if the data are skewed or if they are symmetric. A quantile plot of data that are skewed to the right is steeper at the top right than the bottom left, as in Figure 2-5. A quantile plot of data that are skewed to the left increases sharply near the bottom left of the graph. If the data are symmetric then the top portion of the graph will stretch to the upper right corner in the same way the bottom portion of the graph stretches to the lower left, creating an s-shape.

Box 2-17: Directions for Generating a Quantile Plot

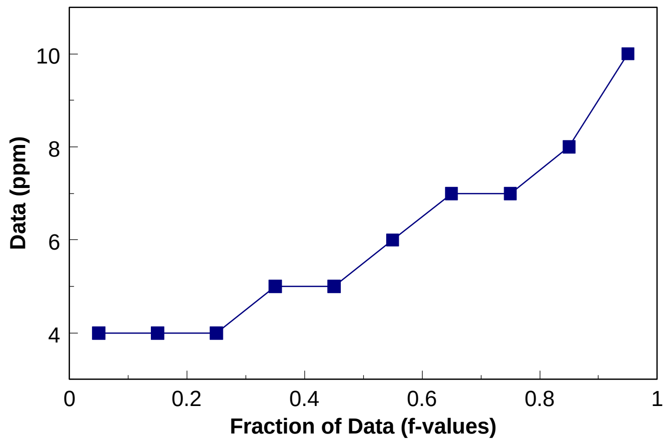
Let X_1, X_2, ..., X_n represent the n data points. To obtain a quantile plot, let $X_{(i)}$, for
i = 1 to n, be the data listed in order from smallest to largest so that $X_{(1)}$ (i = 1) is the smallest, $X_{(2)}$ (i = 2) is the second smallest, and $X_{(n)}$ (i = n) is the largest. For each i, compute the fraction f_i = (i - 0.5)/n. The quantile plot is a plot of the pairs (f_i, $X_{(i)}$), with straight lines connecting consecutive points.

Box 2-18: Example of Generating a Quantile Plot

Consider the following 10 data points: 4 ppm, 5 ppm, 6 ppm, 7 ppm, 4 ppm, 10 ppm, 4 ppm, 5 ppm, 7 ppm, and 8 ppm. The data ordered from smallest to largest, $X_{(i)}$, are shown in the first column of the table below and the ordered number for each observation, i, is shown in the second column. The third column displays the values f_i for each i where f_i = (i - 0.5)/n.

$X_{(i)}$	i	f_i	$X_{(i)}$	i	f_i
4	1	0.05	6	6	0.55
4	2	0.15	7	7	0.65
4	3	0.25	7	8	0.75
5	4	0.35	8	9	0.85
5	5	0.45	10	10	0.95

The pairs (f_i, $X_{(i)}$) are then plotted to yield the following quantile plot:



Note that the graph curves upward; therefore, the data appear to be skewed to the right.

2.3.6 Normal Probability Plot (Quantile-Quantile Plot)

There are two types of quantile-quantile plots or q-q plots. The first type, an empirical quantile-quantile plot (Section 2.3.7.4), involves plotting the quantiles of two data variables against each other. The second type of a quantile-quantile plot, a theoretical quantile-quantile plot, involves graphing the quantiles of a set of data against the quantiles of a specific distribution. The following discussion will focus on the most common of these plots for environmental data, the normal probability plot (the normal q-q plot); however, the discussion holds for other q-q plots. The normal probability plot is used to roughly determine how well the data set is modeled by a normal distribution. Formal tests are contained in Chapter 4, Section 2. Directions for developing a normal probability plot are given in Box 2-19 and an example is given in Box 2-20. A discussion of the normal distribution is contained in Section 2.4.

A normal probability plot is the graph of the quantiles of a data set against the quantiles of the normal distribution using normal probability graph paper (Figure 2-6). If the graph is linear, the data may be normally distributed. If the graph is not linear, the departures from linearity give important information about how the data distribution deviates from a normal distribution.

If the graph of the normal probability plot is not linear, the graph may be used to determine the degree of symmetry (or asymmetry) displayed by the data. If the data in the upper tail fall above and the data in the lower tail fall below the quartile line, the data are too slender to be well modeled by a normal distribution, i.e., there are fewer values in the tails of the data set than what is expected from a normal distribution. If the data in the upper tail fall below and the data in the lower tail fall above the quartile line, then the tails of the data are too heavy to be well modeled using a normal distribution, i.e., there are more values in the tails of the data than what is expected from a normal distribution. A normal probability plot can be used to identify potential outliers. A data value (or a few data values) much larger or much smaller than the rest will cause the other data values to be compressed into the middle of the graph, ruining the resolution.

Box 2-19: Directions for Constructing a Normal Probability Plot

Let $X_1, X_2, \ldots, X_n$ represent the n data points.

STEP 1: For each data value, compute the absolute frequency, AF_i. The absolute frequency is the number of times each value occurs. For distinct values, the absolute frequency is 1. For non-distinct observations, count the number of times an observation occurs. For example, consider the data 1, 2, 3, 3. The absolute frequency of value 1 is 1 and the absolute frequency of value 2 is 1. The absolute frequency of value 3 is 2 since 3 appears 2 times in the data set.

STEP 2: Compute the cumulative frequencies, CF_i. The cumulative frequency is the number of data points that are less than or equal to X_i, i.e., $CF_i = \sum_{j=1}^{i} AF_j$. Using the data given in step 2, the cumulative frequency for value 1 is 1, the cumulative frequency for value 2 is 2 (1+1), and the cumulative frequency for value 3 is 4 (1+1+2).

STEP 3: Compute $Y_i = 100 \ x \ \frac{CF_i}{(n+1)}$ and plot the pairs (Y_i, X_i) using normal probability paper (Figure 2-6). If the graph of these pairs approximately forms a straight line, then the data are probably normally distributed. Otherwise, the data may not be normally distributed.

Box 2-20: Example of Normal Probability Plot

Consider the following 15 data points: 5, 5, 6, 6, 8, 8, 9, 10, 10, 10, 10, 10, 12, 14, and 15.

STEP 1: Because the value 5 appears 2 times, its absolute frequency is 2. Similarly, the absolute frequency of 6 is 2, of 8 is 2, of 9 is 1, of 10 is 5, etc. These values are shown in the second column of the table below.

STEP 2: The cumulative frequency of the data value 8 is 6 because there are 2 values of 5, 2 values of 6, and 2 values of 8. The cumulative frequencies are shown in the 3rd column of the table.

STEP 3: The values $Y_i = 100 \; x \; (\frac{CF_i}{n+1})$ for each data point are shown in column 4 of the table below. A plot of these pairs (Y_i, X_i) using normal probability paper is also shown below.

i	Individual X_i	Absolute Frequency AF_i	Cumulative Frequency CF_i	Y_i
1	5	2	2	12.50
2	6	2	4	25.00
3	8	2	6	37.50
4	9	1	7	43.75
5	10	5	12	75.00
6	12	1	13	81.25
7	14	1	14	87.50
8	15	1	15	93.75

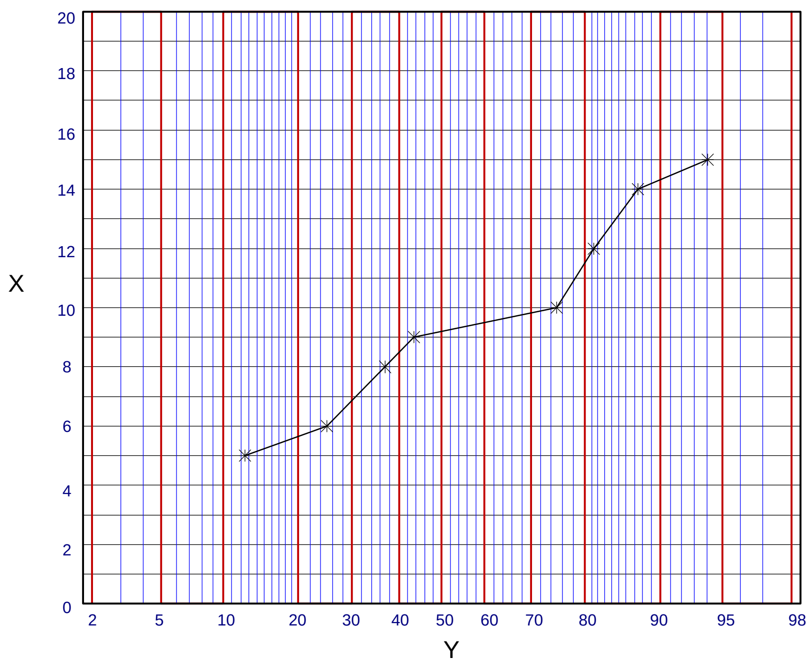


Figure 2-6. Normal Probability Paper

2.3.7 Plots for Two or More Variables

Data often consist of measurements of several characteristics (variables) for each sample point in the data set. For example, a data set may consist of measurements of weight, sex, and age for each animal in a sample or may consist of daily temperature readings for several cities. In this case, graphs may be used to compare and contrast different variables. For example, the analyst may wish to compare and contrast the temperature readings for different cities, or different sample points (each containing several variables) such the height, weight, and sex across individuals in a study.

To compare and contrast individual data points, some special plots have been developed to display multiple variables. These plots are discussed in Section 2.3.7.1. To compare and contrast several variables, collections of the single variable displays described in previous sections are useful. For example, the analyst may generate box and whisker plots or histograms for each variable using the same axis for all of the variables. Separate plots for each variable may be overlaid on one graph, such as overlaying quantile plots for each variable on one graph. Another useful technique for comparing two variables is to place the stem and leaf plots back to back. In addition, some special plots have been developed to display two or more variables. These plots are described in Sections 2.3.7.2 through 2.3.7.4.

2.3.7.1 Plots for Individual Data Points

Since it is difficult to visualize data in more than 2 or 3 dimensions, most of the plots developed to display multiple variables for individual data points involve representing each variable as a distinct piece of a two-dimensional figure. Some such plots include Profiles, Glyphs, and Stars (Figure 2-7). These graphical representations start with a specific symbol to represent each data point, then modify the various features of the symbol in proportion to the magnitude of each variable. The proportion of the magnitude is determined by letting the minimum value for each variable be of length 0, the maximum be of length 1. The remaining values of each variable are then proportioned based on the magnitude of each value in relation to the maximum and minimum.

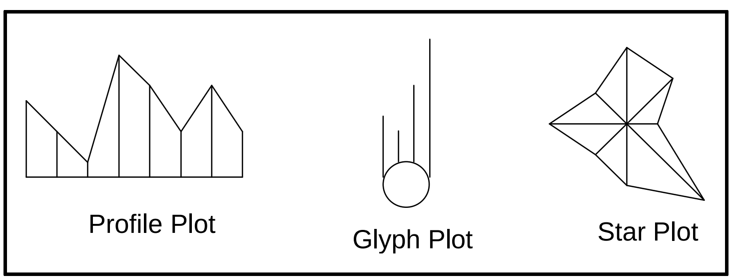


Figure 2-7. Example of Graphical Representations of Multiple Variables

A profile plot starts with a line segment of a fixed length. Then lines spaced an equal distance apart and extended perpendicular to the line segment represent each variable. A glyph plot uses a circle of fixed radius. From the perimeter, parallel rays whose sizes are proportional to the magnitude of the variable extend from the top half of the circle. A star plot starts with a point where rays spaced evenly around the circle represent each variable and a polygon is then drawn around the outside edge of the rays.

2.3.7.2 Scatter Plot

For data sets consisting of paired observations where two or more continuous variables are measured for each sampling point, a scatter plot is one of the most powerful tools for analyzing the relationship between two or more variables. Scatter plots are easy to construct for two variables (Figure 2-8) and many computer graphics packages can construct 3-dimensional scatter plots. Directions for constructing a scatter plot for two variables are given in Box 2-21 along with an example.

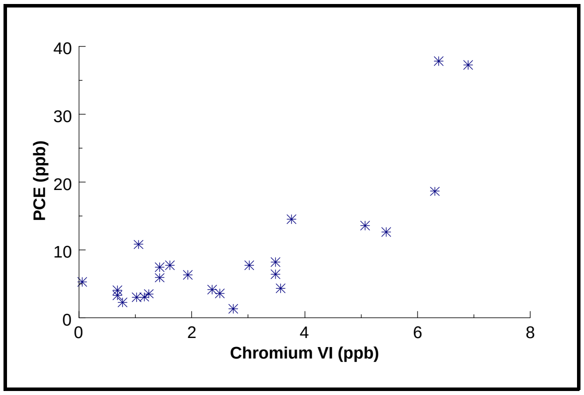


Figure 2-8. Example of a Scatter Plot

A scatter plot clearly shows the relationship between two variables. Both potential outliers from a single variable and potential outliers from the paired variables may be identified on this plot. A scatter plot also displays the correlation between the two variables. Scatter plots of highly linearly correlated variables cluster compactly around a straight line. In addition, nonlinear patterns may be obvious on a scatter plot. For example, consider two variables where one variable is approximately equal to the square of the other. A scatter plot of this data would display a u-shaped (parabolic) curve. Another important feature that can be detected using a scatter plot is any clustering effect among the data.

2.3.7.3 Extensions of the Scatter Plot

It is easy to construct a 2-dimensional scatter plot by hand and many software packages can construct a useful 3-dimensional scatter plot. However, with more than 3 variables, it is difficult to construct and interpret a scatter plot. Therefore, several graphical representations have been developed that extend the idea of a scatter plot for data consisting of 2 or more variables.

Box 2-21: Directions for Generating a Scatter Plot and an Example

Let X_1, X_2, ..., X_n represent one variable of the n data points and let Y_1, Y_2, ..., Y_n represent a second variable of the n data points. The paired data can be written as (X_i, Y_i) for i = 1, ..., n. To construct a scatter plot, plot the first variable along the horizontal axis and the second variable along the vertical axis. It does not matter which variable is placed on which axis.

Example: A scatter plot will be developed for the data below. PCE values are displayed on the vertical axis and Chromium VI values are displayed on the horizontal axis of Figure 2-8.

PCE (ppb)	Chromium VI (ppb)	PCE (ppb)	Chromium VI (ppb)	PCE (ppb)	Chromium VI (ppb)
14.49	3.76	2.23	0.77	4.14	2.36
37.21	6.92	3.51	1.24	3.26	0.68
10.78	1.05	6.42	3.48	5.22	0.65
18.62	6.30	2.98	1.02	4.02	0.68
7.44	1.43	3.04	1.15	6.30	1.93
37.84	6.38	12.60	5.44	8.22	3.48
13.59	5.07	3.56	2.49	1.32	2.73
4.31	3.56	7.72	3.01	7.73	1.61
				5.88	1.42

The simplest of these graphical representations is a coded scatter plot. In this case, all possible pairs of data are given a code and plotted on one scatter plot. For example, consider a data set of 3 variables: variable A, variable B, and variable C. Using the first variable to designate the horizontal axis, the analyst may choose to display the pairs (A, B) using an X, the pairs (A, C) using a Y, and the pairs (B, C) using a Z on one scatter plot. All of the information described above for a scatter plot is also available on a coded scatter plot. However, this method assumes that the ranges of the three variables are comparable and does not provide information on three-way or higher interactions between the variables. An example of a coded scatter plot is given in Figure 2-9.

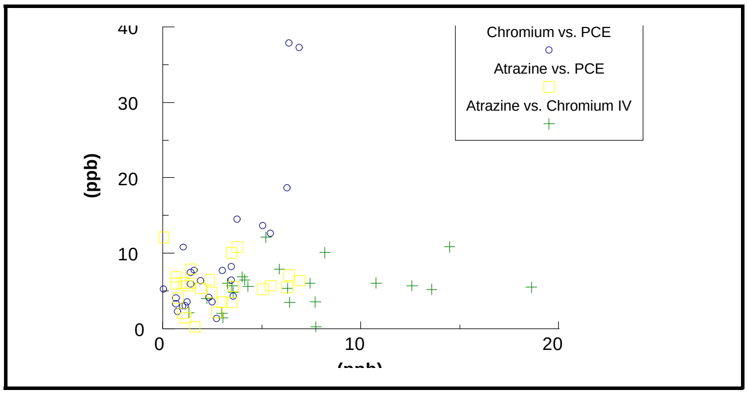


Figure 2-9. Example of a Coded Scatter Plot

A parallel coordinate plot also extends the idea of a scatter plot to higher dimensions. The parallel coordinates method employs a scheme where coordinate axes are drawn in parallel (instead of perpendicular). Consider a sample point X consisting of values X_1 for variable 1, X_2 for variable 2, and so on up to X_p for variable p. A parallel coordinate plot is constructed by placing an axis for each of the p variables parallel to each other and plotting X_1 on axis 1, X_2 on axis 2, and so on through X_p on axis p and joining these points with a broken line. This method contains all of the information available on a scatter plot in addition to information on 3-way and higher interactions (e.g., clustering among three variables). However, for p variables one must construct (p+1)/2 parallel coordinate plots in order to display all possible pairs of variables. An example of a parallel coordinate plot is given in Figure 2-10.

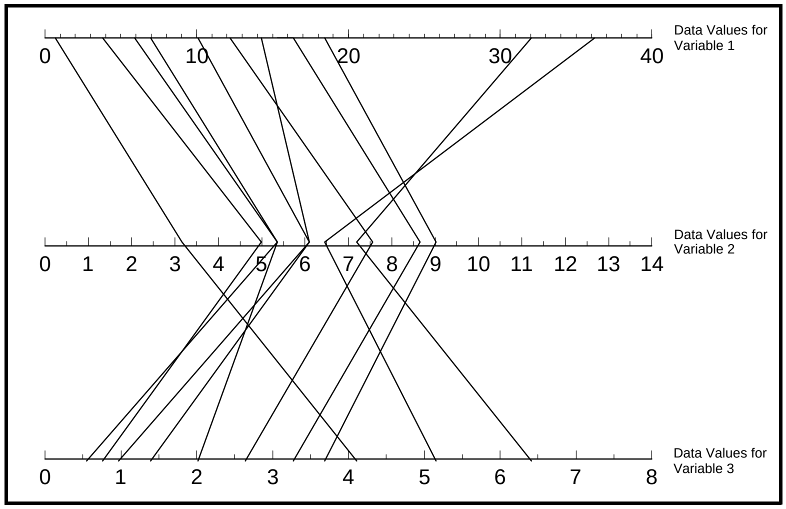


Figure 2-10. Example of a Parallel Coordinates Plot

A scatter plot matrix is another useful method of extending scatter plots to higher dimensions. In this case, a scatter plot is developed for all possible pairs of the variables which are then displayed in a matrix format. This method is easy to implement and provides a concise method of displaying the individual scatter plots. However, this method does not contain information on 3-way or higher interactions between variables. An example of a scatter plot matrix is contained in Figure 2-11.

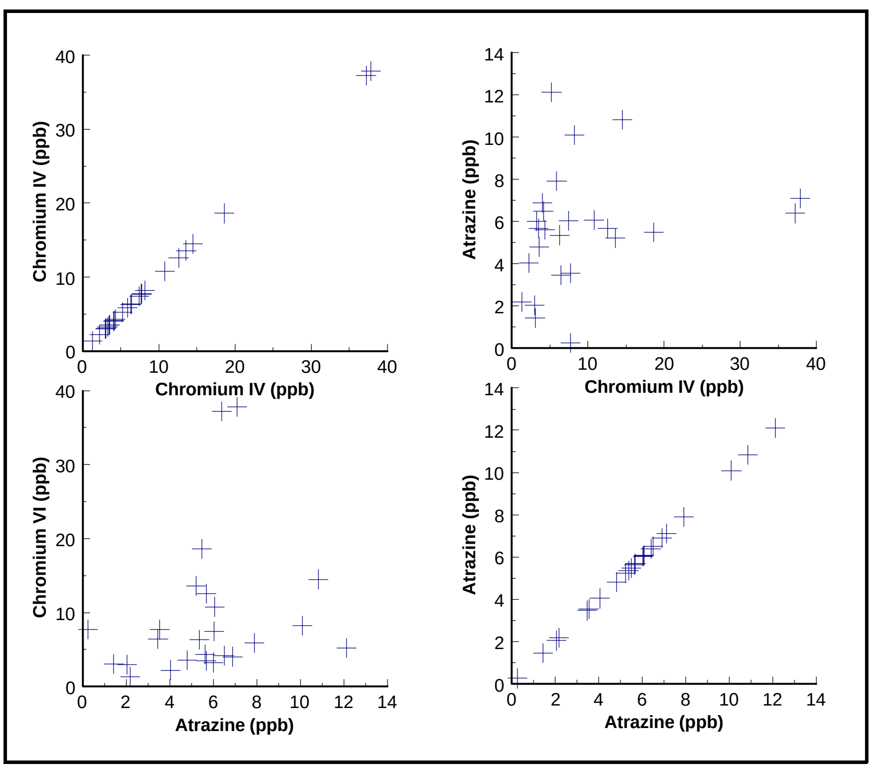


Figure 2-11. Example of a Matrix Scatter Plot

2.3.7.4 Empirical Quantile-Quantile Plot

An empirical quantile-quantile (q-q) plot involves plotting the quantiles (Section 2.2.1) of two data variables against each other. This plot is used to compare distributions of two or more variables; for example, the analyst may wish to compare the distribution of lead and iron samples from a drinking water well. This plot is similar in concept to the theoretical quantile-quantile plot and yields similar information in regard to the distribution of two variables instead of the distribution of one variable in relation to a fixed distribution. Directions for constructing an empirical q-q plot with an example are given in Box 2-22.

An empirical q-q plot is the graph of the quantiles of one variable of a data set against the quantiles of another variable of the data set. This plot is used to determine how well the distribution of the two variables match. If the distributions are roughly the same, the graph is linear or close to linear. If the distributions are not the same, than the graph is not linear. Even if the graph is not linear, the departures from linearity give important information about how the two data distributions differ. For example, a q-q plot can be used to compare the tails of the two data distributions in the same manner a normal probability plot was used to compare the tails of the data to the tails of a normal distribution. In addition, potential outliers (from the paired data) may be identified on this graph.

2.3.8 Plots for Temporal Data

Data collected over specific time intervals (e.g., monthly, biweekly, or hourly) have a temporal component. For example, air monitoring measurements of a pollutant may be collected once a minute or once a day; water quality monitoring measurements of a contaminant level may be collected weekly or monthly. An analyst examining temporal data may be interested in the trends over time, correlation among time periods, and cyclical patterns. Some graphical representations specific to temporal data are the time plot, correlogram, and variogram.

Data collected at regular time intervals are called time series. Time series data may be analyzed using Box-Jenkins modeling and spectral analysis. Both of these methods require a large amount of data collected at regular intervals and are beyond the scope of this guidance. It is recommended that the interested reader consult a statistician.

The graphical representations presented in this section are recommended for all data that have a temporal component regardless of whether formal statistical time series analysis will be used to analyze the data. If the analyst uses a time series methodology, the graphical representations presented below will play an important role in this analysis. If the analyst decides not to use time series methodologies, the graphical representations described below will help identify temporal patterns that need to be accounted for in the analysis of the data
.

Box 2-22: Directions for Constructing an Empirical Q-Q Plot with an Example

Let $X_1, X_2, ..., X_n$ represent n data points of one variable and let $Y_1, Y_2, ..., Y_m$ represent a second variable of m data points. Let $X_{(i)}$, for i = 1 to n, be the first variable listed in order from smallest to largest so that $X_{(1)}$ (i = 1) is the smallest, $X_{(2)}$ (i = 2) is the second smallest, and $X_{(n)}$ (i = n) is the largest. Let $Y_{(i)}$, for i = 1 to n, be the second variable listed in order from smallest to largest so that $Y_{(1)}$ (i = 1) is the smallest, $Y_{(2)}$ (i = 2) is the second smallest, and $Y_{(m)}$ (i = m) is the largest.

If m = n: If the two variables have the same number of observations, then an empirical q-q plot of the two variables is simply a plot of the ordered values of the variables. Since n=m, replace m by n. A plot of the pairs $(X_{(1)}, Y_{(1)})$, $(X_{(2)}, Y_{(2)})$, ..., $(X_{(n)}, Y_{(n)})$ is an empirical quantile-quantile plot.

If n > m: If the two variables have a different number of observations, then the empirical quantile-quantile plot will consist of m (the smaller number) pairs. The empirical q-q plot will then be a plot of the ordered Y values against the interpolated X values. For i = 1, i = 2, ..., i = m, let v = (n/m)(i - 0.5) + 0.5 and separate the result into the integer part and the fractional part, i.e., let v = j + g where j is the integer part and g is the fraction part. If g = 0, plot the pair $(Y_{(i)}, X_{(i)})$. Otherwise, plot the pair $(Y_{(i)}, (1-g)X_{(j)} + gX_{(j+1)})$. A plot of these pairs is an empirical quantile-quantile plot.

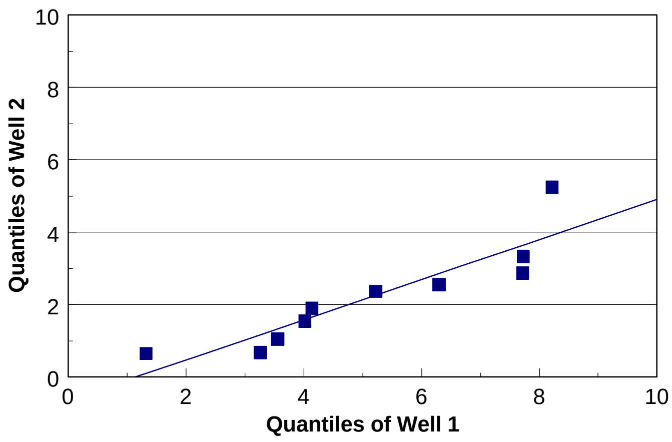
Example: Consider two sets of contaminant readings from two separate drinking water wells at the same site. The data from well 1 are: 1.32, 3.26, 3.56, 4.02, 4.14, 5.22, 6.30, 7.72, 7.73, and 8.22. The data from well 2 are: 0.65, 0.68, 0.68, 1.42, 1.61, 1.93, 2.36, 2.49, 2.73, 3.01, 3.48, and 5.44. An empirical q-q plot will be used to compare the distributions of these two wells. Since there are 10 observations in well 1, and 12 observations in well, the case for n $\neq$ m will be used. Therefore, for i = 1, 2, ..., 10, compute:

i = 1: $v = \frac{12}{10}(1-.5)+.5 = 1.1$ so j=1 and g=.1. Since g$\neq$0, plot (1.32,(.9).65+(.1).68)=(1.32, 0.653)

i = 2: $v = \frac{12}{10}(2-.5)+.5 = 2.3$ so j=2 and g=.3. Since g$\neq$0, plot (3.26,(.7).68+(.3).68)=(3.26, 0.68)

i = 3: $v = \frac{12}{10}(3-.5)+.5 = 3.5$ so j=3 and g=.5. Since g$\neq$0, plot (3.56,(.5).68+(.5)1.42)=(3.56,1.05)

Continue this process for i =4, 5, 6, 7, 8, 9, and 10 to yield the following 10 data pairs (1.32, 0.653), (3.26, 0.68), (3.56, 1.05), (4.02, 1.553), (4.14, 1.898), (5.22, 2.373), (6.30, 2.562), (7.72, 2.87), (7.73, 3.339), and (8.22, 5.244). These pairs are plotted below, along with the best fitting regression line.



The analyst examining temporal environmental data may be interested in seasonal trends, directional trends, serial correlation, and stationarity. Seasonal trends are patterns in the data that repeat over time, i.e., the data rise and fall regularly over one or more time periods. Seasonal trends may be large scale, such as a yearly trend where the data show the same pattern of rising and falling over each year, or the trends may be small scale, such as a daily trend where the data show the same pattern for each day. Directional trends are downward or upward trends in the data which is of importance to environmental applications where contaminant levels may be increasing or decreasing. Serial correlation is a measure of the extent to which successive observations are related. If successive observations are related, statistical quantities calculated without accounting for serial correlation may be biased. Finally, another item of interest for temporal data is stationarity (cyclical patterns). Stationary data look the same over all time periods. Directional trends and increasing (or decreasing) variability among the data imply that the data are not stationary.

Temporal data are sometimes used in environmental applications in conjunction with a statistical hypothesis test to determine if contaminant levels have changed. If the hypothesis test does not account for temporal trends or seasonal variations, the data must achieve a "steady state" before the hypothesis test may be performed. Therefore, the data must be essentially the same for comparable periods of time both before and after the hypothesized time of change.

Sometimes multiple observations are taken in each time period. For example, the sampling design may specify selecting 5 samples every Monday for 3 months. If this is the case, the time plot described in Section 2.3.8.1 may be used to display the data, display the mean weekly level, display a confidence interval for each mean, or display a confidence interval for each mean with the individual data values. A time plot of all the data can be used to determine if the variability for the different time periods changes. A time plot of the means can be used to determine if the means are possibly changing between time periods. In addition, each time period may be treated as a distinct variable and the methods of Section 2.3.7 may be applied.

2.3.8.1 Time Plot

One of the simplest plots to generate that provides a large amount of information is a time plot. A time plot is a plot of the data over time. This plot makes it easy to identify large-scale and small-scale trends over time. Small-scale trends show up on a time plot as fluctuations in smaller time periods. For example, ozone levels over the course of one day typically rise until the afternoon, then decrease, and this process is repeated every day. Larger scale trends, such as seasonal fluctuations, appear as regular rises and drops in the graph. For example, ozone levels tend to be higher in the summer than in the winter so ozone data tend to show both a daily trend and a seasonal trend. A time plot can also show directional trends and increased variability over time. Possible outliers may also be easily identified using a time plot.

A time plot (Figure 2-12) is constructed by numbering the observations in order by time. The time ordering is plotted on the horizontal axis and the corresponding observation is plotted on the vertical axis. The points plotted on a time plot may be joined by lines; however, it is recommended that the plotted points not be connected to avoid creating a false sense of continuity. The scaling of the vertical axis of a time plot is of some importance. A wider scale tends to emphasize large-scale trends, whereas a smaller scale tends to emphasize small-scale trends. Using the ozone example above, a wide scale would emphasize the seasonal component of the data, whereas a smaller scale would tend to emphasize the daily fluctuations. Directions for constructing a time plot are contained in Box 2-23 along with an example.

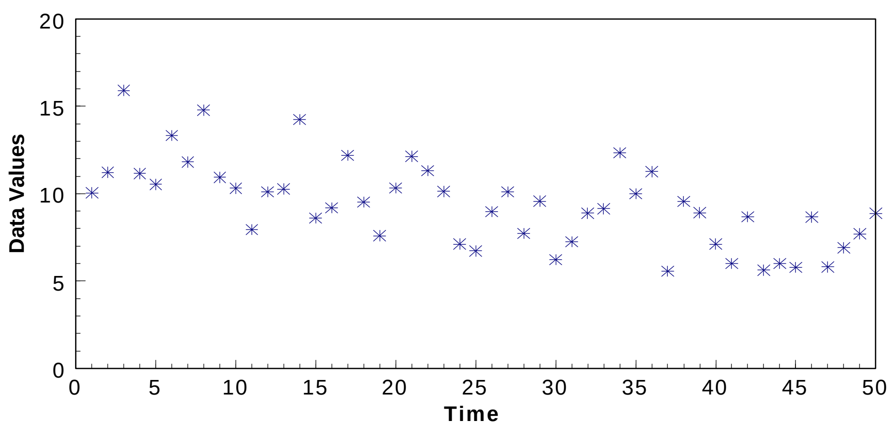


Figure 2-12. Example of a Time Plot Showing a Slight Downward Trend

Box 2-23: Directions for Generating a Time Plot and an Example

Let X_1, X_2, ..., X_n represent n data points listed in order by time, i.e., the subscript represents the ordered time interval. A plot of the pairs (i, X_i) is a time plot of this data.

Example: Consider the following 50 daily observations (listed in order by day): 10.05, 11.22, 15.9, 11.15, 10.53, 13.33, 11.81, 14.78, 10.93, 10.31, 7.95, 10.11, 10.27, 14.25, 8.6, 9.18, 12.2, 9.52, 7.59, 10.33, 12.13, 11.31, 10.13, 7.11, 6.72, 8.97, 10.11, 7.72, 9.57, 6.23, 7.25, 8.89, 9.14, 12.34, 9.99, 11.26, 5.57, 9.55, 8.91, 7.11, 6.04, 8.67, 5.62, 5.99, 5.78, 8.66, 5.8, 6.9, 7.7, 8.87. By labeling day 1 as 1, day 2 as 2, and so on, a time plot is constructed by plotting the pairs (i, X_i) where i represents the number of the day and X_i represents the concentration level. A time plot of this data is shown in Figure 2-12.

2.3.8.2 Plot of the Autocorrelation Function (Correlogram)

Serial correlation is a measure of the extent to which successive observations are related. If successive observations are related, either the data must be transformed or this relationship must be accounted for in the analysis of the data. The correlogram is a plot that is used to display serial correlation when the data are collected at equally spaced time intervals. The autocorrelation function is a summary of the serial correlations of data. The 1st autocorrelation coefficient (r_1) is the correlation between points that are 1 time unit (k_1) apart; the 2nd autocorrelation coefficient (r_2) is the correlation between points that are 2 time units (k_2) apart; etc. A correlogram (Figure 2-13) is a plot of the sample autocorrelation coefficients in which the values of k versus the values of r_k are displayed. Directions for constructing a correlogram are contained in Box 2-24; example calculations are contained in Box 2-25. For large sample sizes, a correlogram is tedious to construct by hand; therefore, software like *Data Quality Evaluation Statistical Tools (DataQUEST) (G-9D)* should be used.

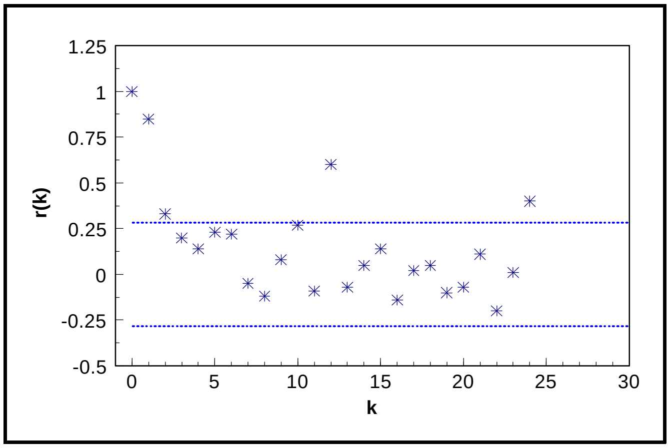


Figure 2-13. Example of a Correlogram

Box 2-24: Directions for Constructing a Correlogram

Let X_1, X_2, ..., X_n represent the data points ordered by time for equally spaced time points, i.e., X_1 was collected at time 1, X_2 was collected at time 2, and so on. To construct a correlogram, first compute the sample autocorrelation coefficients. So for k = 0, 1, ..., compute r_k where

$$r_k = \frac{g_k}{g_0} \quad \text{and} \quad g_k = \sum_{t=k+1}^{n} (X_t - \bar{X})(X_{t-k} - \bar{X}).$$

Once the r_k have been computed, a correlogram is the graph (k, r_k) for k = 0, 1, . . . , and so on. As a approximation, compute up to approximately k = n/6. Also, note that r_0 = 1. Finally, place horizontal lines at $\pm 2/\sqrt{n}$.

The correlogram is used for modeling time series data and may be used to determine if serial correlation is large enough to create problems in the analysis of temporal data using other methodologies besides formal time series methodologies. A quick method for determining if serial correlation is large is to place horizontal lines at $\pm 2/\sqrt{n}$ on the correlogram (shown as dashed lines on Figure 2-13). Autocorrelation coefficients that exceed this value require further investigation.

In application, the correlogram is only useful for data at equally spaced intervals. To relax this restriction, a variogram may be used instead. The variogram displays the same information as a correlogram except that the data may be based on unequally spaced time intervals. For more information on the construction and uses of the variogram, consult a statistician.

2.3.8.3 Multiple Observations Per Time Period

Sometimes in environmental data collection, multiple observations are taken for each time period. For example, the data collection design may specify collecting and analyzing 5 samples from a drinking well every Wednesday for three months. If this is the case, the time plot described in Section 2.3.8.1. may be used to display the data, display the mean weekly level, display a confidence interval for each mean, or display a confidence interval for each mean with the individual data values. A time plot of all the data will allow the analyst to determine if the variability for the different collection periods varies. A time plot of the means will allow the analyst to determine if the means may possibly be changing between the collection periods. In addition, each collection period may be treated as a distinct variable and the methods described in Section 2.3.7 may be applied.

Box 2-25: Example Calculations for Generating a Correlogram

A correlogram will be constructed using the following four hourly data points: hour 1: 4.5, hour 2: 3.5, hour 3: 2.5, and hour 4: 1.5. Only four data points are used so that all computations may be shown. Therefore, the idea that no more than n/6 autocorrelation coefficients should be computed will be broken for illustrative purposes. The first step to constructing a correlogram is to compute the sample mean (Box 2-2) which is 3 for the 4 points. Then,

$$g_0 = \sum_{t=1}^{4}(y_t-\bar{y})(y_{t-0}-\bar{y}) = \frac{\sum_{t=1}^{4}(y_t-\bar{y})^2}{4} = \frac{(4.5-3)^2+(3.5-3)^2+(2.5-3)^2+(1.5-3)^2}{4} = 1.25$$

$$g_1 = \frac{\sum_{t=2}^{4}(y_t-3)(y_{t-1}-3)}{4} = \frac{(y_2-3)(y_1-3) + (y_3-3)(y_2-3) + (y_4-3)(y_3-3)}{4}$$

$$= \frac{(3.5-3)(4.5-3)+(2.5-3)(3.5-3)+(1.5-3)(2.5-3)}{4} = \frac{1.25}{4} = 0.3125$$

$$g_2 = \frac{\sum_{t=3}^{4}(y_t-3)(y_{t-2}-3)}{4} = \frac{(y_3-3)(y_1-3) + (y_4-3)(y_2-3)}{4}$$

$$= \frac{(2.5-3)(4.5-3) + (1.5-3)(3.5-3)}{4} = \frac{-1.5}{4} = -0.375$$

$$g_3 = \frac{\sum_{t=4}^{4}(y_t-3)(y_{t-3}-3)}{4} = \frac{(y_4-3)(y_1-3)}{4} = \frac{(1.5-3)(4.5-3)}{4} = \frac{-2.25}{4} = -0.5625$$

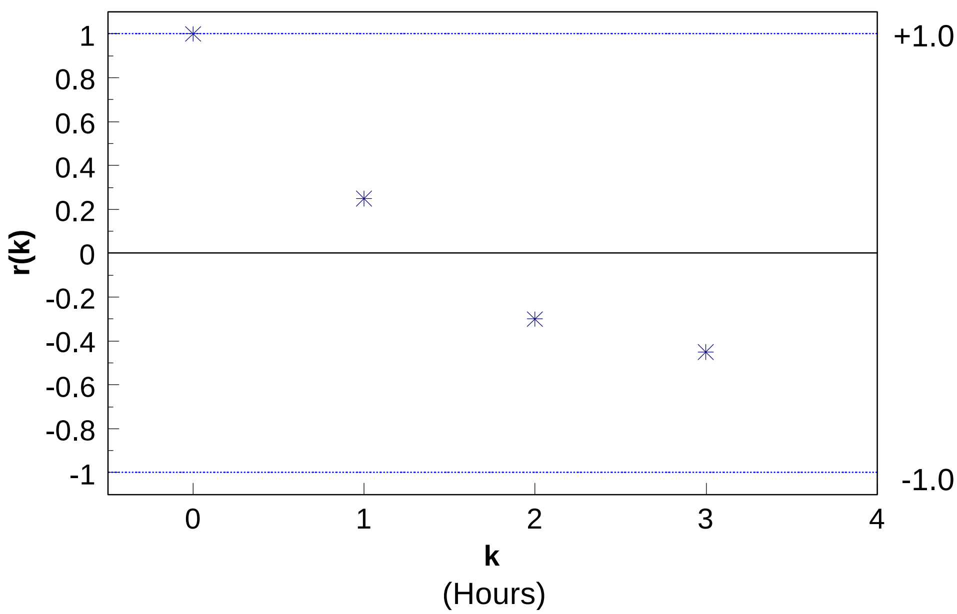
Box 2-25: Example Calculations for Generating a Correlogram - Continued

So $r_1 = \frac{g_1}{g_0} = \frac{0.3125}{1.25} = 0.25$, $r_2 = \frac{g_2}{g_0} = \frac{-.375}{1.25} = -0.3$, and

$$r_3 = \frac{g_3}{g_0} = \frac{-0.5625}{1.25} = -0.45.$$

Remember $r_0 = 1$. Thus, the correlogram of these data is a plot of (0, 1) (1, 0.25), (2, -0.3) and (3, -0.45) with two horizontal lines at $\pm 2/\sqrt{4}$ (±1). This graph is shown below.

In this case, it appears that the observations are not serially correlated because all of the correlogram points are within the bounds of $\pm 2/\sqrt{4}$ (±1.0). In Figure 2-13, if k represents months, then the correlogram shows a yearly correlation between data points since the points at k=12 and k=24 are out of the bounds of $\pm 2/\sqrt{n}$. This correlation will need to be accounted for when the data are analyzed.



2.3.9 Plots for Spatial Data

The graphical representations of the preceding sections may be useful for exploring spatial data. However, an analyst examining spatial data may be interested in the location of extreme values, overall spatial trends, and the degree of continuity among neighboring locations. Graphical representations for spatial data include postings, symbol plots, correlograms, h-scatter plots, and contour plots.

The graphical representations presented in this section are recommended for all spatial data regardless of whether or not geostatistical methods will be used to analyze the data. The graphical representations described below will help identify spatial patterns that need to be accounted for in the analysis of the data. If the analyst uses geostatistical methods such as kriging to analyze the data, the graphical representations presented below will play an important role in geostatistical analysis.

2.3.9.1 Posting Plots

A posting plot (Figure 2-14) is a map of data locations along with corresponding data values. Data posting may reveal obvious errors in data location and identify data values that may be in error. The graph of the sampling locations gives the analyst an idea of how the data were collected (i.e., the sampling design), areas that may have been inaccessible, and areas of special interest to the decision maker which may have been heavily sampled. It is often useful to mark the highest and lowest values of the data to see if there are any obvious trends. If all of the highest concentrations fall in one region of the plot, the analyst may consider some method such as post-stratifying the data (stratification after the data are collected and analyzed) to account for this fact in the analysis. Directions for generating a posting of the data (a posting plot) are contained in Box 2-26.

Figure 2-14. Example of a Posting Plot

2.3.9.2 Symbol Plots

For large amounts of data, a posting plot may not be feasible and a symbol plot (Figure 2-15) may be used. A symbol plot is basically the same as a posting plot of the data, except that instead of posting individual data values, symbols are posted for ranges of the data values. For example, the symbol '0' could represent all concentration levels less than 100 ppm, the symbol '1' could represent all concentration levels between 100 ppm and 200 ppm, etc. Directions for generating a symbol plot are contained in Box 2-26.

Figure 2-15. Example of a Symbol Plot

Box 2-26: Directions for Generating a Posting Plot and a Symbol Plot with an Example

On a map of the site, plot the location of each sample. At each location, either indicate the value of the data point (a posting plot) or indicate by an appropriate symbol (a symbol plot) the data range within which the value of the data point falls for that location, using one unique symbol per data range.

Example: The spatial data displayed in the table below contains both a location (Northing and Easting) and a concentration level ([c]). The data range from 4.0 to 35.5 so units of 5 were chosen to group the data:

Range	Symbol	Range	Symbol
0.0 - 4.9	0	20.0 - 24.9	4
5.0 - 9.9	1	25.0 - 29.9	5
10.0 - 14.9	2	30.0 - 34.9	6
15.0 - 19.9	3	35.0 - 39.9	7

The data values with corresponding symbols then become:

Northing	Easting	[c]	Symbol	Northing	Easting	[c]	Symbol
25.0	0.0	4.0	0	15.0	15.0	16.5	3
25.0	5.0	11.6	2	15.0	0.0	8.9	1
25.0	10.0	14.9	2	10.0	5.0	14.7	2
25.0	15.0	17.4	3	10.0	10.0	10.9	2
20.0	0.0	17.7	3	10.0	15.0	12.4	2
20.0	5.0	12.4	2	5.0	0.0	22.8	4
20.0	10.0	28.6	5	5.0	5.0	19.1	3
20.0	15.0	7.7	1	5.0	10.0	10.2	2
15.0	0.0	15.2	3	5.0	15.0	5.2	1
15.0	5.0	35.5	7	0.0	5.0	4.9	0
15.0	10.0	14.7	2	0.0	15.0	17.2	3

The posting plot of this data is displayed in Figure 2-14 and the symbol plot is displayed in Figure 2-15.

2.3.9.3 Other Spatial Graphical Representations

The two plots described in Sections 2.3.9.1 and 2.3.9.2 provide information on the location of extreme values and spatial trends. The graphs below provide another item of interest to the data analyst, continuity of the spatial data. The graphical representations are not described in detail because they are used more for preliminary geostatistical analysis. These graphical representations can be difficult to develop and interpret. For more information on these representations, consult a statistician.

An h-scatterplot is a plot of all possible pairs of data whose locations are separated by a fixed distance in a fixed direction (indexed by h). For example, a h-scatter plot could be based on all the pairs whose locations are 1 meter apart in a southerly direction. A h-scatter plot is similar in appearance to a scatter plot (Section 2.3.7.2). The shape of the spread of the data in a h-scatter plot indicates the degree of continuity among data values a certain distance apart in particular direction. If all the plotted values fall close to a fixed line, then the data values at locations separated by a fixed distance in a fixed location are very similar. As data values become less and less similar, the spread of the data around the fixed line increases outward. The data analyst may construct several h-scatter plots with different distances to evaluate the change in continuity in a fixed direction.

A correlogram is a plot of the correlations of the h-scatter plots. Because the h-scatter plot only displays the correlation between the pairs of data whose locations are separated by a fixed distance in a fixed direction, it is useful to have a graphical representation of how these correlations change for different separation distances in a fixed direction. The correlogram is such a plot which allows the analyst to evaluate the change in continuity in a fixed direction as a function of the distance between two points. A spatial correlogram is similar in appearance to a temporal correlogram (Section 2.3.8.2). The correlogram spans opposite directions so that the correlogram with a fixed distance of due north is identical to the correlogram with a fixed distance of due south.

Contour plots are used to reveal overall spatial trends in the data by interpolating data values between sample locations. Most contour procedures depend on the density of the grid covering the sampling area (higher density grids usually provide more information than lower densities). A contour plot gives one of the best overall pictures of the important spatial features. However, contouring often requires that the actual fluctuations in the data values are smoothed so that many spatial features of the data may not be visible. The contour map should be used with other graphical representations of the data and requires expert judgement to adequately interpret the findings.

2.4 Probability Distributions

2.4.1 The Normal Distribution

Data, especially measurements, occur in natural patterns that can be considered to be a distribution of values. In most instances the data values will be grouped around some measure of control tendency such as the mean or median. The spread of the data (as determined by the sum of the squared distances from data point to the mean) is called the variance (the square root of this is called the standard deviation). A distribution with a large variance will be more spread out than one with a small variance (Figure 2-16). When the data values fall in a systematic pattern around the mean and then taper off rapidly to the tails, it is often a normal distribution or bell-shaped curve.

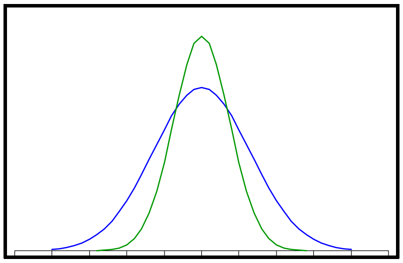


Figure 2-16. The Normal Distribution

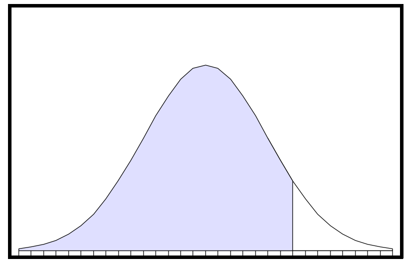


Figure 2-17. The Standard Normal Curve (Z-Curve)

The characteristics of a normal distribution are well known mathematically and when referred to, usually written as "data are distributed N (μ, σ^2)" where the first characteristic is the mean (μ) and the second, the variance (σ^2). It may be shown that any normal distribution can be transformed to a standard normal distribution, N(0,1), and this standard normal referred to as simply Z (Figure 2-17). It is frequently necessary to refer to the percentiles of a standard normal and in this guidance document, the subscript to a quoted Z-value will denote the percentile (or area under the curve, cumulative from the left), see Figure 2-17.

2.4.2 The t-Distribution

The standard normal curve is used when exact information on the mean and variance are available, but when only estimates from a sample are available, a different distribution applies. When only information from a random sample on sample mean and sample variance is known for decision making purposes, a Student's t distribution is appropriate. It resembles a standard normal but is lower in the center and fatter in the tails. The degree of fatness in the tails is a function of the degrees of freedom available, which in turn is related to sample size.

2.4.3 The Lognormal Distribution

A commonly met distribution in environmental work is the lognormal distribution which has a more skewed (lopsided) shape than a normal, see Figure 2-18. The lognormal is bounded by zero and has a fatter tail than the normal. It is related to the normal by the simple relationship: if X is distributed lognormally, then Y = ln (X) is distributed normally. It is common practice to transform data (and any standard being tested against) to achieve approximate normality prior to conducting statistical tests.

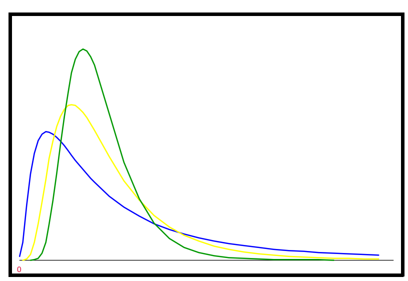


Figure 2-18. Three Different Lognormal Distributions

2.4.4 Central Limit Theorem

In nearly all estimation situations in environmental work, the focus of the investigation centers on the mean of a random sample of observations or measurements. It is rare that true normality of the observations can be assumed and therefore a question as whether to use statistical tests based on normality may be considered.

In many cases, the normally-based statistical tests are not overly affected by the lack of normality as tests are very robust (sturdy) and perform tolerably well unless gross non-normality is present. In addition, the tests become increasingly tolerant of deviations from normality as the number of individual samples constituting the sample mean increases. In simple terms, as the size of the sample increases, the mean of that sample acts increasingly as if it came from a normal distribution regardless of the true distribution of the individual values. The taking of large samples "stabilizes" the mean, so it then acts as if normality was present and the statistical test remain valid.

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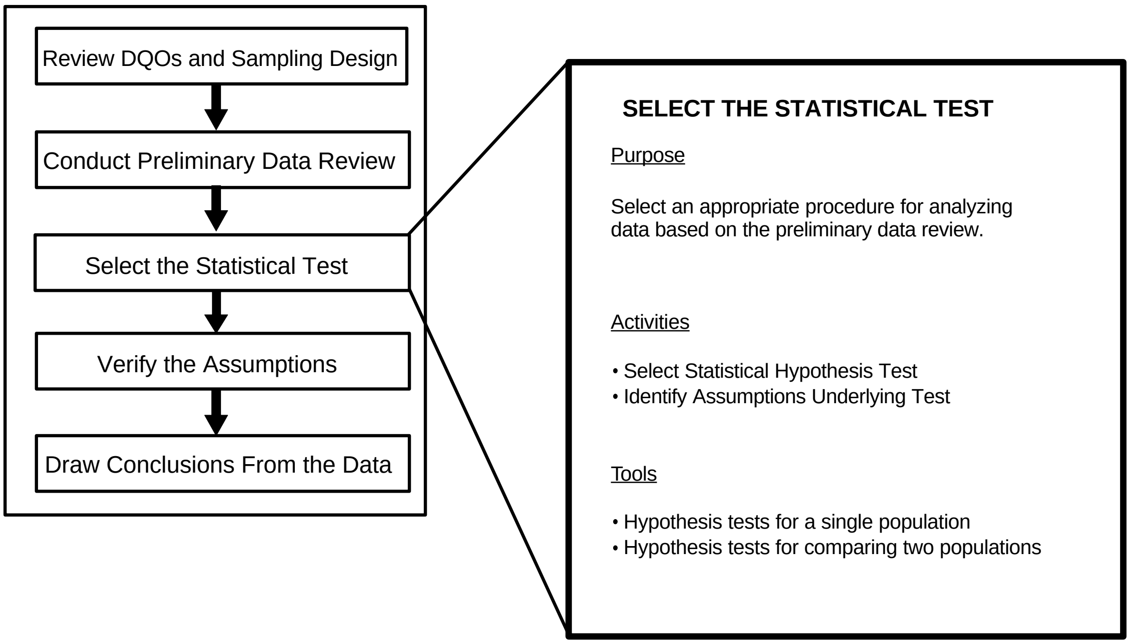
CHAPTER 3

STEP 3: SELECT THE STATISTICAL TEST

THE DATA QUALITY ASSESSMENT PROCESS



Step 3: Select the Statistical Test

- Select the statistical hypothesis test based on the data user's objectives and the results of the preliminary data review.
  - If the problem involves comparing study results to a fixed threshold, such as a regulatory standard, consider the hypothesis tests in Section 3.2.
  - If the problem involves comparing two populations, such as comparing data from two different locations or processes, then consider the hypothesis tests in Section 3.3.

- Identify the assumptions underlying the statistical test.
  - List the key underlying assumptions of the statistical hypothesis test, such as distributional form, dispersion, independence, or others as applicable.
  - Note any sensitive assumptions where relatively small deviations could jeopardize the validity of the test results.

List of Boxes

CHAPTER 3
STEP 3: SELECT THE STATISTICAL TEST

3.1 OVERVIEW AND ACTIVITIES

This chapter provides information that the analyst can use in selecting an appropriate statistical hypothesis test that will be used to draw conclusions from the data. A brief review of hypothesis testing is contained in Chapter 1. There are two important outputs from this step: (1) the test itself, and (2) the assumptions underlying the test that determine the validity of conclusions drawn from the test results.

This section describes the two primary activities in this step of DQA. The remaining sections in this chapter contain statistical tests that may be useful for analyzing environmental data. In the one-sample tests discussed in Section 3.2, data from a population are compared with an absolute criterion such as a regulatory threshold or action level. In the two-sample tests discussed in Section 3.3, data from a population are compared with data from another population (for example, an area expected to be contaminated might be compared with a background area). For each statistical test, this chapter presents its purpose, assumptions, limitations, robustness, and the sequence of steps required to apply the test.

The directions for each hypothesis test given in this chapter are for simple random sampling and randomized systematic sampling designs, except where noted otherwise. If a more complex design is used (such as a stratified design or a composite random sampling design) then different formulas are needed, some of which are contained in this chapter.

3.1.1 Select Statistical Hypothesis Test

If a particular test has been specified either in the DQO Process, the QA Project Plan, or by the particular program or study, the analyst should use the results of the preliminary data review to determine if this statistical test is legitimate for the data collected. If the test is not legitimate, the analyst should document why this particular statistical test should not be applied to the data and then select a different test, possibly after consultation with the decision maker. If a particular test has not been specified, the analyst should select a statistical test based on the data user's objectives, preliminary data review, and likely viable assumptions.

3.1.2 Identify Assumptions Underlying the Statistical Test

All statistical tests make assumptions about the data. Parametric tests assume the data have some distributional form (e.g., the t-test assumes normal distribution), whereas nonparametric tests do not make this assumption (e.g., the Wilcoxon test only assumes the data are symmetric but not necessarily normal). However, both parametric and nonparametric tests may assume that the data are statistically independent or that there are no trends in the data. While examining the data, the analyst should always list the underlying assumptions of the statistical hypothesis test, such as distribution, dispersion, or others as applicable.

Another important feature of statistical tests is their sensitivities (nonrobustness) to departures from the assumptions. A statistical procedure is called robust if its performance is not seriously affected by moderate deviations from its underlying assumptions. The analyst should note any sensitive assumptions where relatively small deviations could jeopardize the validity of the test results.

3.2 TESTS OF HYPOTHESES ABOUT A SINGLE POPULATION

A one-sample test involves the comparison of a population parameter (e.g., a mean, percentile, or variance) to a threshold value. Both the threshold value and the population parameter were specified during Step 1: Review DQOs and Sampling Design. In a one-sample test, the threshold value is a fixed number that does not vary. If the threshold value was estimated (and therefore contains variability), a one-sample test is not appropriate. An example of a one-sample test would be to determine if 95% of all companies emitting sulfur dioxide into the air are below a fixed discharge level. For this example, the population parameter is a percentage (proportion) and the threshold value is 95% (.95). Another example is a common Superfund problem that involves comparing the mean contaminant concentration to a risk-based standard. In this case, the risk-based standard (which is fixed) is the threshold value and the statistical parameter is the true mean contaminant concentration level of the site. However, comparing the mean concentration in an area to the mean concentration of a reference area (background) would not be a one-sample test because the mean concentration in the reference area would need to be estimated.

The statistical tests discussed in this section may be used to determine if $\theta \leq \theta_0$ or $\theta > \theta_0$, where θ represents either the population mean, median, a percentile, or a proportion and θ_0 represents the threshold value. Section 3.2.1 discusses tests concerning the population mean, Section 3.2.2 discusses tests concerning a proportion or percentile, and Section 3.2.2 discusses tests for a median.

3.2.1 Tests for a Mean

A population mean is a measure of the center of the population distribution. It is one of the most commonly used population parameters in statistical hypothesis testing because its distribution is well known for large sample sizes. The hypotheses considered in this section are:

Case 1: H_0: $\mu \leq C$ vs. H_A: $\mu > C$; and

Case 2: H_0: $\mu \geq C$ vs. H_A: $\mu < C$

where C represents a given threshold such as a regulatory level, and μ denotes the (true) mean contaminant level for the population. For example, C may represent the arsenic concentration level of concern. Then if the mean of the population exceeds C, the data user may wish to take action.

The information required for this test (defined in Step 1) includes the null and alternative hypotheses (either Case 1 or Case 2); the gray region, i.e., a value $\mu_1 > C$ for Case 1 or a value $\mu_1 < C$ for Case 2 representing the bound of the gray region; the false rejection error rate α at C; the false acceptance error rate β at μ_1; and any additional limits on decision errors. It may be helpful to label any additional false rejection error limits as α_2 at C_2, α_3 at C_3, etc., and to label any additional false acceptance error limits as β_2 at μ_2, β_3 at μ_3, etc. For example, consider the following decision: determine whether the mean contaminant level at a waste site is greater than 10 ppm. The null hypothesis is H_0: $\mu \geq 10$ ppm and the alternative hypothesis is H_A: $\mu < 10$ ppm. A gray region has been set from 10 to 8 ppm, a false rejection error rate of 5% has been set at 10 ppm, and a false acceptance error rate of 10% has been set at 8 ppm. Thus, C = 10 ppm, μ_1 = 8 ppm, $\alpha = 0.05$, and $\beta = 0.1$. If an additional false acceptance error rate was set, for example, an error rate of 1% at 4 ppm, then $\beta_2 = .01$ and $\mu_2 = 4$ ppm.

3.2.1.1 The One-Sample t-Test

PURPOSE

Given a random sample of size n (or a composite sample of size n, each composite consisting of k aliquots), the one-sample t-test can be used to test hypotheses involving the mean (μ) of the population from which the sample was selected.

ASSUMPTIONS AND THEIR VERIFICATION

The primary assumptions required for validity of the one-sample t-test are that of a random sample (independence of the data values) and that the sample mean $\bar{x}$ is approximately normally distributed. Because the sample mean and standard deviation are very sensitive to outliers, the t-test should be preceded by a test for outliers (see Section 4.4).

Approximate normality of the sample mean follows from approximate normality of the data values. In addition, the Central Limit Theorem states that the sample mean of a random sample from a population with an unknown distribution will be approximately normally distributed provided the sample size is large. This means that although the population distribution from which the data are drawn can be distinctly different from the normal distribution, the distribution of the sample mean can still be approximately normal when the sample size is relatively large. Although preliminary tests for normality of the data can and should be done for small sample sizes, the conclusion that the sample does not follow a normal distribution does not automatically invalidate the t-test, which is robust to moderate violations of the assumption of normality for large sample sizes.

LIMITATIONS AND ROBUSTNESS

The t-test is not robust to outliers because the sample mean and standard deviation are influenced greatly by outliers. The Wilcoxon signed rank test (see Section 3.2.1.2) is more robust, but is slightly less powerful. This means that the Wilcoxon signed rank test is slightly less likely to reject the null hypothesis when it is false than the t-test.

The t-test has difficulty dealing with less-than values, e.g., values below the detection limit, compared with tests based on ranks or proportions. Tests based on a proportion above a given threshold (Section 3.2.2) are more valid in such a case, if the threshold is above the detection limit. It is also possible to substitute values for below detection-level data (e.g., ½ the detection level) or to adjust the statistical quantities to account for nondetects (e.g., Cohen's Method for normally or lognormally distributed data). See Chapter 4 for more information on dealing with data that are below the detection level.

SEQUENCE OF STEPS

Directions for a one-sample t-test for a simple, systematic, and composite random samples are given in Box 3-1 and an example is given in Box 3-2. Directions for a one-sample t-test for a stratified random sample are given in Box 3-3 and an example is given in Box 3-4.

Box 3-1: Directions for a One-Sample t-Test for Simple and Systematic Random Samples with or without Compositing

Let $X_1, X_2, \ldots, X_n$ represent the n data points. These could be either n individual samples or n composite samples consisting of k aliquots each. These are the steps for a one-sample t-test for Case 1 (H_0: $\mu \le C$); modifications for Case 2 (H_0: $\mu \ge C$) are given in braces { }.

STEP 1: Calculate the sample mean, $\bar{x}$ (Section 2.2.2), and the standard deviation, s (Section 2.2.3).

STEP 2: Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ such that 100(1-α)% of the t distribution with n - 1 degrees of freedom is below $t_{1-\alpha}$. For example, if α = 0.05 and n = 16, then n-1 = 15 and $t_{1-\alpha}$ = 1.753.

STEP 3: Calculate the sample value $t = (\bar{X} - C) / (s/\sqrt{n})$.

STEP 4: Compare t with $t_{1-\alpha}$.

1) If $t > t_{1-\alpha}$ $\{t < -t_{1-\alpha}\}$, the null hypothesis may be rejected. Go to Step 6.

2) If $t \ngtr t_{1-\alpha}$ $\{t \nless -t_{1-\alpha}\}$, there is not enough evidence to reject the null hypothesis and the false acceptance error rate should be verified. Go to Step 5.

STEP 5: As the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates. To calculate the power, assume that the true values for the mean and standard deviation are those obtained in the sample and use a software package like the Decision Error Feasibility Trial (DEFT) software (EPA, 1994) to generate the power curve of the test.

If only one false acceptance error rate (β) has been specified (at μ_1), it is possible to calculate the sample size which achieves the DQOs, assuming the true mean and standard deviation are equal to the values estimated from the sample, instead of calculating the power of the test. To do this, calculate $m = \dfrac{s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\mu_1 - C)^2} + (0.5)z^2_{1-\alpha}$ where z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). Round m up to the next integer. If $m \le n$, the false acceptance error rate has been satisfied. If m > n, the false acceptance error rate has not been satisfied.

STEP 6: The results of the test may be:

1) the null hypothesis was rejected and it seems that the true mean is greater than C {less than C};

2) the null hypothesis was not rejected and the false acceptance error rate was satisfied and it seems that the true mean is less than C {greater than C}; or

3) the null hypothesis was not rejected and the false acceptance error rate was not satisfied and it seems that the true mean is less than C {greater than C} but conclusions are uncertain since the sample size was too small.

Report the results of the test, the sample size, sample mean, standard deviation, t and $t_{1-\alpha}$.

Note: The calculations for the t-test are the same for both simple random or composite random sampling. The use of compositing will usually result in a smaller value of "s" than simple random sampling.

Box 3-2: An Example of a One-Sample t-Test for a Simple Random or Composite Sample

Consider the following 9 random (or composite samples each of k aliquots) data points: 82.39 ppm, 103.46 ppm, 104.93 ppm, 105.52 ppm, 98.37 ppm, 113.23 ppm, 86.62 ppm, 91.72 ppm, and 108.21 ppm. This data will be used to test the hypothesis: H_0: $\mu \le 95$ ppm vs. H_A: $\mu > 95$ ppm. The decision maker has specified a 5% false rejection decision error limit (α) at 95 ppm (C), and a 20% false acceptance decision error limit (β) at 105 ppm (μ_1).

STEP 1: Using the directions in Box 2-2 and Box 2-3, it was found that

$$\bar{X} = 99.38\ ppm \quad \text{and} \quad s = 10.41\ ppm.$$

STEP 2: Using Table A-1 of Appendix A, the critical value of the t distribution with 8 degrees of freedom is $t_{0.95} = 1.86$.

STEP 3: $$t = \frac{\bar{X} - C}{s/\sqrt{n}} = \frac{99.38 - 95}{10.41/\sqrt{9}} = 1.26$$

STEP 4: Because $1.26 \not> 1.86$, there is not enough evidence to reject the null hypothesis and the false acceptance error rate should be verified.

STEP 5: Because there is only one false acceptance error rate, it is possible to use the sample size formula to determine if the error rate has been satisfied. Therefore,

$$m = \frac{s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\mu_1 - C)^2} + (0.5)z^2_{1-\alpha}$$

$$= \frac{10.41^2(1.645 + 0.842)^2}{(95 - 105)^2} + (0.5)(1.645)^2 = 8.049,$$

i.e., 9

Notice that it is customary to round upwards when computing a sample size. Since m=n, the false acceptance error rate has been satisfied.

STEP 6: The results of the hypothesis test were that the null hypothesis was not rejected but the false acceptance error rate was satisfied. Therefore, it seems that the true mean is less than 95 ppm.

Box 3-3: Directions for a One-Sample t-Test for a Stratified Random Sample

Let h=1, 2, 3, . . . , L represent the L strata and n_h represent the sample size of stratum h. These steps are for a one-sample t-test for Case 1 (H_0: $\mu \le C$); modifications for Case 2 (H_0: $\mu \ge C$) are given in braces { }.

STEP 1: Calculate the stratum weights (W_h) by calculating the proportion of the volume in stratum h, $W_h = \dfrac{V_h}{\sum_{h=1}^{L} V_h}$ where V_h is the surface area of stratum h multiplied by the depth of sampling in stratum h.

STEP 2: For each stratum, calculate the sample stratum mean $\bar{X}_h = \dfrac{\sum_{i=1}^{n_h} X_{hi}}{n_h}$ and the sample stratum standard error $s_h^2 = \sum_{i=1}^{n_h} \dfrac{(X_{hi} - \bar{X}_h)^2}{n_h - 1}$.

STEP 3: Calculate overall mean $\bar{X}_{ST} = \sum_{h=1}^{L} W_h \bar{X}_h$, and variance $s_{ST}^2 = \sum_{h=1}^{L} W_h^2 \dfrac{s_h^2}{n_h}$.

STEP 4: Calculate the degrees of freedom (dof): $dof = \dfrac{(s_{ST}^2)^2}{\sum_{h=1}^{L} \dfrac{W_h^4 s_h^4}{n_h^2 (n_h - 1)}}$.

Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ so that 100(1-α)% of the t distribution with the above degrees of freedom (rounded to the next highest integer) is below $t_{1-\alpha}$.

STEP 5: Calculate the sample value: $t = \dfrac{\bar{X}_{ST} - C}{\sqrt{s_{ST}^2}}$

STEP 6: Compare t to $t_{1-\alpha}$. If $t > t_{1-\alpha}$ {$t < -t_{1-\alpha}$}, the null hypothesis may be rejected. Go to Step 8. If $t \ngtr t_{1-\alpha}$ {$t \nless -t_{1-\alpha}$}, there is not enough evidence to reject the null hypothesis and the false acceptance error rate should be verified. Go to Step 7.

STEP 7: If the null hypothesis was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates (see Step 5, Box 3-2).

STEP 8: The results of the test may be: 1) the null hypothesis was rejected so it seems that the true mean is less than C {greater than C}; 2) the null hypothesis was not rejected and the false acceptance error rate was satisfied and it seems that the true mean is greater than C {less than C}; or 3) the null hypothesis was not rejected and the false acceptance error rate was not satisfied and it seems that the true mean is greater than C {less than C} but conclusions are uncertain since the sample size was too small.

Report the results of the test, as well as the sample size, sample mean, and sample standard deviation for each stratum, the estimated t, the dof, and $t_{1-\alpha}$.

Box 3-4: An Example of a One-Sample t-Test for a Stratified Random Sample

Consider a stratified sample consisting of two strata where stratum 1 comprises 10% of the total site surface area and stratum 2 comprises the other 90%, and 40 samples were collected from stratum 1, and 60 samples were collected from stratum 2. For stratum 1, the sample mean is 23 ppm and the sample standard deviation is 18.2 ppm. For stratum 2, the sample mean is 35 ppm, and the sample standard deviation is 20.5 ppm. This information will be used to test the null hypothesis that the overall site mean is greater than or equal to 40 ppm, i.e., H_0: $\mu \geq 40$ ppm (Case 2). The decision maker has specified a 1% false rejection decision limit (α) at 40 ppm and a 20% false acceptance decision error limit (β) at 35 ppm (μ_1).

STEP 1: $W_1 = 10/100 = 0.10$, $W_2 = 90/100 = 0.9$.

STEP 2: From above, $\bar{x}_1 = 23$ ppm, $\bar{x}_2 = 35$ ppm, $s_1 = 18.2$, and $s_2 = 20.5$. This information was developed using the equations in step 2 of Box 3-3.

STEP 3: The estimated overall mean concentration is:

$$\bar{X}_{ST} = \sum_{h=1}^{L} W_h \bar{X}_h = W_1 \bar{X}_1 + W_2 \bar{X}_2 = (.1)(23) + (.9)(35) = 33.8 \ ppm.$$

and the estimated overall variance is:

$$s_{ST}^2 = \sum_{h=1}^{L} W_h^2 \frac{s_h^2}{n_h} = \frac{(.1)^2 (18.2)^2}{40} + \frac{(.9)^2 (20.5)^2}{60} = 5.76$$

STEP 4: The approximate degrees of freedom (dof) is:

$$dof = \frac{(s_{ST}^2)^2}{\sum_{h=1}^{L} \frac{W_h^4 s_h^4}{n_h^2 (n_h - 1)}} = \frac{(5.76)^2}{\frac{(.1)^4 (18.2)^4}{(40)^2 39} + \frac{(.9)^4 (20.5)^4}{(60)^2 59}} = 60.8, \text{ i.e.,}$$

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Note how the degrees of freedom has been rounded up to a whole number. Using Table A-1 of Appendix A, the critical value $t_{1-\alpha}$ of the t distribution with 61 dof is approximately 2.39.

STEP 5: Calculate the sample value $t = \frac{\bar{X}_{ST} - C}{\sqrt{s_{ST}^2}} = \frac{33.8 - 40}{\sqrt{5.76}} = -2.58$

STEP 6: Because -2.58 < -2.39 the null hypothesis may be rejected.

STEP 7: Because the null hypothesis was rejected, it is concluded that the mean is probably less than 40 ppm. In this example there is no need to calculate the false acceptance rate as the null hypothesis was rejected and so the chance of making a false acceptance error is zero by definition.

3.2.1.2 The Wilcoxon Signed Rank (One-Sample) Test for the Mean

PURPOSE

Given a random sample of size n (or composite sample size n, each composite consisting of k aliquots), the Wilcoxon signed rank test can be used to test hypotheses regarding the population mean or median of the population from which the sample was selected.

ASSUMPTIONS AND THEIR VERIFICATION

The Wilcoxon signed rank test assumes that the data constitute a random sample from a symmetric continuous population. (Symmetric means that the underlying population frequency curve is symmetric about its mean/median.) Symmetry is a less stringent assumption than normality since all normal distributions are symmetric, but some symmetric distributions are not normal. The mean and median are equal for a symmetric distribution, so the null hypothesis can be stated in terms of either parameter. Tests for symmetry can be devised which are based on the chi-squared distribution, or a test for normality may be used. If the data are not symmetric, it may be possible to transform the data so that this assumption is satisfied. See Chapter 4 for more information on transformations and tests for symmetry.

LIMITATIONS AND ROBUSTNESS

Although symmetry is a weaker assumption than normality, it is nonetheless a strong assumption. If the data are not approximately symmetric, this test should not be used. For large sample sizes ($n > 50$), the t-test is more robust to violations of its assumptions than the Wilcoxon signed rank test. For small sample sizes, if the data are not approximately symmetric and are not normally distributed, this guidance recommends consulting a statistician before selecting a statistical test or changing the population parameter to the median and applying a different statistical test (Section 3.2.3).

The Wilcoxon signed rank test may produce misleading results if many data values are the same. When values are the same, their relative ranks are the same, and this has the effect of diluting the statistical power of the Wilcoxon test. Box 3-5 demonstrates the method used to break tied ranks. If possible, results should be recorded with sufficient accuracy so that a large number of equal values do not occur. Estimated concentrations should be reported for data below the detection limit, even if these estimates are negative, as their relative magnitude to the rest of the data is of importance.

SEQUENCE OF STEPS

Directions for the Wilcoxon signed rank test for a simple random sample and a systematic simple random sample are given in Box 3-5 and an example is given in Box 3-6 for samples sizes smaller than 20. For sample sizes greater than 20, the large sample approximation to the Wilcoxon Signed Rank Test should be used. Directions for this test are given in Box 3-7.

Box 3-5: Directions for the Wilcoxon Signed Rank Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points. The following describes the steps for applying the Wilcoxon signed rank test for a sample size (n) less than 20 for Case 1 (H_0: $\mu \le C$); modifications for Case 2 (H_0: $\mu \ge C$) are given in braces {}. If the sample size is greater than or equal to 20, use Box 3-7.

STEP 1: If possible, assign values to any measurements below the detection limit. If this is not possible, assign the value "Detection Limit divided by 2" to each value. Then subtract each observation X_i from C to obtain the deviations $d_i = C - X_i$. If any of the deviations are zero delete them and correspondingly reduce the sample size n.

STEP 2: Assign ranks from 1 to n based on ordering the absolute deviations $|d_i|$ (i.e., magnitude of differences ignoring the sign) from smallest to largest. The rank 1 is assigned to the smallest value, the rank 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks which would otherwise have been assigned to the tied observations.

STEP 3: Assign the sign for each observation to create the signed rank. The sign is positive if the deviation d_i is positive; the sign is negative if the deviation d_i is negative.

STEP 4: Calculate the sum R of the ranks with a positive sign.

STEP 5: Use Table A-6 of Appendix A to find the critical value w_α.

If $R < w_\alpha$, {$R > n(n+1)/2 - w_\alpha$}, the null hypothesis may be rejected; proceed to Step 7.

Otherwise, there is not enough evidence to reject the null hypothesis, and the false acceptance error rate will need to be verified; proceed to Step 6.

STEP 6: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates using a software package like the DEFT software (EPA , 1994). For large sample sizes, calculate,

$$m = \frac{s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\mu_1 - C)^2} + (0.5)z^2_{1-\alpha}$$

where z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). If $1.16m \le n$, the false acceptance error rate has been satisfied.

STEP 7: The results of the test may be:

1) the null hypothesis was rejected and it seems that the true mean is greater than C {less than C};

2) the null hypothesis was not rejected and the false acceptance error rate was satisfied and it seems that the true mean is less than C {greater than C}; or

3) the null hypothesis was not rejected and the false acceptance error rate was not satisfied and it seems that the true mean is greater than C {less than C} but conclusions are uncertain since the sample size was too small.

Box 3-6: An Example of the Wilcoxon Signed Rank Test for a Simple Random Sample

Consider the following 10 data points: 974 ppb, 1044 ppb, 1093 ppb, 897 ppb, 879 ppb, 1161 ppb, 839 ppb, 824 ppb, 796 ppb, and one observation below the detection limit of 750 ppb. This data will be used to test the hypothesis: H_0: $\mu \geq$ 1000 ppb vs. H_A: $\mu <$ 1000 ppb (Case 2). The decision maker has specified a 10% false rejection decision error limit (α) at 1000 ppb (C), and a 20% false acceptance decision error limit (β) at 900 ppb (μ_1).

STEP 1: Assign the value 375 ppb (750 divided by 2) to the data point below the detection limit. Subtract C (1000) from each of the n observations X_i to obtain the deviations $d_i = 1000 - X_i$. This is shown in row 2 of the table below.

X_i	974	1044	1093	897	879	1161	839	824	796	375
d_i	26	-44	-93	103	121	-161	161	176	204	625
$\lvert d_i\rvert$	26	44	93	103	121	161	161	176	204	625
rank	12	2	3	4	5	6.5	6.5	8	9	10
s-rank	1	-2	-3	4	5	-6.5	6.5	8	9	10

STEP 2: Assign ranks from 1 to n based on ordering the absolute deviations $\lvert d_i\rvert$ (magnitude ignoring any negative sign) from smallest to largest. The absolute deviations are listed in row 3 of the table above. Note that the data have been sorted (rearranged) for clarity so that the absolute deviations are ordered from smallest to largest.

The rank 1 is assigned to the smallest value, the rank 2 to the second smallest value, and so forth. Observations 6 and 7 are ties, therefore, the average (6+7)/2 = 6.5 will be assigned to the two observations. The ranks are shown in row 4.

STEP 3: Assign the sign for each observation to create the signed rank. The sign is positive if the deviation d_i is positive; the sign is negative if the deviation d_i is negative. The signed rank is shown in row 5.

STEP 4: R = 1 + 4 + 5 + 6.5 + 8 + 9 + 10 = 43.5.

STEP 5: Table A-6 of Appendix A was used to find the critical value w_α where α = 0.10. For this example, $w_{0.10}$ = 15. Since 43.5 > (10x11)/2 - 15 = 40, the null hypothesis may be rejected.

STEP 7: The null hypothesis was rejected with a 10% significance level using the Wilcoxon signed rank test. Therefore, it would seem that the true mean is below 1000 ppb.

Box 3-7: Directions for the Large Sample Approximation to the Wilcoxon Signed Rank Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points where n is greater than or equal to 20. The following describes the steps for applying the large sample approximation for the Wilcoxon signed rank test for Case 1 (H_0: $\mu \le C$); modifications for Case 2 (H_0: $\mu \ge C$) are given in braces {}.

STEP 1: If possible, assign values to any measurements below the detection limit. If this is not possible, assign the value "Detection Limit divided by 2" to each value. Then subtract each observation X_i from C to obtain the deviations $d_i = C - X_i$. If any of the deviations are zero delete them and correspondingly reduce the sample size n.

STEP 2: Assign ranks from 1 to n based on ordering the absolute deviations $|d_i|$ (i.e., magnitude of differences ignoring the sign) from smallest to largest. The rank 1 is assigned to the smallest value, the rank 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks which would otherwise have been assigned to the tied observations.

STEP 3: Assign the sign for each observation to create the signed rank. The sign is positive if the deviation d_i is positive; the sign is negative if the deviation d_i is negative.

STEP 4: Calculate the sum R of the ranks with a positive sign.

STEP 5: Calculate $w = \dfrac{n(n+1)}{4} + x_p\sqrt{n(n+1)(2n+1)/24}$ where p = 1 - α {p = α} and z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A).

STEP 6: If R < w {R > w}, the null hypothesis may be rejected. Go to Step 8.

Otherwise, there is not enough evidence to reject the null hypothesis, and the false acceptance error rate will need to be verified. Go to Step 7.

STEP 7: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates using a software package like the DEFT software (EPA , 1994). For large sample sizes, calculate,

$$m = \frac{s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\mu_1 - C)^2} + (0.5)z^2_{1-\alpha}$$

where z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). If $1.16m \le n$, the false acceptance error rate has been satisfied.

STEP 8: The results of the test may be:

1) the null hypothesis was rejected and it seems that the true mean is greater {less} than C;

2) the null hypothesis was not rejected and the false acceptance error rate was satisfied and it seems that the true mean is less than C {greater than C}; or

3) the null hypothesis was not rejected and the false acceptance error rate was not satisfied and it seems that the true mean is greater than C {less than C} but conclusions are uncertain since the sample size was too small.

Report the results of the test, the sample size, R, and w.

3.2.1.3 The Chen Test

PURPOSE

Environmental data such as concentration measurements are often confined to positive values and appear to follow a distribution with most of the data values relatively small or near zero but with a few relatively large data values. Underlying such data is some distribution which is not symmetrical (like a normal) but which is skewed to the right (like a log normal). Given a random sample of size 'n' from a right-skewed distribution, the Chen test can be used to compare the mean (μ) of the distribution with a threshold level or regulatory value. The null hypothesis has the form H_0: $\mu \leq C$, where C is a given threshold level; the alternative hypothesis is H_A: $\mu > C$. The method is not recommended for testing null hypotheses of the form H_0: $\mu \geq C$ against H_A: $\mu < C$.

ASSUMPTIONS AND THEIR VERIFICATION

This test assumes the data arise from a right-skewed distribution and that a random sample has been employed. The data should be examined (e.g., via a histogram) to determine whether the assumption of a right-skewed distribution appears reasonable. In addition, the sample skewness should be calculated (see Box 3-8); a positive value for the skewness will tend to confirm that the distribution has a long right tail.

LIMITATIONS AND ROBUSTNESS

Chen's test is a generalization of the t-test, with slightly more complicated calculations that involve calculating the sample mean, standard deviation, and skewness. The Chen method has been subjected to extensive simulation studies in order to assess its statistical properties. For a broad class of assumed distributions, the method has been found to accurately achieve the desired significance level and to have good power. It is preferred over other tests when the data come from a right-skewed distribution and the direction of the inequalities in the hypotheses are compatible with the user's objective. Like the t test, this test can have some difficulties in dealing with less-than values, especially if there are a large number of such values. For a moderate amount of nondetects, a substituted value for the nondetects (e.g.,½ of the detection limit) will suffice if the threshold level C is much larger than the detection limit.

SEQUENCE OF STEPS

Box 3-8 provides direction for conducting the Chen test; Box 3-9 gives and example.

Box 3-8: Directions for the Chen Test

Let $X_1, X_2, \ldots, X_n$ represent the n data points. Let C denote the threshold level of interest. The null hypothesis is H_0: $\mu \leq C$ and the alternative is H_A: $\mu > C$, the level of significance is α.

STEP 1: If at most 15% of the data points are below the detection limit (DL) and C is much larger than the DL, then replace values below the DL with DL/2.

STEP 2: Visually check the assumption of right-skewness by inspecting a histogram or frequency plot for the data. (The Chen test is appropriate only for data which are skewed to the right.)

STEP 3: Calculate the sample mean, $\bar{x}$ (Section 2.2.2), and the standard deviation, s (Section 2.2.3).

STEP 4: Calculate the sample skewness $b = \dfrac{n\sum_{i=1}^{n}(X_i - \bar{X})^3}{(n-1)(n-2)s^3}$; the quantity $a = b/6\sqrt{n}$, the t-statistic

$$t = \frac{(\bar{X} - C)}{s/\sqrt{n}}$$, and then compute $T = t + a(1 + 2t^2) + 4a^2(t + 2t^3)$.

NOTE: The skewness b should be greater than 1 to confirm the data are skewed to the right.

STEP 5: Use the last row of Table A-1 in Appendix A to find the critical value $z_{1-\alpha}$ such that 100(1-α)% of the Normal distribution is below $t_{1-\alpha}$. For example, if $\alpha = 0.05$ then $z_{1-\alpha} = 1.645$.

STEP 6: Compare t with $z_{1-\alpha}$.

1) If $t > z_{1-\alpha,}$ the null hypothesis may be rejected and it seems that the true mean is greater than C;

2) If $t \not> z_{1-\alpha}$, there is not enough evidence to reject the null hypothesis so it seems that the true mean is less than C.

3.2.2 Tests for a Proportion or Percentile

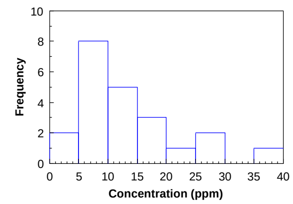
This section considers hypotheses concerning population proportions and percentiles. A population proportion is the ratio of the number of elements of a population that has some specific characteristic to the total number of elements. A population percentile represents the percentage of elements of a population having values less than some threshold C. Thus, if x is the 95th percentile of a population, 95% of the elements of the population have values less than C and 5% of the population have values greater than C.

This section of the guidance covers the following hypothesis: Case 1: H_0: $P \leq P_0$ vs. H_A: $P > P_0$ and Case 2: H_0: $P \geq P_0$ vs. H_A: $P < P_0$ where P is a proportion of the population, and P_0 represents a given proportion ($0 \leq P_0 \leq 1$). Equivalent hypotheses written in terms of percentiles are H_0: the 100Pth percentile is C or larger for Case 1, and H_0: the 100Pth percentile is C or smaller for Case 2. For example, consider the decision to determine whether the 95th percentile of a container of waste is less than 1 mg/L cadmium. The null hypothesis in this case is

Box 3-9: Example of the Chen Test

Consider the following sample of a contaminant concentration measurements in (in ppm):2.0, 2.0, 5.0, 5.2, 5.9, 6.6, 7.4, 7.4, 9.7, 9.7, 10.2, 11.5, 12.4, 12.7, 14.1, 15.2, 17.7, 18.9, 22.8, 28.6, 30.5, 35.5. We want to test the null hypothesis that the mean μ is less than 10 ppm versus the alternative that it exceeds 10 ppm. A significance level of 0.05 is to be used.

STEP 1: Since all of the data points exceed the detection limit, there is no need to substitute values for below the detection limit.



STEP 2: A frequency plot of the 23 data points confirms the right-skewness.

STEP 3: Using boxes 2-2 and 2-4 of Chapter 2, it is found that $\overline{X}$ = 13.08 ppm and s = 8.99 ppm.

STEP 4: $$b = \frac{n\sum_{i=1}^{n}(X_i - \overline{X})^3}{(n-1)(n-2)s^3} = \frac{23\sum_{i=1}^{23}(X_i - 13.08)^3}{(22)(21)(8.99)^3} = 1.14,$$

$$a = b/6\sqrt{n} = 1.14/6\sqrt{23} = 0.0396,$$

the t-statistic $t = \frac{(\overline{X} - C)}{s/\sqrt{n}} = \frac{(13.08 - 10)}{8.99/\sqrt{23}} = 1.65$, and

compute $T = t + a(1 + 2t^2) + 4a^2(t + 2t^3) = 1.965$

(The value of 1.14 for skewness confirms that the data are skewed to the right.)

STEP 5: Using the last row of Table A-1 of Appendix A, the critical value $z_{0.95}$ of the Normal distribution is 1.645.

STEP 6: Since T > $z_{0.95}$ (1.965 > 1.645), the null hypothesis is rejected and we conclude that the true mean is greater than 10 ppm.

H_o: the 95th percentile of cadmium is less than 1 mg/L. Now, instead of considering the population to consist of differing levels of cadmium, consider the population to consist of a binary variable that is '1' if the cadmium level is above 1 mg/L or is '0' if the level is below 1 mg/L. In this case, the hypothesis may be changed to a test for a proportion so that the null hypothesis becomes H_0: P < .95 where P represents the proportion of 1's (cadmium levels above 1 mg/L) in the container of waste. Thus, any hypothesis about the proportion of the site below a threshold can be converted to an equivalent hypothesis about percentiles. Therefore, only hypotheses about the proportion of the site below a threshold will be discussed in this section. The information required for this test includes the null and alternative hypotheses, the gray region, the false rejection error rate α at P_0, the false acceptance error rate β at P_1, and any additional limits on decision errors. It may be helpful to label any additional false rejection error limits as α_2 at $P_{\alpha 2}$, α_3 at $P_{\alpha 3}$, etc., and any additional false acceptance error limits as β_2 at $P_{\beta 2}$, β_3 at $P_{\beta 3}$, etc.

3.2.2.1 The One-Sample Proportion Test

PURPOSE

Given a random sample of size n, the one-sample proportion test may be used to test hypotheses regarding a population proportion or population percentile for a distribution from which the data were drawn. Note that for P=.5, this test is also called the Sign test.

ASSUMPTIONS AND THEIR VERIFICATION

The only assumption required for the one-sample proportion test is the assumption of a random sample. To verify this assumption, review the procedures and documentation used to select the sampling points and ascertain that proper randomization has been used.

LIMITATIONS AND ROBUSTNESS

Since the only assumption is that of a random sample, the procedures are valid for any underlying distributional shape. The procedures are also robust to outliers, as long as they do not represent data errors.

SEQUENCE OF STEPS

Directions for the one-sample test for proportions for a simple random sample and a systematic random sample are given in Box 3-10, an example is given in Box 3-11.

3.2.3 Tests for a Median

A population median ($\tilde{\mu}$) is another measure of the center of the population distribution. This population parameter is less sensitive to extreme values and nondetects than the sample mean. Therefore, this parameter is sometimes used instead of the mean when the data contain a large number of nondetects or extreme values. The hypotheses considered in this section are:

Case 1: H_0: $\tilde{\mu} \le C$ vs. H_A: $\tilde{\mu} > C$; and

Case 2: H_0: $\tilde{\mu} \ge C$ vs. H_A: $\tilde{\mu} < C$

where C represents a given threshold such as a regulatory level.

It is worth noting that the median is the 50^{th} percentile, so the methods described in Section 3.2.2 may be used to test hypotheses concerning the median by letting $P_0 = 0.50$. In this case, the one-sample test for proportions is also called the Sign Test for a median. The Wilcoxon signed rank test (Section 3.2.1.2) can also be applied to a median in the same manner as it is applied to a mean. In

Box 3-10: Directions for the One-Sample Test for Proportions for Simple and Systematic Random Samples

This box describes the steps for applying the one-sample test for proportions for Case 1 (H_0: $P \le P_0$); modifications for Case 2 (H_0: $P \ge P_0$) are given in braces { }.

STEP 1: Given a random sample $X_1, X_2, \ldots, X_n$ of measurements from the population, let p (small p) denote the proportion of X's that do not exceed C, i.e., p is the number (k) of sample points that are less than or equal to C, divided by the sample size n.

STEP 2: Compute np, and n(1-p). If both np and n(1-p) are greater than or equal to 5, use Steps 3 and 4. Otherwise, consult a statistician as analysis may be complex.

STEP 3: Calculate $z = \dfrac{p - .5/n - P_0}{\sqrt{P_0(1-P_0)/n}}$ for Case 1 or $z = \dfrac{p + .5/n - P_0}{\sqrt{P_0(1-P_0)/n}}$ for Case 2.

STEP 4: Use Table A-1 of Appendix A to find the critical value $z_{1-\alpha}$ such that 100(1-α)% of the normal distribution is below $z_{1-\alpha}$. For example, if $\alpha = 0.05$ then $z_{1-\alpha} = 1.645$.

If $z > z_{1-\alpha}$ $\{z < -z_{1-\alpha}\}$, the null hypothesis may be rejected. Go to Step 6.

If $z \not> z_{1-\alpha}$ $\{z \not< -z_{1-\alpha}\}$, there is not enough evidence to reject the null hypothesis. Therefore, the false acceptance error rate will need to be verified. Go to Step 5.

STEP 5: To calculate the power of the test, assume that the true values for the mean and standard deviation are those obtained in the sample and use a statistical software package like the DEFT software (EPA, 1994) or the DataQUEST software (EPA, 1996) to generate the power curve of the test.

If only one false acceptance error rate (β) has been specified (at P_1), it is possible to calculate the sample size which achieves the DQOs. To do this, calculate

$$m = \left[\frac{z_{1-\alpha}\sqrt{P_0(1-P_0)} + z_{1-\beta}\sqrt{P_1(1-P_1)}}{P_1 - P_0}\right]^2$$

If $m \le n$, the false acceptance error rate has been satisfied. Otherwise, the false acceptance error rate has not been satisfied.

STEP 6: The results of the test may be:

1) the null hypothesis was rejected and it seems that the proportion is greater than {less than} P_0;

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems that proportion is less than {greater than} P_0; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it would seem the proportion was less than {greater than} P_0, but the conclusions are uncertain because the sample size was too small.

Box 3-11: An Example of the One-Sample Test for Proportions for a Simple Random Sample

Consider 85 samples of which 11 samples have concentrations greater than the clean-up standard. This data will be used to test the null hypothesis H_0: $P \geq .20$ vs. H_A: $P < .20$ (Case 2). The decision maker has specified a 5% false rejection rate (α) for $P_0 = .2$, and a false acceptance rate (β) of 20% for $P_1 = 0.15$.

STEP 1: From the data, the observed proportion (p) is p = 11/85 = .1294

STEP 2: np = (85)(.1294) = 11 and n(1-p) = (85)(1-.1294) = 74. Since both np and n(1-p) are greater than or equal to 5, Steps 3 and 4 will be used.

STEP 3: Because H_0: $P \geq .20$, Case 2 formulas will be used.

$$z = \frac{p + .5/n - P_0}{\sqrt{P_0(1-P_0)/n}} = \frac{.1294 + .5/85 - .2}{\sqrt{.2(1-.2)/85}} = -1.492$$

STEP 4: Using Table A-1 of Appendix A, it was found that $z_{1-.05} = z_{.95} = 1.645$. Because $z \nless -z_{1-\alpha}$ (i.e.,
$-1.492 \nless -1.645$), the null hypothesis is not rejected so Step 5 will need to be completed.

STEP 5: To determine whether the test was powerful enough, the sample size necessary to achieve the DQOs was calculated as follows:

$$m = \left[\frac{1.64\sqrt{.2(1-.2)} + 1.04\sqrt{.15(1-.15)}}{.15 - .2}\right]^2 = 422.18$$

So 423 samples are required, many more than were actually taken.

STEP 6: The null hypothesis was not rejected and the false acceptance error rate was not satisfied. Therefore, it would seem the proportion is greater than 0.2, but this conclusion is uncertain because the sample size is too small.

addition, this test is more powerful than the Sign Test for symmetric distributions. Therefore, the Wilcoxon signed rank test is the preferred test for the median.

3.2.4 Confidence Intervals

In some instances, a test of hypotheses for the estimated parameter (i.e. mean or difference of two means) is not required, but an idea of the uncertainty of the estimate with respect to the parameter is needed. The most common type of interval estimate is a confidence interval. A confidence interval may be regarded as combining an interval around an estimate with a probabilistic statement about the unknown parameter. When interpreting a confidence interval statement such as "The 95% confidence interval for the mean is 19.1 to 26.3", the implication is that the best estimate for the unknown population mean is 22.7 (halfway between 19.1 and 26.3), and that we are 95% certain that the interval 19.1 to 26.3 captures the unknown population mean. Box 3-12 gives the directions on how to calculate a confidence interval for the mean, Box 3-13 gives and example of the method.

The concept of a confidence interval can be shown by a simple example. Suppose a stable situation producing data without any anomalies was sampled many times. Each time the sample was taken, the mean and standard deviation was calculated from the sample and a confidence interval constructed using the method of Box 3-10.

Box 3-12: Directions for a Confidence Interval for a Mean for Simple and Systematic Random Samples

Let $X_1, X_2, ..., X_n$ represent a sample of size n from a population of normally distributed values.

Step 1: Use the directions in Box 2-2 to calculate the sample mean, $\overline{X}$. Use the directions in Box 2-3 to calculate the sample standard deviation, s.

Step 2: Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha/2}$ such that 100(1-α/2)% of the t distribution with n - 1 degrees of freedom is below $t_{1-\alpha/2}$. For example, if α = 0.10 and n = 16, then n-1 = 15 and $t_{1-\alpha/2}$ = 1.753.

Step 3: The (1-α)100% confidence interval is: $\overline{X} - \frac{t_{1-\alpha/2}s}{\sqrt{n}}$ to $\overline{X} + \frac{t_{1-\alpha/2}s}{\sqrt{n}}$

Box 3-13: An Example of a Confidence Interval for a Mean for a Random or Systematic Random Samples

The effluent from a discharge point in a plating manufacturing plant was sampled 7 times over the course of 4 days for the presence of Arsenic with the following results: 8.1, 7.9, 7.9. 8.2, 8.2, 8.0,7.9. The directions in Box 3-12 will be used to develop a 95% confidence interval for the mean.

Step 1: Using Box 2-2, $\overline{X}$ =8.03. Use Box 2-3, s=0.138.

Step 2: Using Table A-1 of Appendix A and 6 *degrees of freedom,* $t_{1-\alpha/2}$ = 2.447.

Step 3: The (1-α)100% confidence interval is:

$$8.03 - \frac{2.447 x 0.138}{\sqrt{7}} \text{ to } 8.03 + \frac{2.447 x 0.138}{\sqrt{7}}$$ or 7.902 to 8.158.

3.3 TESTS FOR COMPARING TWO POPULATIONS

A two-sample test involves the comparison of two populations or a "before and after" comparison. In environmental applications, the two populations to be compared may be a potentially contaminated area with a background area or concentration levels from an upgradient and a downgradient well. The comparison of the two populations may be based on a statistical parameter that characterizes the relative location (e.g., a mean or median), or it may be based on a distribution-free comparison of the two population distributions. Tests that do not assume an underlying distributions (e.g., normal or lognormal) are called distribution-free or nonparametric tests. These tests are often more useful for comparing two populations than those that assume a specific distribution because they make less stringent assumptions. Section 3.3.1 covers tests for differences in the means of two populations. Section 3.3.2 covers tests for differences in the proportion or percentiles of two populations. Section 3.3.3 describes distribution-free comparisons of two populations. Section 3.3.4 describes tests for comparing two medians.

Often, a two-sample test involves the comparison of the difference of two population parameters to a threshold value. For environmental applications, the threshold value is often zero, representing the case where the data are used to determine which of the two population parameters is greater than the other. For example, concentration levels from a Superfund site may be compared to a background site. Then, if the Superfund site levels exceed the background levels, the site requires further investigation. A two-sample test may also be used to compare readings from two instruments or two separate populations of people.

If the exact same sampling locations are used for both populations, then the two samples are not independent. This case should be converted to a one-sample problem by applying the methods described in Section 3.2 to the differences between the two populations at the same location. For example, one could compare contaminant levels from several wells after treatment to contaminant levels from the same wells before treatment. The methods described in Section 3.2 would then be applied to the differences between the before and after treatment contaminant levels for each well.

3.3.1 Comparing Two Means

Let μ_1 represent the mean of population 1 and μ_2 represent the mean of population 2. The hypotheses considered in this section are:

Case 1: H_0: $\mu_1 - \mu_2 \leq \delta_0$ vs. H_A: $\mu_1 - \mu_2 > \delta_0$; and

Case 2: H_0: $\mu_1 - \mu_2 \geq \delta_0$ vs. H_A: $\mu_1 - \mu_2 < \delta_0$.

An example of a two-sample test for population means is comparing the mean contaminant level at a remediated Superfund site to a background site; in this case, δ_0 would be zero. Another example is a Record of Decision for a Superfund site which specifies that the remediation technique must reduce the mean contaminant level by 50 ppm each year. Here, each year would be considered a separate population and δ_0 would be 50 ppm.

The information required for these tests includes the null and alternative hypotheses (either Case 1 or Case 2); the gray region (i.e., a value $\delta_1 > \delta_0$ for Case 1 or a value $\delta_1 < \delta_0$ for Case 2 representing the bound of the gray region); the false rejection error rate α at δ_0; the false acceptance error rate β at δ_1; and any additional limits on decision errors. It may be helpful to label additional false rejection error limits as α_2 at $\delta_{\alpha2}$, α_3 at $\delta_{\alpha3}$, etc., and to label additional false acceptance error limits as β_2 at $\delta_{\beta2}$, β_3 at $\delta_{\beta3}$, etc.

3.3.1.1 Student's Two-Sample t-Test (Equal Variances)

PURPOSE

Student's two-sample t-test can be used to compare two population means based on the independent random samples $X_1, X_2, \ldots, X_m$ from the first population, and $Y_1, Y_2, \ldots, Y_n$ from the second population. This test assumes the variabilities (as expressed by the variance) of the two populations are approximately equal. If the two variances are not equal (a test is described in Section 4.5), use Satterthwaite's t test (Section 3.3.1.2).

ASSUMPTIONS AND THEIR VERIFICATION

The principal assumption required for the two-sample t-test is that a random sample of size m ($X_1, X_2, \ldots, X_m$) is drawn from population 1, and an independent random sample of size n ($Y_1, Y_2, \ldots, Y_n$) is drawn from population 2. Validity of the random sampling and independence assumptions should be confirmed by reviewing the procedures used to select the sampling points.

The second assumption required for the two-sample t-tests are that the sample means $\bar{X}$ (sample 1) and $\bar{Y}$ (sample 2) are approximately normally distributed. If both m and n are large, one may make this assumption without further verification. For small sample sizes, approximate normality of the sample means can be checked by testing the normality of each of the two samples.

LIMITATIONS AND ROBUSTNESS

The two-sample t-test with equal variances is robust to violations of the assumptions of normality and equality of variances. However, if the investigator has tested and rejected normality or equality of variances, then nonparametric procedures may be applied. The t-test is not robust to outliers because sample means and standard deviations are sensitive to outliers.

SEQUENCE OF STEPS

Directions for the two-sample t-test for a simple random sample and a systematic simple random sample are given in Box 3-14 and an example in Box 3-15.

3.3.1.2 Satterthwaite's Two-Sample t-Test (Unequal Variances)

Satterthwaite's t-test should be used to compare two population means when the variances of the two populations are not equal. It requires the same assumptions as the two-sample t-test (Section 3.3.1.1) except the assumption of equal variances.

Directions for Satterthwaite's t-test for a simple random sample and a systematic simple random sample are given in Box 3-16 and an example in Box 3-17.

Box 3-14: Directions for the Student's Two-Sample t-Test (Equal Variances) for Simple and Systematic Random Samples

This describes the steps for applying the two-sample t-tests for differences between the population means when the two population variances are equal for Case 1 (H_0: $\mu_1 - \mu_2 \le \delta_0$). Modifications for Case 2
(H_0: $\mu_1 - \mu_2 \ge \delta_0$) are given in parentheses { }.

STEP 1: Calculate the sample mean $\overline{X}$ and the sample variance s_X^2 for sample 1 and compute the sample mean $\overline{Y}$ and the sample variance s_Y^2 for sample 2.

STEP 2: Use Section 4.5 to determine if the variances of the two populations are equal. If the variances of the two populations are not equal, use Satterthwaite's t test (Section 3.3.1.2). Otherwise, compute the pooled standard deviation

$$s_E = \sqrt{\frac{(m-1)s_X^2 + (n-1)s_Y^2}{(m-1) + (n-1)}}.$$

STEP 3: Calculate $t = \dfrac{\overline{X} - \overline{Y} - \delta_0}{s_E\sqrt{1/n + 1/m}}.$

Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ such that 100(1-α)% of the t-distribution with (m+n-2) degrees of freedom is below $t_{1-\alpha}$.

If $t > t_{1-\alpha}$ {$t < -t_{1-\alpha}$}, the null hypothesis may be rejected. Go to Step 5.

If $t \not> t_{1-\alpha}$ {$t \not< -t_{1-\alpha}$}, there is not enough evidence to reject the null hypothesis. Therefore, the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: To calculate the power of the test, assume that the true values for the mean and standard deviation are those obtained in the sample and use a statistical software package like the DEFT software (EPA, 1994) or the DataQUEST software (EPA, 1996) to generate the power curve of the two-sample t-test. If only one false acceptance error rate (β) has been specified (at δ_1), it is possible to calculate the sample size which achieves the DQOs, assuming the true mean and standard deviation are equal to the values estimated from the sample, instead of calculating the power of the test. Calculate

$$m^* = n^* = \frac{2s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\delta_1 - \delta_0)^2} + (0.25)z_{1-\alpha}^2$$

If $m^* \le m$ and $n^* \le n$, the false acceptance error rate has been satisfied. Otherwise, the false acceptance error rate has not been satisfied.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected, and it seems $\mu_1 - \mu_2 > \delta_0$ {$\mu_1 - \mu_2 < \delta_0$};

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems $\mu_1 - \mu_2 \le \delta_0$ {$\mu_1 - \mu_2 \ge \delta_0$}; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems $\mu_1 - \mu_2 \le \delta_0$ {$\mu_1 - \mu_2 \ge \delta_0$}, but this conclusion is uncertain because the sample size

Box 3-15: An Example of a Student's Two-Sample t-Test (Equal Variances) for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. Seven random samples were taken from area 1, and eight were taken from area 2. Because the contaminant concentrations in the two areas are supposedly equal, the null hypothesis is H_0: $\mu_1 - \mu_2 \leq 0$ (Case 1). The false rejection error rate was set at 5% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb.

STEP 1:

	Sample Mean	Sample Variance
Area 1	7.8 ppm	2.1 ppm^2
Area 2	6.6 ppm	2.2 ppm^2

STEP 2: Methods described in Section 4.5 were used to determine that the variances were essentially equal. Therefore,

$$s_E = \sqrt{\frac{(7-1)2.1 + (8-1)2.2}{(7-1) + (8-1)}} = 1.4676$$

STEP 3:

$$t = \frac{7.8 - 6.6 - 0}{1.4676\sqrt{1/7 + 1/8}} = 1.5798$$

Table A-1 of Appendix A was used to find that the critical value $t_{0.95}$ with (7 + 8 - 2) = 13 degrees of freedom is 1.771.

Because $t \ngtr t_{1-\alpha}$ (i.e., $1.5798 \ngtr 1.771$), there is not enough evidence to reject the null hypothesis. The false acceptance error rate will need to be verified.

STEP 4: Assuming the true values for the mean and standard deviation are those obtained in the sample:

$$m^* = n^* = \frac{2(1.4676^2)(1.645 + 0.842)^2}{(2.5 - 0)^2} + (0.25)1.645^2 = 4.938, \text{ i.e., } 5.$$

Because $m^* \leq m$ (7) and $n^* \leq n$ (8), the false acceptance error rate has been satisfied.

STEP 5: The null hypothesis was not rejected and the false acceptance error rate was satisfied. Therefore, it seems there is no difference between the two areas and that the in-situ methodology worked as expected.

Box 3-16: Directions for Satterthwaite's t-Test (Unequal Variances) for Simple and Systematic Random Samples

This describes the steps for applying the two-sample t-test for differences between the population means for Case 1 (H_0: $\mu_1 - \mu_2 \leq \delta_0$). Modifications for Case 2 (H_0: $\mu_1 - \mu_2 \geq \delta_0$) are given in parentheses { }.

STEP 1: Calculate the sample mean $\bar{X}$ and the sample variance s_X^2 for sample 1 and compute the sample mean $\bar{Y}$ and the sample variance s_Y^2 for sample 2.

STEP 2: Using Section 4.5, test whether the variances of the two populations are equal. If the variances of the two populations are not equal, compute:

$$s_{NE} = \sqrt{\frac{s_X^2}{m} + \frac{s_Y^2}{n}}$$

If the variances of the two populations appear approximately equal, use Student's two-sample t-test (Section 3.3.1.1, Box 3-14).

STEP 3: Calculate $t = \dfrac{\bar{X} - \bar{Y} - \delta_0}{s_{NE}}$

Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ such that 100(1-α)% of the t-distribution with f degrees of freedom is below $t_{1-\alpha}$, where

$$f = \frac{\left[\dfrac{s_X^2}{m} + \dfrac{s_Y^2}{n}\right]^2}{\dfrac{s_X^4}{m^2(m-1)} + \dfrac{s_Y^4}{n^2(n-1)}}$$

(Round f <u>down</u> to the nearest integer.)

If $t > t_{1-\alpha}$ {$t < -t_{1-\alpha}$}, the null hypothesis may be rejected. Go to Step 5.

If $t \ngtr t_{1-\alpha}$ {$t \nless -t_{1-\alpha}$}, there is not enough evidence to reject the null hypothesis and therefore, the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates. To calculate the power of the test, assume that the true values for the mean and standard deviation are those obtained in the sample and use a statistical software package to generate the power curve of the two-sample t-test. A simple method to check on statistical power does not exist.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected, and it seems $\mu_1 - \mu_2 > \delta_0$ {$\mu_1 - \mu_2 < \delta_0$};

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}, but this conclusion is uncertain because the sample

Box 3-17: An Example of Satterthwaite's t-Test (Unequal Variances) for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. Seven random samples were taken from area 1, and eight were taken from area 2. Because the contaminant concentrations in the two areas are supposedly equal, the null hypothesis is H_0: $\mu_1 - \mu_2 \leq 0$ (Case 1). The false rejection error rate was set at 5% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb.

STEP 1:

	Sample Mean	Sample Variance
Area 1	9.2 ppm	1.3 ppm^2
Area 2	6.1 ppm	5.7 ppm^2

STEP 2: Using Section 4.5, it was determined that the variances of the two populations were not equal, and therefore using Satterthwaite's method is appropriate:

$$s_{NE} = \sqrt{1.3/7 + 5.7/8} = 0.9477$$

STEP 3:
$$t = \frac{9.2 - 6.1 - 0}{0.9477} = 3.271$$

Table A-1 was used with f degrees of freedom, where

$$f = \frac{[1.3/7 + 5.7/8]^2}{\frac{1.3^2}{7^2(7-1)} + \frac{5.7^2}{8^2(8-1)}} = 10.307 \; (i.e., \; 10 \; degrees \; of \; freedom)$$

(recall that f is rounded down to the nearest integer), to find $t_{1-\alpha} = 1.812$.

Because $t > t_{0.95}$ (3.271 > 1.812), the null hypothesis may be rejected.

STEP 5: Because the null hypothesis was rejected, it would appear there is a difference between the two areas (area 1 being more contaminated than area 2, the reference area) and that the in-situ methodology has not worked as intended.

3.3.2 Comparing Two Proportions or Percentiles

This section considers hypotheses concerning two population proportions (or two population percentiles); for example, one might use these tests to compare the proportion of children with elevated blood lead in one urban area compared with the proportion of children with elevated blood lead in another area. The population proportion is the ratio of the number of elements in a subset of the total population to the total number of elements, where the subset has some specific characteristic that the rest of the elements do not. A population percentile represents the percentage of elements of a population having values less than some threshold value C.

Let P_1 represent the true proportion for population 1, and P_2 represent the true proportion of population 2. The hypotheses considered in this section are:

Case 1: H_0: $P_1 - P_2 \leq \delta_0$ vs. H_A: $P_1 - P_2 > \delta_0$; and

Case 2: H_0: $P_1 - P_2 \geq \delta_0$ vs. H_A: $P_1 - P_2 < \delta_0$

where δ_0 is some numerical value. An equivalent null hypothesis for Case 1, written in terms of percentiles, is H_0: the $100P_1^{th}$ percentile minus the $100P_2^{th}$ percentile is C or larger, the reverse applying to Case 2. Since any hypothesis about the proportion below a threshold can be converted to an equivalent hypothesis about percentiles (see Section 3.2.2), this guidance will only consider hypotheses concerning proportions.

The information required for this test includes the null and alternative hypotheses (either Case 1 or Case 2); the gray region (i.e., a value $\delta_1 > \delta_0$ for Case 1 or a value $\delta_1 < \delta_0$ for Case 2, representing the bound of the gray region); the false rejection error rate α at δ_0; the false acceptance error rate β at δ_1; and any additional limits on decision errors.

3.3.2.1 Two-Sample Test for Proportions

PURPOSE

The two-sample test for proportions can be used to compare two population percentiles or proportions and is based on an independent random sample of m ($X_1, X_2, \ldots, X_m$) from the first population and an independent random sample size n ($Y_1, Y_2, \ldots, Y_n$) from the second population.

ASSUMPTIONS AND THEIR VERIFICATION

The principal assumption is that of random sampling from the two populations.

LIMITATIONS AND ROBUSTNESS

The two-sample test for proportions is valid (robust) for any underlying distributional shape and is robust to outliers, providing they are not pure data errors.

SEQUENCE OF STEPS

Directions for a two-sample test for proportions for a simple random sample and a systematic simple random sample are given in Box 3-18; an example is provided in Box 3-19.

Box 3-18: Directions for a Two-Sample Test for Proportions for Simple and Systematic Random Samples

The following describes the steps for applying the two-sample test for proportions for Case 1 (H_0: $P_1 - P_2 \leq 0$). Modifications for Case 2 (H_0: $P_1 - P_2 \geq 0$) are given in braces { }.

STEP 1: Given m random samples $X_1, X_2, \ldots, X_m$ from the first population, and n samples from the second population, $Y_1, Y_2, \ldots, Y_n$, let k_1 be the number of points from sample 1 which exceed C, and let k_2 be the number of points from sample 2 which exceed C. Calculate the sample proportions $p_1 = k_1/m$ and $p_2 = k_2/n$. Then calculate the pooled proportion

$$p = (k_1 + k_2) / (m + n).$$

STEP 2: Compute mp_1, $m(1-p_1)$, np_2, $n(1-p_2)$. If all of these values are greater than or equal to 5, continue. Otherwise, seek assistance from a statistician as analysis is complicated.

STEP 3: Calculate $z = (p_1 - p_2) / \sqrt{p(1 - p)(1/m + 1/n)}$.

Use Table A-1 of Appendix A to find the critical value $z_{1-\alpha}$ such that $100(1-\alpha)\%$ of the normal distribution is below $z_{1-\alpha}$. For example, if $\alpha = 0.05$ then $z_{1-\alpha} = 1.645$.

If $z > z_{1-\alpha}$ $\{z < -z_{1-\alpha}\}$, the null hypothesis may be rejected. Go to Step 5.

If $z \not> z_{1-\alpha}$ $\{z \not< -z_{1-\alpha}\}$, there is not enough evidence to reject the null hypothesis. Therefore, the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates. If only one false acceptance error rate (β) has been specified at $P_1 - P_2$, it is possible to calculate the sample sizes that achieve the DQOs (assuming the proportions are equal to the values estimated from the sample) instead of calculating the power of the test. To do this, calculate

$$m^* = n^* = \frac{2(z_{1-\alpha} + z_{1-\beta})^2 \bar{P}(1 - \bar{P})}{(P_2 - P_1)^2} \quad \text{where} \quad \bar{P} = \frac{P_1 + P_2}{2}.$$

and z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). If both m and n exceed m^*, the false acceptance error rate has been satisfied. If both m and n are below m^*, the false acceptance error rate has not been satisfied.

If m^* is between m and n, use a software package like the DEFT software (EPA, 1994) or the DataQUEST software (EPA, 1996) to calculate the power of the test, assuming that the true values for the proportions P_1 and P_2 are those obtained in the sample. If the estimated power is below $1-\beta$, the false acceptance error rate has not been satisfied.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected, and it seems the difference in proportions is greater than 0 {less than 0};

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems the difference in proportions is less than or equal to 0 {greater than or equal to 0}; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems the difference in proportions is less than or equal to 0 {greater than or equal to 0}, but this outcome is uncertain because the sample size was probably too small.

Box 3-19: An Example of a Two-Sample Test for Proportions for Simple and Systematic Random Samples

At a hazardous waste site, investigators must determine whether an area suspected to be contaminated with dioxin needs to be remediated. The possibly contaminated area (area 1) will be compared to a reference area (area 2) to see if dioxin levels in area 1 are greater than dioxin levels in the reference area. An inexpensive surrogate probe was used to determine if each individual sample is either "contaminated," i.e., over the health standard of 1 ppb, or "clean," i.e., less than the health standard of 1 ppb. The null hypothesis will be that the proportion or contaminant levels in area 1 is less than or equal to the proportion in area 2, or H_0: $P_1 - P_2 \leq 0$ (Case 1). The decision maker is willing to accept a false rejection decision error rate of 10% (α) and a false-negative decision error rate of 5% (β) when the difference in proportions between areas exceeds 0.10. A team collected 92 readings from area 1 (of which 12 were contaminated) and 80 from area 2, the reference area, (of which 10 were contaminated).

STEP 1: The sample proportion for area 1 is $p_1 = 12/92 = 0.130$, the sample proportion for area 2 is $p_2 = 10/80 = 0.125$, and the pooled proportion $p = (12 + 10) / (92 + 80) = 0.128$.

STEP 2: $mp_1 = 12$, $m(1-p_1) = 80$, $np_2 = 10$, $n(1-p_2) = 70$. Because these values are greater than or equal to 5, continue to step 3.

STEP 3:

$$z = (0.130 - 0.125) / \sqrt{0.128(1 - 0.128)(1/92 + 1/80)} = 0.098$$

Table A-1 of Appendix A was used to find the critical value $z_{0.90} = 1.282$.

Because $z \not> z_{0.90}$ ($0.098 \not> 1.282$), there is not enough evidence to reject the null hypothesis and the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: Because the null hypothesis (H_0) was not rejected, calculate the sample size necessary to achieve the false rejection and false acceptance error rates. Because only one false acceptance error rate ($\beta = 0.05$) has been specified (at a difference of $P_1 - P_2 = 0.1$), it is possible to calculate the sample sizes that achieve the DQOs, assuming the proportions are equal to the values estimated from the sample:

$$m^* = n^* = \frac{2(1.282 + 1.645)^2 0.1275(1 - 0.1275)}{(0.1)^2} = 190.6 \ (i.e., 191 \ samples)$$

where $0.1275 = \bar{P} = \dfrac{0.115 + 0.055}{2}$

Because both m and n are less than m^*, the false acceptance error rate has not been satisfied.

STEP 5: The null hypothesis was not rejected, and the false acceptance error rate was not satisfied. Therefore, it seems that there is no difference in proportions and that the contaminant concentrations of the investigated area and the reference area are probably the same. However, this outcome is uncertain because the sample sizes obtained were in all likelihood too small.

3.3.3 Nonparametric Comparisons of Two Populations

In many cases, assumptions on distributional characteristics are difficult to verify or difficult to satisfy for both populations. In this case, several distribution-free test procedures are available that compare the shape and location of the two distributions instead of a statistical parameter (such as a mean or median). The statistical tests described below test the null hypothesis "H_0: the distributions of population 1 and population 2 are identical (or, the site is not more contaminated than background)" versus the alternative hypothesis "H_A: part of the distribution of population 1 is located to the right of the distribution of population 2 (or the site is more contaminated than background)." Because of the structure of the hypothesis tests, the labeling of populations 1 and 2 is of importance. For most environmental applications, population 1 is the area of interest (i.e., the potentially contaminated area) and population 2 is the reference area.

There is no formal statistical parameter of interest in the hypotheses stated above. However, the concept of false rejection and false acceptance error rates still applies.

3.3.3.1 The Wilcoxon Rank Sum Test

PURPOSE

The Wilcoxon rank sum test can be used to compare two population distributions based on m independent random samples $X_1, X_2, \ldots, X_m$ from the first population, and n independent random samples $Y_1, Y_2, \ldots, Y_n$ from the second population. When applied with the Quantile test (Section 3.3.3.2), the combined tests are most powerful for detecting true differences between two population distributions.

ASSUMPTIONS AND THEIR VERIFICATION

The validity of the random sampling and independence assumptions should be verified by review of the procedures used to select the sampling points. The two underlying distributions are assumed to have the same shape and dispersion, so that one distribution differs by some fixed amount (or is increased by a constant) when compared to the other distribution. For large samples, to test whether both site distributions have approximately the same shape, one can create and compare histograms for the samples.

LIMITATIONS AND ROBUSTNESS

The Wilcoxon rank sum test may produce misleading results if many data values are the same. When values are the same, their relative ranks are the same, and this has the effect of diluting the statistical power of the Wilcoxon rank sum test. Estimated concentrations should be reported for data below the detection limit, even if these estimates are negative, because their relative magnitude to the rest of the data is of importance. An important advantage of the Wilcoxon rank sum test is its partial robustness to outliers, because the analysis is conducted in terms of rankings of the observations. This limits the influence of outliers because a given data point can be no more extreme than the first or last rank.

SEQUENCE OF STEPS

Directions and an example for the Wilcoxon rank sum test are given in Box 3-20 and Box 3-21. However, if a relatively large number of samples have been taken, it is more efficient in terms of statistical power to use a large sample approximation to the Wilcoxon rank sum test (Box 3-22) to obtain the critical values of W.

Box 3-20: Directions for the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points from population 1 and $Y_1, Y_2, \ldots, Y_m$ represent the m data points from population 2 where both n and m are less than or equal to 20. For Case 1, the null hypothesis will be that population 1 is shifted to the left of population 2 with the alternative that population 1 is either the same as or shifted to the right of population 2; Case 2 will be that population 1 is shifted to the right of population 2 with the alternative that population 1 is the same as or shifted to the left of population 2; for Case 3, the null hypothesis will be that there is no difference between the two populations and the alternative hypothesis will be that population 1 is shifted either to the right or left of population 2. If either m or n are larger than 20, use Box 3-22.

STEP 1: List and rank the measurements from both populations from smallest to largest, keeping track of which population contributed each measurement. The rank of 1 is assigned to the smallest value, the rank of 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks that would otherwise have been assigned to the tied observations.

STEP 2: Calculate R as the sum of the ranks of the data from population 1, then calculate

$$W = R - \frac{n(n+1)}{2}.$$

STEP 3: Use Table A-7 of Appendix A to find the critical value w_α (or $w_{\alpha/2}$ for Case 3). For Case 1, reject the null hypothesis if $W > nm - w_\alpha$. For Case 2, reject the null hypothesis if $W < w_\alpha$. For Case 3, reject the null hypothesis if $W > nm - w_{\alpha/2}$ or $W < w_{\alpha/2}$. If the null hypothesis is rejected, go to Step 5. Otherwise, go to Step 4.

STEP 4: If the null hypothesis (H_0) was not rejected, the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates should be calculated. For small samples sizes, these calculations are too complex for this document.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected and it seems that population 1 is shifted to the right (Case 1), to the left (Case 2) or to the left or right (Case 3) of population 2.

2) the null hypothesis was not rejected and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population 2, or there is no difference between the two populations (Case 3).

Box 3-21: An Example of the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. The null hypothesis will be that area 1 is shifted to the right of area 2 and the alternative hypothesis will be that there is no difference between the two areas or that area 1 is shifted to the left of area 2 (Case 2). The false rejection error rate was set at 10% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb. Seven random samples were taken from area 1 and eight samples were taken from area 2:

Area 1	Area 2
17, 23, 26, 5	16, 20, 5, 4
13, 13, 12	8, 10, 7, 3

STEP 1: The data listed and ranked by size are (Area 1 denoted by *):

Data (ppb):	3,	4,	5,	5*,	7,	8,	10,	12*,	13*,	13*,	16,	17*,	20,	23*,	26*
Rank:	1,	2,	3.5,	3.5*,	5,	6,	7,	8*,	9.5*,	9.5*	11,	12*,	13,	14*,	15*

STEP 2: R = 3.5 + 8 + 9.5 + 9.5 + 12 + 14 + 15 = 71..5. W = 71.5 - 7(7 + 1)/2 = 43.5

STEP 3: Using Table A-7 of Appendix A, $\alpha = 0.10$ and $W_\alpha = 17$. Since 43.5 > 17, do not reject the null hypothesis.

STEP 4: The null hypothesis was not rejected and it would be appropriate to calculate the probable power of the test. However, because the number of samples is small, extensive computer simulations are required in order to estimate the power of this test which is beyond the scope of this guidance.

STEP 5: The null hypothesis was not rejected. Therefore, it is likely that there is no difference between the investigated area and the reference area, although the statistical power is low due to the small sample sizes involved.

Box 3-22: Directions for the Large Sample Approximation to the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points from population 1 and $Y_1, Y_2, \ldots, Y_m$ represent the m data points from population 2 where both n and m are greater than 20. For Case 1, the null hypothesis will be that population 1 is shifted to the left of population 2 with the alternative that population 1 is the same as or shifted to the right of population 2; for Case 2, the null hypothesis will be that population 1 is shifted to the right of population 2 with the alternative that population 1 is the same as or shifted to the left of population 2; for Case 3, the null hypothesis will be that there is no difference between the populations and the alternative hypothesis will be that population 1 is shifted either to the right or left of population 2.

STEP 1: List and rank the measurements from both populations from smallest to largest, keeping track of which population contributed each measurement. The rank of 1 is assigned to the smallest value, the rank of 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks that would otherwise have been assigned to the tied observations.

STEP 2: Calculate W as the sum of the ranks of the data from population 1.

STEP 3: Calculate $w_p = \frac{mn}{2} + Zp\sqrt{mn(n + m + 1)/12}$ where p = 1 - α for Case 1, p = α for Case 2, and z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). For Case 3, calculate both $w_{\alpha/2}$ (p = α/2) and $w_{1-\alpha/2}$ (p = 1 - α/2).

STEP 4: For Case 1, reject the null hypothesis if $W > w_{1-\alpha}$. For Case 2, reject the null hypothesis if $W < w_{\alpha}$. For Case 3, reject the null hypothesis if $W > w_{1-\alpha/2}$ or $W < w_{\alpha/2}$. If the null hypothesis is rejected, go to Step 6. Otherwise, go to Step 5.

STEP 5: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and negative error rates. If only one false acceptance error rate (β) has been specified (at δ_1), it is possible to calculate the sample size that achieves the DQOs, assuming the true mean and standard deviation are equal to the values estimated from the sample, instead of calculating the power of the test. If m and n are large, calculate:

$$m^* = n^* = \frac{2s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\delta_1 - \delta_0)^2} + (0.25)z^2_{1-\alpha}$$

where z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). If $1.16m^* \leq m$ and $1.16n^* \leq n$, the false acceptance error rate has been satisfied.

STEP 6: The results of the test could be:

1) the null hypothesis was rejected, and it seems that population 1 is shifted to the right (Case 1), to the left (Case 2) or to the left or right (Case 3) of population 2.

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population 2, or there is no difference between the two populations (Case 3).

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population

3.3.3.2 The Quantile Test

PURPOSE

The Quantile test can be used to compare two populations based on the independent random samples $X_1, X_2, \ldots, X_m$ from the first population and $Y_1, Y_2, \ldots, Y_n$ from the second population. When the Quantile test and the Wilcoxon rank sum test (Section 3.3.3.1) are applied together, the combined tests are the most powerful at detecting true differences between two populations. The Quantile test is useful in detecting instances where only parts of the data are different rather than a complete shift in the data. It essentially looks at a certain number of the largest data values to determine if too many data values from one population are present to be accounted for by pure chance.

ASSUMPTIONS AND THEIR VERIFICATION

The Quantile test assumes that the data $X_1, X_2, \ldots, X_m$ are a random sample from population 1, and the data $Y_1, Y_2, \ldots, Y_n$ are a random sample from population 2, and the two random samples are independent of one another. The validity of the random sampling and independence assumptions is assured by using proper randomization procedures, either random number generators or tables of random numbers. The primary verification required is to review the procedures used to select the sampling points. The two underlying distributions are assumed to have the same underlying dispersion (variance).

LIMITATIONS AND ROBUSTNESS

The Quantile test is not robust to outliers. In addition, the test assumes either a systematic (e.g., a triangular grid) or simple random sampling was employed. The Quantile test may not be used for stratified designs. In addition, exact false rejection error rates are not available, only approximate rates.

SEQUENCE OF STEPS

The Quantile test is difficult to implement by hand. Therefore, directions are not included in this guidance but the DataQUEST software (EPA, 1996) can be used to conduct this test. However, directions for a modified Quantile test that can be implemented by hand are contained in Box 3-23 and an example is given in Box 3-24.

Box 3-23: Directions for a Modified Quantile Test for Simple and Systematic Random Samples

Let there be ‘m’ measurements from population 1 (the reference area or group) and ‘n’ measurement from population 2 (the test area or group). The Modified Quantile test can be used to detect differences in shape and location of the two distributions. For this test, the significance level (α) can either be approximately 0.10 or approximately 0.05. The null hypothesis for this test is that the two population are the same (i.e., the test group is the same as the reference group) and the alternative is that population 2 has larger measurements than population 1 (i.e., the test group has larger values than the reference group).

STEP 1: Combine the two samples and order them from smallest to largest keeping track of which sample a value came from.

STEP 2: Using Table A-13 of Appendix A, determine the critical number (C) for a sample size n from the reference area, sample size m from the test area using the significance level α. If the C^{th} largest measurement of the combined population is the same as others, increase C to include all of these tied values.

STEP 3: If the largest C measurements from the combined samples are all from population 2 (the test group), then reject the null hypothesis and conclude that there are differences between the two populations. Otherwise, the null hypothesis is not rejected and it appears that there is no difference between the two populations.

3.3.4 Comparing Two Medians

Let $\tilde{\mu}_1$ represent the median of population 1 and $\tilde{\mu}_2$ represent the median of population 2. The hypothesis considered in this section are:

Case 1: H_0: $\tilde{\mu}_1 - \tilde{\mu}_2 \leq \delta_0$ vs. H_A: $\tilde{\mu}_1 - \tilde{\mu}_2 > \delta_0$; and

Case 2: H_0: $\tilde{\mu}_1 - \tilde{\mu}_2 \geq \delta_0$ vs. H_A: $\tilde{\mu}_1 - \tilde{\mu}_2 < \delta_0$.

An example of a two-sample test for the difference between two population medians is comparing the median contaminant level at a Superfund site to the median of a background site. In this case, δ_0 would be zero.

The median is also the 50^{th} percentile, and, therefore, the methods described in Section 3.3.2 for percentiles and proportions may be used to test hypotheses concerning the difference between two medians by letting $P_1 = P_0 = 0.50$. The Wilcoxon rank sum test (Section 3.3.3.1) is also recommended for comparing two medians. This test is more powerful than those for proportions for symmetric distributions.

Box 3-24: A Example of a Modified Quantile Test for Simple and Systematic Random Samples

At a hazardous waste site a new, cheaper, in-site methodology was compared against an existing methodology by remediating separate areas of the site using each method. If the new methodology works, the overall contamination of the area of the site remediated using the new methodology should be the same as the area of the site remediated using the standard methodology. If the new methodology does not work, then there would be higher contamination values remaining on the area of the site remediated using the new methodology. The site manager wishes to determine if the new methodology works and has chosen a 5% significance level. A modified Quantile Test will be used to make this determination based on 7 samples from the area remediated using the standard methodology (population 1) and 12 samples from the area remediated using the new methodology (population 2). The sampled values are:

Standard Methodology	New Methodology
17, 8, 20, 4, 6, 5, 4	7, 18, 2, 4, 6, 11, 5, 9, 10, 2, 3, 3

STEP 1: Combine the two samples and ordering them from smallest to largest yields:

2* 2* 3* 3* 4 4 4* 5* 5 6 6* 7* 8 9* 10* 11* 17 18* 20

where * denoted samples from the new methodology portion of the site (population 2).

STEP 2: Using Table A-13 of Appendix A with m = 7, n = 12, and $\alpha = 0.05$, the critical value C = 5. Since the 5th largest value is 10, there is not need to increase C.

(Note however, if the data were 2* 2* 3* 3* 4 4 4* 5* 5 6 6* 7* 8 9* 9* 11* 17 18* 20 then the 5th largest value would have been 9 which is the same tied with 1 other value. In this case, C would have been raised to 6 to include the tied value.)

STEP 3: From Step 1, the 5 largest values are 10* 11* 17 18* 20. Only 3 of these 5 values come from population 2, therefore the null hypothesis can not be rejected and the site manager concludes that it seems that the new in-situ methodology works as well as the standard methodology.

3.4 Tests for Comparing Several Populations

3.4.1 Tests for Comparing Several Means

This section describes procedures to test the differences between several sample means from different populations either against a control population or among themselves. For example, the test described in this section could be used identify whether or not there are differences between several drinking water wells or could be used to identify if several downgradient wells differ from an upgradient well.

In this situation, it would be possible to apply the tests described in Section 3.3.1 multiple times. However, applying a test multiple times underestimates the true false rejection decision error rate. Therefore, the test described in this section controls the overall false rejection decision error rate by making the multiple comparisons simultaneously.

3.4.1.1 Dunnett's Test

PURPOSE

Dunnett's test is used to test the difference between sample means from different populations against a control population. A typical application would involve different cleaned areas of a hazardous waste site being compared to a reference sample; this reference sample having been obtained from a uncontaminated part of the hazardous waste site.

ASSUMPTIONS AND THEIR VERIFICATION

Multiple application of any statistical test is inappropriate because the continued use of the same reference sample violates the assumption that the two samples were obtained independently for each statistical test. The tests are strongly correlated between themselves with the degree of correlation depending on the degree of similarity in number of samples used for the control group and investigated groups. The test is really best suited for approximately equal sample sizes in both the control group and the groups under investigation.

LIMITATIONS AND ROBUSTNESS

Dunnett's method is the same in operation as the standard two-sample t-test of Section 3.3.1 except for the use of a larger pooled estimate of variance and the need for special t-type tables (Table A-14 of Appendix A). These tables are for the case of equal number of samples in the control and each of the investigated groups, but remain valid provided the number of samples from the investigated group are approximately more than half but less than double the size of the control group. In this guidance, only the null hypothesis that the mean of the sample populations is the same as the mean of the control population will be considered.

SEQUENCE OF STEPS

Directions for the use of Dunnett's method for a simple random sample or a systematic random sample are given in Box 3-25 and an example is contained in Box 3-26.

Box 3-25: Directions for Dunnett's Test for Simple Random and Systematic Samples

Let k represent the total number of populations to be compared so there are (k-1) sample populations and a single control population. Let n_1, n_2, ... n_{k-1} represent the sample sizes of each of the (k-1) sample populations and let m represent the sample size of the control population. The null hypothesis is H_0: $\mu_i - \mu_C \le 0$ (i.e., no difference between the sample means and the control mean) and the alternative hypothesis is H_A: $\mu_i - \mu_C > 0$ for 1 = 1, 2, ..., k-1 where μ_i represents the mean of the ith sample population and μ_C represents the mean of the control population. Let α represent the chosen significance level for the test.

STEP 1: For each sample population, make sure that approximately $0.5 < m/n_i < 2$. If not, Dunnett's Test should not be used.

STEP 2: Calculate the sample mean, $\bar{X}_i$ (Section 2.2.2), and the variance, s_i^2 (Section 2.2.3) for each of the k populations (i.e., i = 1, 2, ... k).

STEP 3: Calculated the pooled standard:

$$s_D = \sqrt{\frac{(m-1)s_C^2 + (n_1 - 1)s_{n_1}^2 + ... + (n_{k-1} - 1)s_{k-1}^2}{(m-1) + (n_1 - 1) + ... + (n_{k-1} - 1)}}$$

STEP 4: For each of the k-1 sample populations, compute

$$t_i = \frac{\left|\overline{X_i} - \overline{X}_C\right|}{s_D \sqrt{1/n_i + 1/n_C}}$$

STEP 5: Use Table A-14 of Appendix A to determine the critical value $T_{D(1-\alpha)}$ where the degrees of freedom is $(m - 1) + (n_1 - 1) + . . . + (n_{k-1} - 1)$.

STEP 6: Compare t_i to $T_{D(1-\alpha)}$ for each of the k-1 sample populations. If $t_i > T_{D(1-\alpha)}$ for any of the sample populations, then reject the null hypothesis and conclude that there are differences between the means of the sample populations and the mean of the control populations. Otherwise, conclude that there is no difference between the sample and control population means.

Box 3-26: An Example of Dunnett's Test for Simple Random and Systematic Samples

At a hazardous work site, 6 designated areas previously identified as 'hotspots' have been cleaned. In order for this site to be a potential candidate for the local Brownfields program, it must be demonstrated that these areas are not longer contaminated. Therefore, the means of these areas will be compared to mean of a reference area also located on the site using Dunnett's test. The null hypothesis will be that there is no difference between the means of the 'hotspot' areas and the mean of the reference area. A summary of the data from the areas follows.

	Reference Area	**IAK3**	**ZBF6**	**3BG5**	**4GH2**	**5FF3**	**6GW4**
Number of Samples:	7	6	5	6	7	8	7
Mean:	10.3	11.4	12.2	10.2	11.4	11.9	12.1
Variance:	2.5	2.6	3.3	3.0	3.2	2.6	2.8
Ratio: m/n		7/6 = 1.16	7/5 = 1.4	7/6 = 1.16	7/7 = 1	7/8 = 0.875	7/7 = 1
t_i:		1.18	1.93	0.11	1.22	1.84	2.00

STEP 1: Calculate the ratio m/n for each investigated area. These are shown in the 4th row of the table above. Since all of these ration fall within the range of 0.5 to 2.0, Dunnett's test may be used.

STEP 2: The sample means, $\bar{x}_i$ and the variance, s_i^2 were calculated using Sections 2.2.2 and 2.2.3 of Chapter 2. These are shown in the 2nd and 3rd row of the table above.

STEP 3: The pooled standard deviation for all 7 areas is:

$$s_D = \sqrt{\frac{(7-1)2.5 + (6-1)2.6 + \ldots + (7-1)2.8}{(7-1) + (6_1 - 1) + \ldots + (7-1)}} = \sqrt{\frac{110.4}{39}} = \sqrt{2.831} = 1.68$$

STEP 4: For each 'hotspot' area, t_i was computed. For example, $t_1 = \dfrac{|11.4 - 10.3|}{1.68\sqrt{1/6 + 1/7}} = 1.18$

These are shown in the 5th row of the table above.

STEP 5: The degrees of freedom is (7 - 1) + (6 - 1) + . . . + (7 - 1) = 39. So using Table A-14 of Appendix A with 39 for the degrees of freedom, the critical value $T_{D(0.95)}$ = 2.37 and $T_{D(0.90)}$ = 2.03.

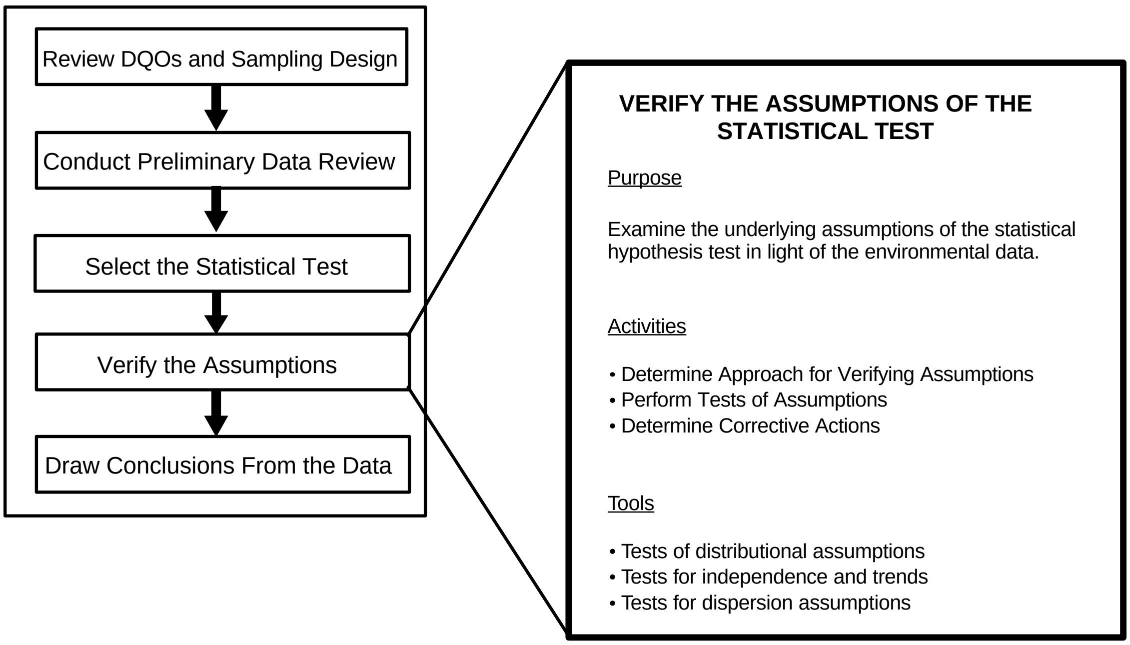
STEP 6: Since none of the values in row 5 of the table are greater than either 2.37 or 2.03, it appears that none of the 'hotspot' areas have contamination levels that are significantly different than the reference area. Therefore, this site may be a potential candidate to be a Brownsfield site.

NOTE: If an ordinary 2-sample t-test (see Section 3.3.1.1) had been used to compare each 'hotspot' area with the reference area at the 5% level of significance, areas 2BF6, 5FF3, and 69W4 would have erroneously been declared different from the reference area, which would probably alter the final conclusion to include the site as a Brownfields candidate.

CHAPTER 4

STEP 4: VERIFY THE ASSUMPTIONS OF THE STATISTICAL TEST

THE DATA QUALITY ASSESSMENT PROCESS



Step 4: Verify the Assumptions of the Statistical Test

- Determine approach for verifying assumptions.
  - Identify any strong graphical evidence from the preliminary data review.
  - Review (or develop) the statistical model for the data.
  - Select the tests for verifying assumptions.

- Perform tests of assumptions.
  - Adjust for bias if warranted.
  - Perform the calculations required for the tests.

- If necessary, determine corrective actions.
  - Determine whether data transformations will correct the problem.
  - If data are missing, explore the feasibility of using theoretical justification or collecting new data.
  - Consider robust procedures or nonparametric hypothesis tests.

List of Boxes

CHAPTER 4
STEP 4: VERIFY THE ASSUMPTIONS OF THE STATISTICAL TEST

4.1 OVERVIEW AND ACTIVITIES

In this step, the analyst should assess the validity of the statistical test chosen in step 3 by examining its underlying assumptions in light of the newly generated environmental data. The principal thrust of this section is the determination of whether the data support the underlying assumptions necessary for the selected test, or if modifications to the data are necessary prior to further statistical analysis.

This determination can be performed quantitatively using statistical analysis of data to confirm or reject the assumptions that accompany any statistical test. Almost always, however, the quantitative techniques must be supported by qualitative judgments based on the underlying science and engineering aspects of the study. Graphical representations of the data, such as those described in Chapter 2, can provide important qualitative information about the reasonableness of the assumptions. Documentation of this step is important, especially when subjective judgments play a pivotal role in accepting the results of the analysis.

If the data support all of the key assumptions of the statistical test, then the DQA continues to the next step, drawing conclusions from the data (Chapter 5). However, often one or more of the assumptions will be called into question which may trigger a reevaluation of one of the previous steps. This iteration in the DQA is an important check on the validity and practicality of the results.

4.1.1 Determine Approach for Verifying Assumptions

In most cases, assumptions about distributional form, independence, and dispersion can be verified formally using the statistical tests described in the technical sections in the remainder of this chapter, although in some situations, information from the preliminary data review may serve as sufficiently strong evidence to support the assumptions. As part of this activity, the analyst should identify methods to verify that the type and quantity of data required to perform the desired test are available. The outputs of this activity should include a list of the specific tests that will be used to verify the assumptions.

For each statistical test it will be necessary for the investigator to select the "level of significance." For the specific null hypothesis for the test under consideration, the level of significance is the chance that this null hypothesis is rejected even though it is true. For example, if testing for normality of data, the null hypothesis is that the data do indeed exhibit normality. When a test statistic is computed, choosing a level of significance of 5% is saying that if the null hypothesis is true then the chance that normally distributed data will produce a statistic more extreme than that value tabulated is only 1 in 20 (5%).

The choice of specific level of significance is up to the investigator and is a matter of experience or personal choice. It does not have to be the same as that chosen in Step 3 (Select the Statistical Test). If more than a couple of statistical tests are contemplated, it is advisable to choose a numerically low value for the level of significance to prevent the accumulation of potential errors. The level of significance for a statistical test is by definition the same as false rejection error.

The methods and approach chosen for assumption verification depend on the nature of the study and its documentation. For example, if computer simulation was used to estimate the theoretical power of the statistical test, then this simulation model should be the basis for evaluation of the effect of changes to assumptions using estimates calculated from the data to replace simulation values.

If it is not already part of the design documentation, the analyst may need to formulate a statistical model that describes the data. In a statistical model, the data are conceptually decomposed into elements that are assumed to be "fixed" (i.e., the component is either a constant but unknown feature of the population or is controlled by experimentation) or "random" (i.e., the component is an uncontrolled source of variation). Which components are considered fixed and which are random is determined by the assumptions made for the statistical test and by the inherent structure of the sampling design. The random components that represent the sources of uncontrolled variation could include several types of measurement errors, as well as other sources such as temporal and/or spatial components.

In addition to identifying the components that make up an observation and specifying which are fixed and which are random, the model should also define whether the various components behave in an additive or multiplicative fashion (or some combination). For example, if temporal or spatial autocorrelations are believed to be present, then the model needs to identify the autocorrelation structure (see Section 2.3.8).

4.1.2 Perform Tests of Assumptions

For most statistical tests, investigators will need to assess the reasonableness of assumptions in relation to the structure of the components making up an observation. For example, a t-test assumes that the components, or errors, are additive, uncorrelated, and normally distributed with homogeneous variance. Basic assumptions that should be investigated include:

(1) *Is it reasonable to assume that the errors (deviations from the model) are normally distributed?* If adequate data are available, then standard tests for normality can be conducted (e.g., the Shapiro-Wilk test or the Kolmogorov-Smirnov test).

(2) *Is it reasonable to assume that errors are uncorrelated?* While it is natural to assume that analytical errors imbedded in measurements made on different sample units are independent, other errors from other sources may not be independent. If

sample units are "too close together," either in time or space, independence may not hold. If the statistical test assumes independence and this assumption is not correct, the proposed false rejection and false acceptance error rates for the statistical test cannot be verified.

(3) *Is it reasonable to assume that errors are additive and have a constant variability?* If sufficient data are available, a plot of the relevant standard deviations versus mean concentrations may be used to discern if variability tends to increase with concentration level. If so, transformations of the data may make the additivity assumption more tenable.

One of the most important assumptions underlying the statistical procedures described herein is that there is no inherent bias (systematic deviation from the true value) in the data. The general approach adopted here is that if a long term bias is known to exist, then adjustment for this bias should be made. If bias is present, then the basic effect is to shift the power curves associated with a given test to the right or left, depending on the direction of the bias. Thus substantial distortion of the nominal false rejection and false acceptance decision error rates may occur and so the level of significance could be very different than that assumed, and the power of the test be far less than expected. In general, bias cannot be discerned by examination of routine data; rather, appropriate and adequate QA data are needed, such as performance evaluation data. If one chooses not to make adjustment for bias on the basis of such data, then one should, at a minimum, construct the estimated worse-case power curves so as to understand the potential effects of the bias.

4.1.3 Determine Corrective Actions

Sometimes the assumptions underlying the primary statistical test will not be satisfied and some type of corrective action will be required before proceeding. In some cases, a transformation of the data will correct a problem with distributional assumptions. In other cases, the data for verifying some key assumption may not be available, and existing information may not support a theoretical justification of the validity of the assumption. In this situation, it may be necessary to collect additional data to verify the assumptions. If the assumptions underlying a hypothesis test are not satisfied, and data transformations or other modifications do not appear feasible, then it may be necessary to consider an alternative statistical test. These include robust test procedures and nonparametric procedures. Robust test procedures involve modifying the parametric test by using robust estimators. For instance, as a substitute for a t-test, a trimmed mean and its associated standard error (Section 4.7.2) might be used to form a t-type statistic.

4.2 TESTS FOR DISTRIBUTIONAL ASSUMPTIONS

Many statistical tests and models are only appropriate for data that follow a particular distribution. This section will aid in determining if a distributional assumption of a statistical test is satisfied, in particular, the assumption of normality. Two of the most important distributions for tests involving environmental data are the normal distribution and the lognormal distribution, both of which are discussed in this section. To test if the data follow a distribution other than the normal distribution or the lognormal distribution, apply the chi-square test discussed in Section 4.2.7 or consult a statistician.

There are many methods available for verifying the assumption of normality ranging from simple to complex. This section discusses methods based on graphs, sample moments (kurtosis and skewness), sample ranges, the Shapiro-Wilk test and closely related tests, and goodness-of-fit tests. Discussions for the simplest tests contain step-by-step directions and examples based on the data in Table 4-1. These tests are summarized in Table 4-2. This section ends with a comparison of the tests to help the analyst select a test for normality.

Table 4-1. Data for Examples in Section 4.2

15.63	11.00	11.75	10.45	13.18	10.37	10.54	11.55	11.01	10.23	$\bar{x}$ =11.57 s = 1.677

Table 4-2. Tests for Normality

Test	Section	Sample Size	Recommended Use	Data-QUEST
Shapiro Wilk W Test	4.2.2	$\le$ 50	Highly recommended.	Yes
Filliben's Statistic	4.2.3	$\le$ 100	Highly recommended.	Yes
Coefficient of Variation Test	4.2.4	Any	Only use to quickly discard an assumption of normality.	Yes
Skewness and Kurtosis Tests	4.2.5	> 50	Useful for large sample sizes.	Yes
Geary's Test	4.2.6	> 50	Useful when tables for other tests are not available.	Yes
Studentized Range Test	4.2.6	$\le$ 1000	Highly recommended (with some conditions).	Yes
Chi-Square Test	4.2.7	Large[a]	Useful for grouped data and when the comparison distribution is known.	No
Lilliefors Kolmogorov-Smirnoff Test	4.2.7	> 50	Useful when tables for other tests are not available.	No

[a] The necessary sample size depends on the number of groups formed when implementing this test. Each group should contain at least 5 observations.

The assumption of normality is very important as it is the basis for the majority of statistical tests. A normal, or Gaussian, distribution is one of the most common probability distributions in the analysis of environmental data. A normal distribution is a reasonable model of the behavior of certain random phenomena and can often be used to approximate other probability distributions. In addition, the Central Limit Theorem and other limit theorems state that as the sample size gets large, some of the sample summary statistics (e.g., the sample mean) behave as if they are a normally distributed variable. As a result, a common assumption associated with parametric tests or statistical models is that the errors associated with data or a model follow a normal distribution.

The graph of a normally distributed random variable, a normal curve, is bell-shaped (see Figure 4-1) with the highest point located at the mean which is equal to the median. A normal curve is symmetric about the mean, hence the part to the left of the mean is a mirror image of the part to the right. In environmental data, random errors occurring during the measurement process may be normally distributed.

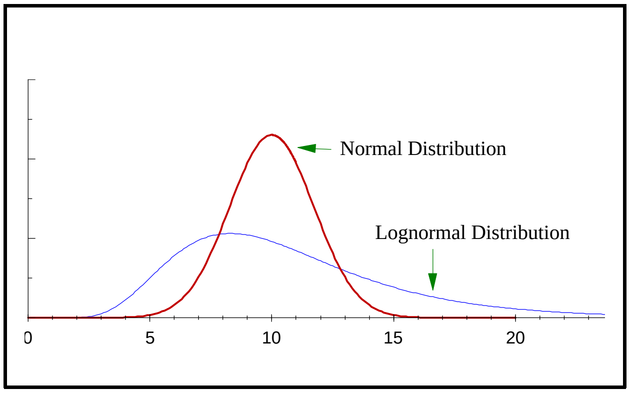


Figure 4-1. Graph of a Normal and Lognormal Distribution

Environmental data commonly exhibit frequency distributions that are non-negative and skewed with heavy or long right tails. Several standard parametric probability models have these properties, including the Weibull, gamma, and lognormal distributions. The lognormal distribution (Figure 4-1) is a commonly used distribution for modeling environmental contaminant data. The advantage to this distribution is that a simple (logarithmic) transformation will transform a lognormal distribution into a normal distribution. Therefore, the methods for testing for normality described in this section can be used to test for lognormality if a logarithmic transformation has been used.

4.2.1 Graphical Methods

Graphical methods (Section 2.3) present detailed information about data sets that may not be apparent from a test statistic. Histograms, stem-and-leaf plots, and normal probability plots are some graphical methods that are useful for determining whether or not data follow a normal curve. Both the histogram and stem-and-leaf plot of a normal distribution are bell-shaped. The normal probability plot of a normal distribution follows a straight line. For non-normally distributed data, there will be large deviations in the tails or middle of a normal probability plot.

Using a plot to decide if the data are normally distributed involves making a subjective decision. For extremely non-normal data, it is easy to make this determination; however, in many cases the decision is not straightforward. Therefore, formal test procedures are usually necessary to test the assumption of normality.

4.2.2 Shapiro-Wilk Test for Normality (the W test)

One of the most powerful tests for normality is the W test by Shapiro and Wilk. This test is similar to computing a correlation between the quantiles of the standard normal distribution and the ordered values of a data set. If the normal probability plot is approximately linear (i.e., the data follow a normal curve), the test statistic will be relatively high. If the normal probability plot contains significant curves, the test statistic will be relatively low.

The W test is recommended in several EPA guidance documents and in many statistical texts. Tables of critical values for sample sizes up to 50 have been developed for determining the significance of the test statistic. However, this test is difficult to compute by hand since it requires two different sets of tabled values and a large number of summations and multiplications. Therefore, directions for implementing this test are not given in this document, but the test is contained in the *Data Quality Assessment Statistical Toolbox (QA/G-9D)* (EPA, 1996).

4.2.3 Extensions of the Shapiro-Wilk Test (Filliben's Statistic)

Because the W test may only be used for sample sizes less than or equal to 50, several related tests have been proposed. D'Agostino’s test for sample sizes between 50 and 1000 and Royston’s test for sample sizes up to 2000 are two such tests that approximate some of the key quantities or parameters of the W test.

Another test related to the W test is the Filliben statistic, also called the probability plot correlation coefficient. This test measures the linearity of the points on the normal probability plot. Similar to the W test, if the normal probability plot is approximately linear (i.e., the data follow a normal curve), the correlation coefficient will be relatively high. If the normal probability plot contains significant curves (i.e., the data do not follow a normal curve), the correlation coefficient will be relatively low. Although easier to compute that the W test, the Filliben statistic is still difficult to compute by hand. Therefore, directions for implementing this test are not given in this guidance; however, it is contained in the software, *Data Quality Assessment Statistical Toolbox (QA/G-9D)* (EPA, 1996).

4.2.4 Coefficient of Variation

The coefficient of variation (CV) may be used to quickly determine whether or not the data follow a normal curve by comparing the sample CV to 1. The use of the CV is only valid for some environmental applications if the data represent a non-negative characteristic such as contaminant concentrations. If the CV is greater than 1, the data should not be modeled with a normal curve. However, this method *should not be used to conclude the opposite,* i.e., do not conclude that the data can be modeled with a normal curve if the CV is less than 1. This test is to be used only in conjunction with other statistical tests or when graphical representations of the data indicate extreme departures from normality. Directions and an example of this method are contained in Box 4-1.

Box 4-1: Directions for the Coefficient of Variation Test for Environmental Data and an Example

Directions

STEP 1: Calculate the coefficient of variation (CV): $CV = s / \bar{X} = \dfrac{\left[\dfrac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2 \right]^{1/2}}{\dfrac{1}{n} \sum_{i=1}^{n} X_i}$

STEP 2: If CV > 1.0, conclude that the data are not normally distributed. Otherwise, the test is inconclusive.

Example

The following example demonstrates using the coefficient of variation to determine that the data in Table 4-1 should not be modeled using a normal curve.

STEP 1: Calculate the coefficient of variation (CV): $CV = \dfrac{s}{\bar{X}} = \dfrac{1.677}{11.571} = 0.145$

STEP 2: Since 0.145 $\ngtr$ 1.0, the test is inconclusive.

4.2.5 Coefficient of Skewness/Coefficient of Kurtosis Tests

The degree of symmetry (or asymmetry) displayed by a data set is measured by the coefficient of skewness (g_3). The coefficient of kurtosis, g_4, measures the degree of flatness of a probability distribution near its center. Several test methods have been proposed using these coefficients to test for normality. One method tests for normality by adjusting the coefficients of skewness and kurtosis to approximate a standard normal distribution for sample sizes greater than 50.

Two other tests based on these coefficients include a combined test based on a chi-squared (χ^2) distribution and Fisher's cumulant test. Fisher's cumulant test computes the exact sampling distribution of g_3 and g_4; therefore, it is more powerful than previous methods which assume that the distributions of the two coefficients are normal. Fisher's cumulant test requires a table of critical values, and these tests require a sample size of greater than 50. Tests based on skewness and kurtosis are rarely used as they are less powerful than many alternatives.

4.2.6 Range Tests

Almost 100% of the area of a normal curve lies within ±5 standard deviations from the mean and tests for normality have been developed based on this fact. Two such tests, which are both simple to apply, are the studentized range test and Geary's test. Both of these tests use a ratio of an estimate of the sample range to the sample standard deviation. Very large and very small values of the ratio then imply that the data are not well modeled by a normal curve.

a. The studentized range test (or w/s test). This test compares the range of the sample to the sample standard deviation. Tables of critical values for sample sizes up to 1000 (Table A-2 of Appendix A) are available for determining whether the absolute value of this ratio is significantly large. Directions for implementing this method are given in Box 4-2 along with an example. The studentized range test does not perform well if the data are asymmetric and if the tails of the data are heavier than the normal distribution. In addition, this test may be sensitive to extreme values. Unfortunately, lognormally distributed data, which are common in environmental applications, have these characteristics. If the data appear to be lognormally distributed, then this test should not be used. In most cases, the studentized range test performs as well as the Shapiro-Wilk test and is much easier to apply.

Box 4-2: Directions for Studentized Range Test and an Example

Directions

STEP 1: Calculate sample range (w) and sample standard deviation (s) using Section 2.2.3.

STEP 2: Compare $\frac{w}{s} = \frac{X_{(n)} - X_{(1)}}{s}$ to the critical values given in Table A-2 (labeled a and b).

If w/s falls outside the two critical values then the data do not follow a normal curve.

Example

The following example demonstrates the use of the studentized range test to determine if the data from Table 4-1 can be modeled using a normal curve.

STEP 1: $w = X_{(n)} - X_{(1)} = 15.63 - 10.23 = 5.40$ and s = 1.677.

STEP 2: w/s = 5.4 / 1.677 = 3.22. The critical values given in Table A-2 are 2.51 and 3.875. Since 3.22 falls between these values, the assumption of normality is not rejected.

b. Geary's Test. Geary's test uses the ratio of the mean deviation of the sample to the sample standard deviation. This ratio is then adjusted to approximate a standard normal distribution. Directions for implementing this method are given in Box 4-3 and an example is given in Box 4-4. This test does not perform as well as the Shapiro-Wilk test or the studentized range test. However, since Geary's test statistic is based on the normal distribution, critical values for all possible sample sizes are available.

Box 4-3: Directions for Geary's Test

STEP 1: Calculate the sample mean $\bar{x}$, the sample sum of squares (SSS), and the sum of absolute deviations (SAD):

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i, \quad SSS = \sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n}, \quad and \quad SAD = \sum_{i=1}^{n} |X_i - \bar{X}|$$

STEP 2: Calculate Geary's test statistic $a = \frac{SAD}{\sqrt{n(SSS)}}$

STEP 3: Test "a" for significance by computing $Z = \frac{a - 0.7979}{0.2123/\sqrt{n}}$. Here 0.7979 and 0.2123 are constants used to achieve normality.

STEP 4: Use Table A-1 of Appendix A to find the critical value $z_{1-\alpha}$ such that 100(1-α)% of the normal distribution is below $z_{1-\alpha}$. For example, if $\alpha = 0.05$, then $z_{1-\alpha} = 1.645$. Declare "a" to be sufficiently small or large (i.e., conclude the data are not normally distributed) if $|Z| > Z_{1-\alpha}$.

Box 4-4: Example of Geary's Test

The following example demonstrates the use of Geary's test to determine if the data from Table 4-1 can be modeled using a normal curve.

STEP 1: $$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i = 11.571, \quad SAD = \sum_{i=1}^{n} |X_i - \bar{X}| = 11.694, \; and$$

$$SSS = \sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n} = 1364.178 - 1338.88 = 25.298$$

STEP 2: $$a = \frac{SAD}{\sqrt{n(SSS)}} = \frac{11.694}{\sqrt{10(25.298)}} = 0.735$$

STEP 3: $$Z = \frac{0.735 - 0.7979}{0.2123/\sqrt{10}} = -0.934$$

STEP 4: Since $|Z| \ngtr 1.64$ (5% significance level), there is not enough information to conclude that the data do not follow a normal distribution.

4.2.7 Goodness-of-Fit Tests

Goodness-of-fit tests are used to test whether data follow a specific distribution, i.e., how "good" a specified distribution fits the data. In verifying assumptions of normality, one would compare the data to a normal distribution with a specified mean and variance.

a. Chi-square Test. One classic goodness-of-fit test is the chi-square test which involves breaking the data into groups and comparing these groups to the expected groups from the known distribution. There are no fixed methods for selecting these groups and this test also requires a large sample size since at least 5 observations per group are required to implement this test. In addition, the chi-square test does not have the power of the Shapiro-Wilk test or some of the other tests mentioned above.

b. Tests Based on the Empirical Distribution Function. The cumulative distribution function, denoted by F(x), and the empirical distribution function of the data for a given sample of size n are defined in Section 2.3.7.4. Since empirical distribution functions estimate the true F(x) underlying a set of data, and as the cumulative distribution function for a given type of distribution [e.g., a normal distribution (see Section 2.4) with given mean and standard deviation] can be computed, a goodness of fit test can be performed using the empirical distribution function. If the empirical distribution function is "not close to" the given cumulative distribution function, then there is evidence that the data do not come from the distribution having that cumulative distribution function.

Various methods have been used to measure the discrepancy between the sample empirical distribution function and the theoretical cumulative distribution function. These measures are referred to as empirical distribution function statistics. The best known empirical distribution function statistic is the Kolmogorov-Smirnov (K-S) statistic. The K-S approach is appropriate if the sample size exceeds 50 and if F(x) represents a specific distribution with known parameters (e.g., a normal distribution with mean 100 and variance 30). A modification to the test, called the Lilliefors K-S test, is appropriate (for $n>50$) for testing that the data are normally distributed when the F(x) is based on an estimated mean and variance.

Unlike the K-S type statistics, most empirical distribution function statistics are based on integrated or average values between the empirical distribution function and cumulative distribution functions. The two most powerful are the Cramer-von Mises and Anderson-Darling statistics. Extensive simulations show that the Anderson-Darling empirical distribution function statistic is just as good as any, including the Shapiro-Wilk statistic, when testing for normality. However, the Shapiro-Wilk test is applicable only for the case of a normal-distribution cumulative distribution function, while the Anderson-Darling method is more general.

Most goodness-of-fit tests are difficult to perform manually and are usually included in standard statistical software. The application of goodness-of-fit tests to non-normal data is beyond the scope of this guidance and consultation with a statistician recommended.

4.2.8 Recommendations

Analysts can perform tests for normality with samples as small as 3. However, the tests lack statistical power for small sample size. Therefore, for small sample sizes, it is recommended that a nonparametric statistical test (i.e., one that does not assume a distributional form of the data) be selected during Step 3 of the DQA in order to avoid incorrectly assuming the data are normally distributed when there is simply not enough information to test this assumption.

If the sample size is less than 50, then this guidance recommends using the Shapiro-Wilk W test, wherever practicable. The Shapiro-Wilk W test is one of most powerful tests for normality and it is recommended in several EPA guidance as the preferred test when the sample size is less than 50. This test is difficult to implement by hand but can be applied easily using the *Data Quality Assessment Statistical Toolbox (QA/G-9D)* (EPA, 1996). If the Shapiro-Wilk W test is not feasible, then this guidance recommends using either Filliben's statistic or the studentized range test. Filliben's statistic performs similarly to the Shapiro-Wilk test. The studentized range is a simple test to perform; however, it is not applicable for non-symmetric data with large tails. If the data are not highly skewed and the tails are not significantly large (compared to a normal distribution), the studentized range provides a simple and powerful test that can be calculated by hand.

If the sample size is greater than 50, this guidance recommends using either the Filliben's statistic or the studentized range test. However, if critical values for these tests (for the specific sample size) are not available, then this guidance recommends implementing either Geary's test or the Lilliefors Kolmogorov-Smirnoff test. Geary's test is easy to apply and uses standard normal tables similar to Table A-1 of Appendix A and widely available in standard textbooks. Lilliefors Kolmogorov-Smirnoff is more statistically powerful but is also more difficult to apply and uses specialized tables not readily available.

4.3 TESTS FOR TRENDS

4.3.1 Introduction

This section presents statistical tools for detecting and estimating trends in environmental data. The detection and estimation of temporal or spatial trends are important for many environmental studies or monitoring programs. In cases where temporal or spatial patterns are strong, simple procedures such as time plots or linear regression over time can reveal trends. In more complex situations, sophisticated statistical models and procedures may be needed. For example, the detection of trends may be complicated by the overlaying of long- and short-term trends, cyclical effects (e.g., seasonal or weekly systematic variations), autocorrelations, or impulses or jumps (e.g., due to interventions or procedural changes).

The graphical representations of Chapter 2 are recommended as the first step to identify possible trends. A plot of the data versus time is recommended for temporal data, as it may reveal long-term trends and may also show other major types of trends, such as cycles or impulses. A posting plot is recommended for spatial data to reveal spatial trends such as areas of high concentration or areas that were inaccessible.

For most of the statistical tools presented below, the focus is on monotonic long-term trends (i.e., a trend that is exclusively increasing or decreasing, but not both), as well as other sources of systematic variation, such as seasonality. The investigations of trend in this section are limited to one-dimensional domains, e.g., trends in a pollutant concentration over time. The current edition of this document does not address spatial trends (with 2- and 3-dimensional domains) and trends over space and time (with 3- and 4-dimensional domains), which may involve sophisticated geostatistical techniques such as kriging and require the assistance of a statistician. Section 4.3.2 discusses estimating and testing for trends using regression techniques. Section 4.3.3 discusses more robust trend estimation procedures, and Section 4.3.4 discusses hypothesis tests for detecting trends under several types of situations.

4.3.2 Regression-Based Methods for Estimating and Testing for Trends

4.3.2.1 Estimating a Trend Using the Slope of the Regression Line

The classic procedures for assessing linear trends involve regression. Linear regression is a commonly used procedure in which calculations are performed on a data set containing pairs of observations (X_i, Y_i), so as to obtain the slope and intercept of a line that "best fits" the data. For temporal trends, the X_i values represent time and the Y_i values represent the observations, such as contaminant concentrations. An estimate of the magnitude of trend can be obtained by performing a regression of the data versus time (or some function of the data versus some function of time) and using the slope of the regression line as the measure of the strength of the trend.

Regression procedures are easy to apply; most scientific calculators will accept data entered as pairs and will calculate the slope and intercept of the best fitting line, as well as the correlation coefficient r (see Section 2.2.4). However, regression entails several limitations and assumptions. First of all, simple linear regression (the most commonly used method) is designed to detect linear relationships between two variables; other types of regression models are generally needed to detect non-linear relationships such as cyclical or non-monotonic trends. Regression is very sensitive to extreme values (outliers), and presents difficulties in handling data below the detection limit, which are commonly encountered in environmental studies. Regression also relies on two key assumptions: normally distributed errors, and constant variance. It may be difficult or burdensome to verify these assumptions in practice, so the accuracy of the slope estimate may be suspect. Moreover, the analyst must ensure that time plots of the data show no cyclical patterns, outlier tests show no extreme data values, and data validation reports indicate that nearly all the measurements were above detection limits. Because of these drawbacks, regression is not recommended as a general tool for estimating and detecting trends, although it may be useful as an informal, quick, and easy screening tool for identifying strong linear trends.

4.3.2.2 Testing for Trends Using Regression Methods

The limitations and assumptions associated with estimating trends based on linear regression methods apply also to other regression-based statistical tests for detecting trends. Nonetheless, for situations in which regression methods can be applied appropriately, there is a solid body of literature on hypothesis testing using the concepts of statistical linear models as a basis for inferring the existence of temporal trends. The methodology is complex and beyond the scope of this document.

For simple linear regression, the statistical test of whether the slope is significantly different from zero is equivalent to testing if the correlation coefficient is significantly different from zero. Directions for this test are given in Box 4-5 along with an example. This test assumes a linear relation between Y and X with independent normally distributed errors and constant variance across all X and Y values. Censored values (e.g., below the detection limit) and outliers may invalidate the tests.

Box 4-5: Directions for the Test for a Correlation Coefficient and an Example

Directions

STEP 1: Calculate the correlation coefficient, r (Section 2.2.4).

STEP 2: Calculate the t-value $t = \dfrac{r}{\sqrt{\dfrac{1 - r^2}{n - 2}}}$.

STEP 3: Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha/2}$ such that 100(1-α/2)% of the t distribution with n - 2 degrees of freedom is below $t_{1-\alpha}$. For example, if α = 0.10 and n = 17, then n-2 = 15 and $t_{1-\alpha/2}$ = 1.753. Conclude that the correlation is significantly different from zero if $|t| > t_{1-\alpha/2}$.

Example: Consider the following data set (in ppb): for Sample 1, arsenic (X) is 4.0 and lead (Y) is 8.0; for Sample 2, arsenic is 3.0 and lead is 7.0; for Sample 3, arsenic is 2.0 and lead is 7.0; and for Sample 4, arsenic is 1.0 and lead is 6.0.

STEP 1: In Section 2.2.4, the correlation coefficient r for this data was calculated to be 0.949.

STEP 2: $t = \dfrac{0.949}{\sqrt{\dfrac{1 - 0.949^2}{4 - 2}}} = 4.26$

STEP 3: Using Table A-1 of Appendix A, $t_{1-\alpha/2}$ = 2.920 for a 10% level of significance and 4-2 = 2 degrees of freedom. Therefore, there appears to be a significant correlation between the two variables lead and arsenic.

4.3.3 General Trend Estimation Methods

4.3.3.1 Sen's Slope Estimator

Sen's Slope Estimate is a nonparametric alternative for estimating a slope. This approach involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope. As such, it is insensitive to outliers and can handle a moderate number of values below the detection limit and missing values. Assume that there are n time points (or n periods of time), and let X_i denote the data value for the i^{th} time point. If there are no missing data, there will be n(n-1)/2 possible pairs of time points (i, j) in which i > j. The slope for such a pair is called a pairwise slope, b_{ij}, and is computed as $b_{ij} = (X_i - X_j) / (i - j)$. Sen's slope estimator is then the median of the n(n-1)/2 pairwise slopes.

If there is no underlying trend, then a given X_i is as likely to be above another X_j as it is below. Hence, if there is no underlying trend, there would be an approximately equal number of positive and negative slopes, and thus the median would be near zero. Due to the number of calculations required, Sen's estimator is rarely calculated by hand and directions are not given in this document.

4.3.3.2 Seasonal Kendall Slope Estimator

If the data exhibit cyclic trends, then Sen's slope estimator can be modified to account for the cycles. For example, if data are available for each month for a number of years, 12 separate sets of slopes would be determined (one for each month of the year); similarly, if daily observations exhibit weekly cycles, seven sets of slopes would be determined, one for each day of the week. In these estimates, the above pairwise slope is calculated for each time period and the median of all of the slopes is an estimator of the slope for a long-term trend. This is known as the seasonal Kendall slope estimator. Because of the number of calculations required, this estimator is rarely calculated by hand.

4.3.4 Hypothesis Tests for Detecting Trends

Most of the trend tests treated in this section involve the Mann-Kendall test or extensions of it. The Mann-Kendall test does not assume any particular distributional form and accommodates trace values or values below the detection limit by assigning them a common value. The test can also be modified to deal with multiple observations per time period and generalized to deal with multiple sampling locations and seasonality.

4.3.4.1 One Observation per Time Period for One Sampling Location

The Mann-Kendall test involves computing a statistic S, which is the difference between the number of pairwise slopes (described in 4.3.3.1) that are positive minus the number that are negative. If S is a large positive value, then there is evidence of an increasing trend in the data. If S is a large negative value, then there is evidence of a decreasing trend in the data. The null hypothesis or baseline condition for this test is that there is no temporal trend in the data values, i.e., "H_0: no trend". The alternative condition or hypothesis will usually be either "H_A: upward trend" or "H_A: downward trend."

The basic Mann-Kendall trend test involves listing the observations in temporal order, and computing all differences that may be formed between measurements and earlier measurements, as depicted in Box 4-6. The test statistic is the difference between the number of strictly positive differences and the number of strictly negative differences. If there is an underlying upward trend, then these differences will tend to be positive and a sufficiently large value of the test statistic will suggest the presence of an upward trend. Differences of zero are not included in the test statistic (and should be avoided, if possible, by recording data to sufficient accuracy). The steps for conducting the Mann-Kendall test for small sample sizes (i.e., less than 10) are contained in Box 4-7 and an example is contained in Box 4-8.

Box 4-6: "Upper Triangular" Data for Basic Mann-Kendall Trend Test with a Single Measurement at Each Time Point

Data Table

Original Time Measurement	t_1 X_1	t_2 X_2	t_3 X_3	t_4 X_4	. . . . . .	t_{n-1} X_{n-1}	t_n X_n	(time from earliest to latest) (actual values recorded)
X_1		X_2-X_1	X_3-X_1	X_4-X_1	. . .	$X_{n-1}-X_1$	X_n-X_1	
X_2			X_3-X_2	X_4-X_2	. . .	$X_{n-1}-X_2$	X_n-X_2	
.						.	.	
.						.	.	
.						.	.	
X_{n-2}						$X_{n-1}-X_{n-2}$	X_n-X_{n-2}	
X_{n-1}							X_n-X_{n-1}	

After performing the subtractions this table converts to:

Original Time Measurement	t_1 X_1	t_2 X_2	t_3 X_3	t_4 X_4	. . . . . .	t_{n-1} X_{n-1}	t_n X_n	# of + Differences (>0)	# of - Differences (<0)
X_1		Y_{21}	Y_{31}	Y_{41}	. . .	$Y_{(n-1)1}$	Y_{n1}		
X_2			Y_{32}	Y_{42}	. . .	$Y_{(n-1)2}$	Y_{n2}		
.						.	.		
.						.	.		
.						.	.		
X_{n-2}						$Y_{(n-1)(n-2)}$	$Y_{n(n-2)}$		
X_{n-1}							$Y_{n\,(n-1)}$		
NOTE: $X_{ij}-Y_k=0$ do not contribute to either total and are discarded.								Total # >0	Total # <0

$$
\begin{aligned}
\text{where } Y_{ik} = \text{sign}(X_i - X_k) &= + \text{ if } X_i - X_k > 0\\
&= 0 \text{ if } X_i - X_k = 0\\
&= - \text{ if } X_i - X_k < 0
\end{aligned}
$$

Box 4-7: Directions for the Mann-Kendall Trend Test for Small Sample Sizes

If the sample size is less than 10 and there is only one datum per time period, the Mann-Kendall Trend Test for small sample sizes may be used.

STEP 1: List the data in the order collected over time: $X_1, X_2, ..., X_n$, where X_i is the datum at time t_i. Assign a value of DL/2 to values reported as below the detection limit (DL). Construct a "Data Matrix" similar to the top half of Box 4-6.

STEP 2: Compute the sign of all possible differences as shown in the bottom portion of Box 4-6.

STEP 3: Compute the Mann-Kendall statistic S, which is the number of positive signs minus the number of negative signs in the triangular table: S = (number of + signs) - (number of - signs).

STEP 4: Use Table A-11 of Appendix A to determine the probability p using the sample size n and the absolute value of the statistic S. For example, if n=5 and S=8, p=0.042.

STEP 5: For testing the null hypothesis of no trend against H_1 (upward trend), reject H_0 if $S > 0$ and if $p < \alpha$. For testing the null hypothesis of no trend against H_2 (downward trend), reject H_0 if $S < 0$ and if $p < \alpha$.

Box 4-8: An Example of Mann-Kendall Trend Test for Small Sample Sizes

Consider 5 measurements ordered by the time of their collection: 5, 6, 11, 8, and 10. This data will be used to test the null hypothesis, H_0: no trend, versus the alternative hypothesis H_1 of an upward trend at an $\alpha = 0.05$ significance level.

STEP 1: The data listed in order by time are: 5, 6, 11, 8, 10.

STEP 2: A triangular table (see Box 4-6) was used to construct the possible differences. The sum of signs of the differences across the rows are shown in the columns 7 and 8.

Time Data	1 5	2 6	3 11	4 8	5 10	No. of + Signs	No. of - Signs
5		+	+	+	+	4	0
6			+	+	+	3	0
11				-	-	0	2
8					+	1	0
						8	2

STEP 3: Using the table above, S = 8 - 2 = 6.

STEP 4: From Table A-11 of Appendix A for n = 5 and S = 6, p = 0.117.

STEP 5: Since $S > 0$ but $p = 0.117 \nless 0.05$, the null hypothesis is not rejected. Therefore, there is not enough evidence to conclude that there is an increasing trend in the data.

For sample sizes greater than 10, a normal approximation to the Mann-Kendall test is quite accurate. Directions for this approximation are contained in Box 4-9 and an example is given in Box 4-10. Tied observations (i.e., when two or more measurements are equal) degrade the statistical power and should be avoided, if possible, by recording the data to sufficient accuracy.

4.3.4.2 Multiple Observations per Time Period for One Sampling Location

Often, more than one sample is collected for each time period. There are two ways to deal with multiple observations per time period. One method is to compute a summary statistic, such as the median, for each time period and to apply one of the Mann-Kendall trend tests of Section 4.3.4.1 to the summary statistic. Therefore, instead of using the individual data points in the triangular table, the summary statistic would be used. Then the steps given in Box 4-7 and Box 4-9 could be applied to the summary statistics.

An alternative approach is to consider all the multiple observations within a given time period as being essentially equal (i.e., tied) values within that period. The S statistic is computed as before with n being the total of all observations. The variance of the S statistic (previously calculated in step 2) is changed to:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} w_p(w_p-1)(2w_p+5) - \sum_{q=1}^{h} u_q(u_q-1)(2u_q+5)\right]$$

$$+ \frac{\sum_{p=1}^{g} w_p(w_p-1)(w_p-2)\sum_{q=1}^{h} u_q(u_q-1)(u_q-2)}{9n(n-1)(n-2)} + \frac{\sum_{p=1}^{g} w_p(w_p-1)\sum_{q=1}^{h} u_q(u_q-1)}{2n(n-1)}$$

Box 4-9: Directions for the Mann-Kendall Procedure Using Normal Approximation

If the sample size is 10 or more, a normal approximation to the Mann-Kendall procedure may be used.

STEP 1: Complete steps 1, 2, and 3 of Box 4-7.

STEP 2: Calculate the variance of S: $V(S) = \frac{n(n-1)(2n+5)}{18}$.

If ties occur, let g represent the number of tied groups and w_p represent the number of data points in the p^{th} group. The variance of S is: $V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} w_p(w_p-1)(2w_p+5)\right]$

STEP 4: Calculate $Z = \frac{S-1}{[V(S)]^{1/2}}$ if S > 0, Z = 0 if S = 0, or $Z = \frac{S+1}{[V(S)]^{1/2}}$ if S < 0.

STEP 5: Use Table A-1 of Appendix A to find the critical value $z_{1-\alpha}$ such that 100(1-α)% of the normal distribution is below $z_{1-\alpha}$. For example, if α=0.05 then $z_{1-\alpha}$=1.645.

STEP 6: For testing the hypothesis, H_0 (no trend) against 1) H_1 (an upward trend) – reject H_0 if $Z > z_{1-\alpha}$, or 2) H_2 (a downward trend) – reject H_0 if Z < 0 and the absolute value of $Z > z_{1-\alpha}$.

Box 4-10: An Example of Mann-Kendall Trend Test by Normal Approximation

A test for an upward trend with α=.05 will be based on the 11 weekly measurements shown below.

STEP 1: Using Box 4-6, a triangular table was constructed of the possible differences. A zero has been used if the difference is zero, a "+" sign if the difference is positive, and a "-" sign if the difference is negative.

Week	1	2	3	4	5	6	7	8	9	10	11	No. of	No. of
Data	10	10	10	5	10	20	18	17	15	24	15	+ Signs	- Signs
10		0	0	-	0	+	+	+	+	+	+	6	1
10			0	-	0	+	+	+	+	+	+	6	1
10				-	0	+	+	+	+	+	+	6	1
5					+	+	+	+	+	+	+	7	0
10						+	+	+	+	+	+	6	0
20							-	-	-	+	-	1	4
18								-	-	+	-	1	3
17									-	+	-	1	2
15										+	0	1	0
24											-	0	1
												35	13

STEP 2: S = (sum of + signs) - (sum of - signs) = 35 - 13 = 22

STEP 3: There are several observations tied at 10 and 15. Thus, the formula for tied values will be used. In this formula, g=2, t_1=4 for tied values of 10, and t_2=2 for tied values of 15.

$$V(S) = \frac{1}{18}\left[11(11-1)(2(11)+5) - [4(4-1)(2(4)+5) + 2(2-1)(2(2)+5)]\right] = 155.33$$

STEP 4: Since S is positive: $Z = \frac{S-1}{[V(S)]^{1/2}} = \frac{22-1}{(155.33)^{1/2}} = \frac{20}{12.46} = 1.605$

STEP 5: From Table A-1 of Appendix A, $z_{1-.05}$=1.645.

STEP 6: H_1 is the alternative of interest. Therefore, since 1.605 is not greater than 1.645, H_0 is not rejected. Therefore, there is not enough evidence to determine that there is an upward trend.

where g represents the number of tied groups, w_p represents the number of data points in the p^{th} group, h is the number of time periods which contain multiple data, and u_q is the sample size in the q^{th} time period.

The preceding variance formula assumes that the data are not correlated. If correlation within single time periods is suspected, it is preferable to use a summary statistic (e.g., the median) for each time period and then apply either Box 4-7 or Box 4-9 to the summary statistics.

4.3.4.3 Multiple Sampling Locations with Multiple Observations

The preceding methods involve a single sampling location (station). However, environmental data often consist of sets of data collected at several sampling locations (see Box 4-11). For example, data are often systematically collected at several fixed sites on a lake or river, or within a region or basin. The data collection plan (or experimental design) must be systematic in the sense that approximately the same sampling times should be used at all locations.

In this situation, it is desirable to express the results by an overall regional summary statement across all sampling locations. However, there must be consistency in behavioral characteristics across sites over time in order for a single summary statement to be valid across all sampling locations. A useful plot to assess the consistency requirement is a single time plot (Section 2.3.8.1) of the measurements from all stations where a different symbol is used to represent each station.

Box 4-11: Data for Multiple Times and Multiple Stations

Let i = 1, 2, ..., n represent time, k = 1, 2, ..., K represent sampling locations, and X_{ik} represent the measurement at time i for location k. This data can be summarized in matrix form, as shown below.

		Stations			
		1	2	. . .	K
Time	1	X_{11}	X_{12}	. . .	X_{1K}
	2	X_{21}	X_{22}	. . .	X_{2K}
	.	.	.	. . .	.
	.	.	.	. . .	.
	.	.	.	. . .	.
	n	X_{n1}	X_{n2}	. . .	X_{nK}
		S_1	S_2	. . .	S_K
		$V(S_1)$	$V(S_2)$	. . .	$V(S_K)$
		Z_1	Z_2	. . .	Z_K

where S_k = Mann-Kendall statistic for station k (see STEP 3, Box 4-7),
$V(S_k)$ = variance for S statistic for station k (see STEP 2, Box 4-9), and
$Z_k = S_k/\sqrt{VAR(S_k)}$

If the stations exhibit approximately steady trends in the same direction (upward or downward), with comparable slopes, then a single summary statement across stations is valid and this implies two relevant sets of hypotheses should be investigated:

Comparability of stations. H_0: Similar dynamics affect all K stations vs. H_A: At least two stations exhibit different dynamics.

Testing for overall monotonic trend. H_0*: Contaminant levels do not change over time vs. H_A': There is an increasing (or decreasing) trend consistently exhibited across all stations.

Therefore, the analyst must first test for homogeneity of stations, and then, if homogeneity is confirmed, test for an overall monotonic trend.

Ideally, the stations in Box 4-11 should have equal numbers. However, the numbers of observations at the stations can differ slightly, because of isolated missing values, but the overall time periods spanned must be similar. This guidance recommends that for less than 3 time periods, an equal number of observations (a balanced design) is required. For 4 or more time periods, up to 1 missing value per sampling location may be tolerated.

a. One Observation per Time Period. When only one measurement is taken for each time period for each station, a generalization of the Mann-Kendall statistic can be used to test the above hypotheses. This procedure is described in Box 4-12.

Box 4-12: Testing for Comparability of Stations and an Overall Monotonic Trend

Let i = 1, 2, ..., n represent time, k = 1, 2, ..., K represent sampling locations, and X_{ik} represent the measurement at time i for location k. Let α represent the significance level for testing homogeneity and α* represent the significance level for testing for an overall trend.

STEP 1: Calculate the Mann-Kendall statistic S_k and its variance $V(S_k)$ for each of the K stations using the methods of Section 4.3.4.1, Box 4-9.

STEP 2: For each of the K stations, calculate $Z_k = S_k / \sqrt{V(S_k)}$.

STEP 3: Calculate the average $\bar{Z} = \sum_{k=1}^{K} Z_k / K$.

STEP 4: Calculate the homogeneity chi-square statistic $\chi_h^2 = \sum_{k=1}^{K} Z_k^2 - K\,\bar{Z}^2$.

STEP 5: Using a chi-squared table (Table A-8 of Appendix A), find the critical value for χ^2 with (K-1) degrees of freedom at an α significance level. For example, for a significance level of 5% and 5 degrees of freedom, $\chi^2_{(5)} = 11.07$, i.e., 11.07 is the cut point which puts 5% of the probability in the upper tail of a chi-square variable with 5 degrees of freedom.

STEP 6: If $\chi^2_h \le \chi^2_{(K-1)}$, there are comparable dynamics across stations at significance level α. Go to Step 7.

If $\chi^2_h > \chi^2_{(K-1)}$, the stations are not homogeneous (i.e., different dynamics at different stations) at the significance level α. Therefore, individual α*-level Mann-Kendall tests should be conducted at each station using the methods presented in Section 4.3.4.1.

STEP 7: Using a chi-squared table (Table A-8 of Appendix A), find the critical value for χ^2 with 1 degree of freedom at an α significance level. If

$$K\,\bar{Z}^2 > \chi^2_{(1)},$$

then reject H_0* and conclude that there is a significant (upward or downward) monotonic trend across all stations at significance level α*. The signs of the S_k indicate whether increasing or decreasing trends are present. If

$$K\,\bar{Z}^2 \le \chi^2_{(1)},$$

there is not significant evidence at the α' level of a monotonic trend across all stations. That is, the stations appear approximately stable over time.

b. Multiple Observations per Time Period. If multiple measurements are taken at some times and station, then the previous approaches are still applicable. However, the variance of the statistic S_k must be calculated using the equation for calculating V(S) given in Section 4.3.4.2. Note that S_k is computed for each station, so n, w_p, g, h, and u_q are all station-specific.

4.3.4.4 One Observation for One Station with Multiple Seasons

Temporal data are often collected over extended periods of time. Within the time variable, data may exhibit periodic cycles, which are patterns in the data that repeat over time (e.g., the data may rise and fall regularly over the months in a year or the hours in a day). For example, temperature and humidity may change with the season or month, and may affect environmental measurements. (For more information on seasonal cycles, see Section 2.3.8). In the following discussion, the term season represents one time point in the periodic cycle, such as a month within a year or an hour within a day.

If seasonal cycles are anticipated, then two approaches for testing for trends are the seasonal Kendall test and Sen's test for trends. The seasonal Kendall test may be used for large sample sizes, and Sen's test for trends may be used for small sample sizes. If different seasons manifest similar slopes (rates of change) but possibly different intercepts, then the Mann-Kendall technique of Section 4.3.4.3 is applicable, replacing time by year and replacing station by season.

The seasonal Kendall test, which is an extension of the Mann-Kendall test, involves calculating the Mann-Kendall test statistic, S, and its variance separately for each "season" (e.g., month of the year, day of the week). The sum of the S's and the sum of their variances are then used to form an overall test statistic that is assumed to be approximately normally distributed for larger size samples.

For data at a single site, collected at multiple seasons within multiple years, the techniques of Section 4.3.4.3 can be applied to test for homogeneity of time trends across seasons. The methodology follows Boxes 4-11 and 4-12 exactly except that "station" is replaced by "season" and the inferences refer to seasons.

4.3.5 A Discussion on Tests for Trends

This section discusses some further considerations for choosing among the many tests for trends. All of the nonparametric trend tests and estimates use ordinal time (ranks) rather than cardinal time (actual time values, such as month, day or hour) and this restricts the interpretation of measured trends. All of the Mann-Kendall Trend Tests presented are based on certain pairwise differences in measurements at different time points. The only information about these differences that is used in the Mann-Kendall calculations is their signs (i.e., whether they are positive or negative) and therefore are generalizations of the sign test. Mann-Kendall calculations are relatively easy and simply involve counting the number of cases in which X_{i+j} exceeds X_i and the number of cases in which X_i exceeds X_{i+j}. Information about magnitudes of these differences is not used by the Mann-Kendall methods and this can adversely affect the statistical power when only limited amounts of data are available.

There are, however, nonparametric methods based on ranks that takes such magnitudes into account and still retains the benefit of robustness to outliers. These procedures can be thought of as replacing the data by their ranks and then conducting parametric analyses. These include the Wilcoxon rank sum test and its many generalizations. These methods are more resistant to outliers than parametric methods; a point can be no more extreme than the smallest or largest value.

Rank-based methods, which make fuller use of the information in the data than the Mann-Kendall methods, are not as robust with respect to outliers as the sign and the Mann-Kendall tests. They are, however, more statistically powerful than the sign test and the Mann-Kendall methods; the Wilcoxon test being a case in point. If the data are random samples from normal distributions with equal variances, then the sign test requires approximately 1.225 times as many observations as the Wilcoxon rank sum test to achieve a given power at a given significance level. This kind of tradeoff between power and robustness exemplifies the analyst's evaluation process leading to the selection of the best statistical procedure for the current situation. Further statistical tests will be developed in future editions of this guidance.

4.3.6 Testing for Trends in Sequences of Data

There are cases where it is desirable to see if a long sequence (for example, readings from a monitoring station) could be considered random variation or correlated in some way, that is, if consecutive results are attributable to random chance. An everyday example would be to determine if a basketball player exhibited "hot streaks" during the season when shooting a basket from the free-throw line. One test to make this determination is the Wald-Wolfowitz test. This test can only be used if the data are binary, i.e., there are only two potential values. For example, the data could either be 'Yes/No', '0/1', or 'black/white'. Directions for the Wald-Wofowitz test are given in Box 4-13 and an example in Box 4-14.

4.4 OUTLIERS

4.4.1 Background

Outliers are measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected. Outliers may result from transcription errors, data-coding errors, or measurement system problems such as instrument breakdown. However, outliers may also represent true extreme values of a distribution (for instance, hot spots) and indicate more variability in the population than was expected. Not removing true outliers and removing false outliers both lead to a distortion of estimates of population parameters.

Statistical outlier tests give the analyst probabilistic evidence that an extreme value (potential outlier) does not "fit" with the distribution of the remainder of the data and is therefore a statistical outlier. These tests should only be used to *identify* data points that require further investigation. The

Box 4-13: Directions for the Wald-Wolfowitz Runs Test

Consider a sequence of two values and let n denote the number of observations of one value and m denote the number of observations of the other value. Note that if is customary for $n < m$ (i.e., n denotes the value that occurs the least amount of times. This test is used to test the null hypothesis that the sequence is random against the alternative hypothesis that the data in the sequence are correlated or may come from different populations.

STEP 1: List the data in the order collected and identify which will be the 'n' values, and which will be the 'm' values.

STEP 2: Bracket the sequences within the series. A sequence is a group of consecutive values. For example, consider the data AAABAABBBBBBBABB. The following are sequences in the data

{AAA} {B} {AA} {BBBBBB} {A} {BB}

In the example above, the smallest sequence is has one data value and the largest sequence has 6.

STEP 3: Count the number of sequences for the 'n' values and call it T. For the example sequence, the 'n' values are 'A' since there are 6 A's and 9 B's, and T = 3: {AAA}, {AA}, and {A}.

STEP 4: If T is less than the critical value from Table A-12 of Appendix A for the specified significance level α, then reject the null hypothesis that the sequence is random in favor of the alternative that the data are correlated amongst themselves or possibly came from different distributions. Otherwise, conclude the sequence is random. In the example above, $3 < 6$ (where 6 is the critical value from Table A-12 using $n=6$, $m=9$, and $\alpha = 0.01$) so the null hypothesis that the sequence is random is rejected.

tests alone cannot determine whether a statistical outlier should be discarded or corrected within a data set; this decision should be based on judgmental or scientific grounds.

There are 5 steps involved in treating extreme values or outliers:

1. Identify extreme values that may be potential outliers;
2. Apply statistical test;
3. Scientifically review statistical outliers and decide on their disposition;
4. Conduct data analyses with and without statistical outliers; and
5. Document the entire process.

Potential outliers may be identified through the graphical representations of Chapter 2 (step 1 above). Graphs such as the box and whisker plot, ranked data plot, normal probability plot, and time plot can all be used to identify observations that are much larger or smaller than the rest of the data. If potential outliers are identified, the next step is to apply one of the statistical tests described in the following sections. Section 4.4.2 provides recommendations on selecting a statistical test for outliers.

Box 4-14: An Example of the Wald-Wolfowitz Runs Test

This is a set of monitoring data from the main discharge station at a chemical manufacturing plant. The permit states that the discharge should have a pH of 7.0 and should never be less than 5.0. So the plant manager has decided to use a pH of 6.0 to an indicate potential problems. In a four-week period the following values were recorded:

6.5	6.6	6.4	6.2	5.9	5.8	5.9	6.2	6.2	6.3	6.6	6.6	6.7	6.4
6.2	6.3	6.2	5.8	5.9	5.8	6.1	5.9	6.0	6.2	6.3	6.2		

STEP 1: Since the plant manager has decided that a pH of 6.0 will indicate trouble the data have been replaced with a binary indicator. If the value is greater than 6.0, the value will be replaced by a 1; otherwise the value will be replaced by a 0. So the data are now:

1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 1 0 0 1 1 1

As there are 8 values of '0'and 19 values of '1', n = 8 and m = 19.

STEP 2: The bracketed sequence is: {1 1 1 1} {0 0 0} {1 1 1 1 1 1 1 1 1 1} {0 0 0} {1} {0 0 } {1 1 1}

STEP 3: T = 3: {000}, {000}, and {00}

STEP 4: Since 3 < 9 (where 9 is the critical value from Table A-12 using $\alpha = 0.05$) so the null hypothesis that the sequence is random is rejected.

If a data point is found to be an outlier, the analyst may either: 1) correct the data point; 2) discard the data point from analysis; or 3) use the data point in all analyses. This decision should be based on scientific reasoning *in addition to* the results of the statistical test. For instance, data points containing transcription errors should be corrected, whereas data points collected while an instrument was malfunctioning may be discarded. One should never discard an outlier based solely on a statistical test. Instead, the decision to discard an outlier should be based on some scientific or quality assurance basis. Discarding an outlier from a data set should be done with extreme caution, particularly for environmental data sets, which often contain legitimate extreme values. If an outlier is discarded from the data set, all statistical analysis of the data should be applied to both the full and truncated data set so that the effect of discarding observations may be assessed. If scientific reasoning does not explain the outlier, it should not be discarded from the data set.

If any data points are found to be statistical outliers through the use of a statistical test, this information will need to be documented along with the analysis of the data set, regardless of whether any data points are discarded. If no data points are discarded, document the identification of any "statistical" outliers by documenting the statistical test performed and the possible scientific reasons investigated. If any data points are discarded, document each data point, the statistical test performed, the scientific reason for discarding each data point, and the effect on the analysis of deleting the data points. This information is critical for effective peer review.

4.4.2 Selection of a Statistical Test

There are several statistical tests for determining whether or not one or more observations are statistical outliers. Step by step directions for implementing some of these tests are described in Sections 4.4.3 through 4.4.6. Section 4.4.7 describes statistical tests for multivariate outliers.

If the data are normally distributed, this guidance recommends Rosner's test when the sample size is greater than 25 and the Extreme Value test when the sample size is less than 25. If only one outlier is suspected, then the Discordance test may be substituted for either of these tests. If the data are not normally distributed, or if the data cannot be transformed so that the transformed data are normally distributed, then the analyst should either apply a nonparametric test (such as Walsh's test) or consult a statistician. A summary of this information is contained in Table 4-3.

Table 4-3. Recommendations for Selecting a Statistical Test for Outliers

Sample Size	Test	Section	Assumes Normality	Multiple Outliers
n ≤ 25	**Extreme Value Test**	**4.4.3**	**Yes**	**No/Yes**
n ≤ 50	**Discordance Test**	**4.4.4**	**Yes**	**No**
n ≥ 25	**Rosner's Test**	**4.4.5**	**Yes**	**Yes**
n ≥ 50	**Walsh's Test**	**4.4.6**	**No**	**Yes**

4.4.3 Extreme Value Test (Dixon's Test)

Dixon's Extreme Value test can be used to test for statistical outliers when the sample size is less than or equal to 25. This test considers both extreme values that are much smaller than the rest of the data (case 1) and extreme values that are much larger than the rest of the data (case 2). This test assumes that the data without the suspected outlier are normally distributed; therefore, it is necessary to perform a test for normality on the data without the suspected outlier before applying this test. If the data are not normally distributed, either transform the data, apply a different test, or consult a statistician. Directions for the Extreme Value test are contained in Box 4-15; an example of this test is contained in Box 4-16.

This guidance recommends using this test when only one outlier is suspected in the data. If more than one outlier is suspected, the Extreme Value test may lead to masking where two or more outliers close in value "hide" one another. Therefore, if the analyst decides to use the Extreme Value test for multiple outliers, apply the test to the least extreme value first.

Box 4-15: Directions for the Extreme Value Test (Dixon's Test)

STEP 1: Let $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$ represent the data ordered from smallest to largest. Check that the data without the suspect outlier are normally distributed, using one of the methods of Section 4.2. If normality fails, either transform the data or apply a different outlier test.

STEP 2: $X_{(1)}$ is a Potential Outlier (case 1): Compute the test statistic C, where

$$C = \frac{X_{(2)} - X_{(1)}}{X_{(n)} - X_{(1)}} \text{ for } 3 \le n \le 7, \quad C = \frac{X_{(3)} - X_{(1)}}{X_{(n-1)} - X_{(1)}} \text{ for } 11 \le n \le 13,$$

$$C = \frac{X_{(2)} - X_{(1)}}{X_{(n-1)} - X_{(1)}} \text{ for } 8 \le n \le 10, \quad C = \frac{X_{(3)} - X_{(1)}}{X_{(n-2)} - X_{(1)}} \text{ for } 14 \le n \le 25.$$

STEP 3: If C exceeds the critical value from Table A-3 of Appendix A for the specified significance level α, $X_{(1)}$ is an outlier and should be further investigated.

STEP 4: $X_{(n)}$ is a Potential Outlier (case 2): Compute the test statistic C, where

$$C = \frac{X_{(n)} - X_{(n-1)}}{X_{(n)} - X_{(1)}} \text{ for } 3 \le n \le 7, \quad C = \frac{X_{(n)} - X_{(n-2)}}{X_{(n)} - X_{(2)}} \text{ for } 11 \le n \le 13,$$

$$C = \frac{X_{(n)} - X_{(n-1)}}{X_{(n)} - X_{(2)}} \text{ for } 8 \le n \le 10, \quad C = \frac{X_{(n)} - X_{(n-2)}}{X_{(n)} - X_{(3)}} \text{ for } 14 \le n \le 25$$

STEP 5: If C exceeds the critical value from Table A-3 of Appendix A for the specified significance level α, $X_{(n)}$ is an outlier and should be further investigated.

Box 4-16: An Example of the Extreme Value Test (Dixon's Test)

The data in order of magnitude from smallest to largest are: 82.39, 86.62, 91.72, 98.37, 103.46, 104.93, 105.52, 108.21, 113.23, and 150.55 ppm. Because the largest value (150.55) is much larger than the other values, it is suspected that this data point might be an outlier which is Case 2 in Box 4-15.

STEP 1: A normal probability plot of the data shows that there is no reason to suspect that the data (without the extreme value) are not normally distributed. The studentized range test (Section 4.2.6) also shows that there is no reason to suspect that the data are not normally distributed. Therefore, the Extreme Value test may be used to determine if the largest data value is an outlier.

STEP 4: $$C = \frac{X_{(n)} - X_{(n-1)}}{X_{(n)} - X_{(2)}} = \frac{150.55 - 113.23}{150.55 - 86.62} = \frac{37.32}{63.93} = 0.584$$

STEP 5: Since C = 0.584 > 0.477 (from Table A-3 of Appendix A with n=10), there is evidence that $X_{(n)}$ is an outlier at a 5% significance level and should be further investigated.

4.4.4 Discordance Test

The Discordance test can be used to test if one extreme value is an outlier. This test considers two cases: 1) where the extreme value (potential outlier) is the smallest value of the data set, and 2) where the extreme value (potential outlier) is the largest value of the data set. The Discordance test assumes that the data are normally distributed; therefore, it is necessary to perform a test for normality before applying this test. If the data are not normally distributed either transform the data, apply a different test, or consult a statistician. Note that the test assumes that the data without the outlier are normally distributed; therefore, the test for normality should be performed without the suspected outlier. Directions and an example of the Discordance test are contained in Box 4-17 and Box 4-18.

Box 4-17: Directions for the Discordance Test

STEP 1: Let $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$ represent the data ordered from smallest to largest. Check that the data without the suspect outlier are normally distributed, using one of the methods of Section 4.2. If normality fails, either transform the data or apply a different outlier test.

STEP 2: Compute the sample mean, $\bar{x}$ (Section 2.2.2), and the sample standard deviation, s (Section 2.2.3). If the minimum value $X_{(1)}$ is a suspected outlier, perform Steps 3 and 4. If the maximum value $X_{(n)}$ is a suspected outlier, perform Steps 5 and 6.

STEP 3: <u>If $X_{(1)}$ is a Potential Outlier (case 1)</u>: Compute the test statistic $D = \frac{\bar{X} - X_{(1)}}{s}$

STEP 4: If D exceeds the critical value from Table A-4, $X_{(1)}$ is an outlier and should be further investigated.

STEP 5: <u>If $X_{(n)}$ is a Potential Outlier (case 2)</u>: Compute the test statistic $D = \frac{X_{(n)} - \bar{X}}{s}$

STEP 6: If D exceeds the critical value from Table A-4, $X_{(n)}$ is an outlier and should be further investigated.

Box 4-18: An Example of the Discordance Test

The ordered data are 82.39, 86.62, 91.72, 98.37, 103.46, 104.93, 105.52, 108.21, 113.23, and 150.55 ppm. Because the largest value of this data set (150.55) is much larger than the rest, it may be an outlier.

STEP 1: A normal probability plot of the data shows that there is no reason to suspect that the data (without the extreme value) are not normally distributed. The studentized range test (Section 4.2.6) also shows that there is no reason to suspect that the data are not normally distributed. Therefore, the Discordance test may be used to determine if the largest data value is an outlier.

STEP 2: $\bar{x}$ = 104.5 ppm and s = 18.922 ppm.

STEP 5: $D = \frac{X_{(n)} - \bar{X}}{s} = \frac{150.55 - 104.50}{18.92} = 2.43$

STEP 6: Since D = 2.43 > 2.176 (from Table A-4 of Appendix A with n = 10), there is evidence that $X_{(n)}$ is an outlier at a 5% significance level and should be further investigated.

4.4.5 Rosner's Test

A parametric test developed by Rosner can be used to detect up to 10 outliers for sample sizes of 25 or more. This test assumes that the data are normally distributed; therefore, it is necessary to perform a test for normality before applying this test. If the data are not normally distributed either transform the data, apply a different test, or consult a statistician. Note that the test assumes that the data without the outlier are normally distributed; therefore, the test for normality may be performed without the suspected outlier. Directions for Rosner's test are contained in Box 4-19 and an example is contained in Box 4-20.

Rosner's test is not as easy to apply as the preceding tests. To apply Rosner's test, first determine an upper limit r_0 on the number of outliers ($r_0 \le 10$), then order the r_0 extreme values from most extreme to least extreme. Rosner's test statistic is then based on the sample mean and sample

Box 4-19: Directions for Rosner's Test for Outliers

STEP 1: Let $X_1, X_2, \ldots, X_n$ represent the ordered data points. By inspection, identify the maximum number of possible outliers, r_0. Check that the data are normally distributed, using one of the methods of Section 4.2.

STEP 2: Compute the sample mean $\bar{x}$, and the sample standard deviation, s, for <u>all</u> the data. Label these values $\bar{x}^{(0)}$ and $s^{(0)}$, respectively. Determine the observation farthest from $\bar{x}^{(0)}$ and label this observation $y^{(0)}$. Delete $y^{(0)}$ from the data and compute the sample mean, labeled $\bar{x}^{(1)}$, and the sample standard deviation, labeled $s^{(1)}$. Then determine the observation farthest from $\bar{x}^{(1)}$ and label this observation $y^{(1)}$. Delete $y^{(1)}$ and compute $\bar{x}^{(2)}$ and $s^{(2)}$. Continue this process until r_0 extreme values have been eliminated.

In summary, after the above process the analyst should have

$$[\bar{X}^{(0)},\ s^{(0)},\ y^{(0)}];\ [\bar{X}^{(1)},\ s^{(1)},\ y^{(1)}];\ \ldots,\ [\bar{X}^{(r_0-1)},\ s^{(r_0-1)},\ y^{(r_0-1)}] \quad \text{where}$$

$$\bar{X}^{(i)} = \frac{1}{n-i}\sum_{j=1}^{n-i} x_j, \quad s^{(i)} = [\frac{1}{n-i}\sum_{j=1}^{n-i}(x_j - \bar{x}^{(i)})^2]^{1/2},$$ and $y^{(i)}$ is the farthest value from $\bar{x}^{(i)}$.

(Note, the above formulas for $\bar{x}^{(i)}$ and $s^{(i)}$ assume that the data have been renumbered after each observation is deleted.)

STEP 3: To test if there are 'r' outliers in the data, compute: $R_r = \frac{|y^{(r-1)} - \bar{x}^{(r-1)}|}{s^{(r-1)}}$ and compare R_r to λ_r in Table A-5 of Appendix A. If $R_r \ge \lambda_r$, conclude that there are r outliers.

First, test if there are r_0 outliers (compare $R_{r_{o-1}}$ to $\lambda_{r_{o-1}}$). If not, test if there are r_0 - 1 outliers (compare $R_{r_{o-1}}$ to $\lambda_{r_{o-1}}$). If not, test if there are r_0 - 2 outliers, and continue, until either it is determined that there are a certain number of outliers or that there are no outliers at all.

Box 4-20: An Example of Rosner's Test for Outliers

STEP 1: Consider the following 32 data points (in ppm) listed in order from smallest to largest: 2.07, 40.55, 84.15, 88.41, 98.84, 100.54, 115.37, 121.19, 122.08, 125.84, 129.47, 131.90, 149.06, 163.89, 166.77, 171.91, 178.23, 181.64, 185.47, 187.64, 193.73, 199.74, 209.43, 213.29, 223.14, 225.12, 232.72, 233.21, 239.97, 251.12, 275.36, and 395.67.

A normal probability plot of the data shows that there is no reason to suspect that the data (without the suspect outliers) are not normally distributed. In addition, this graph identified four potential outliers: 2.07, 40.55, 275.36, and 395.67. Therefore, Rosner's test will be applied to see if there are 4 or fewer (r_0 = 4) outliers.

STEP 2: First the sample mean and sample standard deviation were computed for the entire data set ($\bar{x}^{(0)}$ and $s^{(0)}$). Using subtraction, it was found that 395.67 was the farthest data point from $\bar{x}^{(0)}$, so $y^{(0)}$ = 395.67. Then 395.67 was deleted from the data and the sample mean, $\bar{x}^{(1)}$, and the sample standard deviation, $s^{(1)}$, were computed. Using subtraction, it was found that 2.07 was the farthest value from $\bar{x}^{(1)}$. This value was then dropped from the data and the process was repeated again on 40.55 to yield $\bar{x}^{(2)}$, $s^{(2)}$, and $y^{(2)}$ and $\bar{x}^{(3)}$, $s^{(3)}$, and $y^{(3)}$. These values are summarized below.

i	$\bar{x}^{(i)}$	$s^{(i)}$	$y^{(i)}$
0	169.923	75.133	395.67
1	162.640	63.872	2.07
2	167.993	57.460	40.55
3	172.387	53.099	275.36

STEP 3: To apply Rosner's test, it is first necessary to test if there are 4 outliers by computing

$$R_4 = \frac{|y^{(3)} - \bar{x}^{(3)}|}{s^{(3)}} = \frac{|275.36 - 172.387|}{53.099} = 1.939$$

and comparing R_4 to λ_4 in Table A-5 of Appendix A with n = 32. Since $R_4 = 1.939 \ngtr \lambda_4 = 2.89$, there are not 4 outliers in the data set. Therefore, it will next be tested if there are 3 outliers by computing

$$R_3 = \frac{|y^{(2)} - \bar{x}^{(2)}|}{s^{(2)}} = \frac{|40.55 - 167.993|}{57.460} = 2.218$$

and comparing R_3 to λ_3 in Table A-5 with n = 32. Since $R_3 = 2.218 \ngtr \lambda_3 = 2.91$, there are not 3 outliers in the data set. Therefore, it will next be tested if there are 2 outliers by computing

$$R_2 = \frac{|y^{(1)} - \bar{x}^{(1)}|}{s^{(1)}} = \frac{|2.07 - 162.640|}{63.872} = 2.514$$

and comparing R_2 to λ_2 in Table A-5 with n = 32. Since $R_2 = 2.514 \ngtr \lambda_3 = 2.92$, there are not 2 outliers in the data set. Therefore, it will next be tested if there is 1 outlier by computing

$$R_1 = \frac{|y^{(0)} - \bar{x}^{(0)}|}{s^{(0)}} = \frac{|395.67 - 169.923|}{75.133} = 3.005$$

and comparing R_1 to λ_1 in Table A-5 with n = 32. Since $R_1 = 3.005 > \lambda_1 = 2.94$, there is evidence at a 5% significance level that there is 1outlier in the data set. Therefore, observation 355.67 is a statistical outlier and should be further investigated.

standard deviation computed without the $r = r_0$ extreme values. If this test statistic is greater than the critical value given in Table A-5 of Appendix A, there are r_0 outliers. Otherwise, the test is performed again without the $r = r_0 - 1$ extreme values. This process is repeated until either Rosner's test statistic is greater than the critical value or $r = 0$.

4.4.6 Walsh's Test

A nonparametric test was developed by Walsh to detect multiple outliers in a data set. This test requires a large sample size: $n > 220$ for a significance level of $\alpha = 0.05$, and $n > 60$ for a significance level of $\alpha = 0.10$. However, since the test is a nonparametric test, it may be used whenever the data are not normally distributed. Directions for the test by Walsh for large sample sizes are given in Box 4-21.

Box 4-21: Directions for Walsh's Test for Large Sample Sizes

Let $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$ represent the data ordered from smallest to largest. If $n \le 60$, do not apply this test. If $60 < n \le 220$, then $\alpha = 0.10$. If $n > 220$, then $\alpha = 0.05$.

STEP 1: Identify the number of possible outliers, r. Note that r can equal 1.

STEP 2: Compute $c = [\sqrt{2n}],\ k = r + c,\ b^2 = 1/\alpha,\ and\ \ a = \dfrac{1 + b\sqrt{(c - b^2)/(c-1)}}{c - b^2 - 1}$.

where [ ] indicates rounding the value to the largest possible integer (i.e., 3.24 becomes 4).

STEP 3: The r smallest points are outliers (with a α% level of significance) if

$$x_{(r)} - (1 + a)x_{(r+1)} + a x_{(k)} < 0$$

STEP 4: The r largest points are outliers (with a α% level of significance) if

$$x_{(n+1-r)} - (1 + a)x_{(n-r)} + a x_{(n+1-k)} > 0$$

STEP 5: If both of the inequalities are true, then both small and large outliers are indicated.

4.4.7 Multivariate Outliers

Multivariate analysis, such as factor analysis and principal components analysis, involves the analysis of several variables simultaneously. Outliers in multivariate analysis are then values that are extreme in relationship to either one or more variables. As the number of variables increases, identifying potential outliers using graphical representations becomes more difficult. In addition, special procedures are required to test for multivariate outliers. Details of these procedures are beyond the scope of this guidance. However, procedures for testing for multivariate outliers are contained in statistical textbooks on multivariate analysis.

4.5 TESTS FOR DISPERSIONS

Many statistical tests make assumptions on the dispersion (as measured by variance) of data; this section considers some of the most commonly used statistical tests for variance assumptions. Section 4.5.1 contains the methodology for constructing a confidence interval for a single variance estimate from a sample. Section 4.5.2 deals with the equality of two variances, a key assumption for the validity of a two-sample t-test. Section 4.5.3 describes Bartlett's test and Section 4.5.4 describes Levene's test. These two tests verify the assumption that two or more variances are equal, a requirement for a standard two-sample t-test, for example. The analyst should be aware that many statistical tests only require the assumption of approximate equality and that many of these tests remain valid unless gross inequality in variances is determined.

4.5.1 Confidence Intervals for a Single Variance

This section discusses confidence intervals for a single variance or standard deviation for analysts interested in the precision of variance estimates. This information may be necessary for performing a sensitivity analysis of the statistical test or analysis method. The method described in Box 4-22 can be used to find a two-sided 100(1-α)% confidence interval. The upper end point of a two-sided 100(1-α)% confidence *interval* is a 100(1-α/2)% upper confidence *limit*, and the lower end point of a two-sided 100(1-α)% confidence *interval* is a 100(1-α/2)% lower confidence *limit*. For example, the upper end point of a 90% confidence interval is a 95% upper confidence limit and the lower end point is a 95% lower confidence limit. Since the standard deviation is the square root of the variance, a confidence interval for the variance can be converted to a confidence interval for the standard deviation by taking the square roots of the endpoints of the interval. This confidence interval assumes that the data constitute a random sample from a normally distributed population and can be highly sensitive to outliers and to departures from normality.

4.5.2 The F-Test for the Equality of Two Variances

An F-test may be used to test whether the true underlying variances of two populations are equal. Usually the F-test is employed as a preliminary test, before conducting the two-sample t-test for the equality of two means. The assumptions underlying the F-test are that the two samples are independent random samples from two underlying normal populations. The F-test for equality of variances is highly sensitive to departures from normality. Directions for implementing an F-test with an example are given in Box 4-23.

4.5.3 Bartlett's Test for the Equality of Two or More Variances

Bartlett's test is a means of testing whether two or more population variances of normal distributions are equal. In the case of only two variances, Bartlett's test is equivalent to the F-test. Often in practice unequal variances and non-normality occur together and Bartlett's test is itself sensitive

Box 4-22: Directions for Constructing Confidence Intervals and Confidence Limits for the Sample Variance and Standard Deviation with an Example

Directions: Let $X_1, X_2, \ldots, X_n$ represent the n data points.

STEP 1: Calculate the sample variance s^2 (Section 2.2.3).

STEP 2: For a 100(1-α)% two-sided confidence interval, use Table A-8 of Appendix A to find the cutoffs L and U such that $L = \chi^2_{\alpha/2}$ and $U = \chi^2_{(1-\alpha/2)}$ with (n-1) degrees of freedom (*dof)*.

STEP 3: A 100(1-α)% confidence interval for the true underlying variance is: $\frac{(n-1)s^2}{L}$ *to* $\frac{(n-1)s^2}{U}$.

A 100(1-α)% confidence interval for the true standard deviation is: $\sqrt{\frac{(n-1)s^2}{L}}$ *to* $\sqrt{\frac{(n-1)s^2}{U}}$.

Example: Ten samples were analyzed for lead: 46.4, 46.1, 45.8, 47, 46.1, 45.9, 45.8, 46.9, 45.2, 46 ppb.

STEP 1: Using Section 2.2.3, $s^2 = 0.286$.

STEP 2: Using Table A-8 of Appendix A and 9 *dof*, $L = \chi^2_{.05/2} = \chi^2_{.025} = 19.02$ and $U = \chi^2_{(1-.05/2)} = \chi^2_{.975} = 2.70$.

STEP 3: A 95% confidence interval for the variance is: $\frac{(10-1)0.286}{19.02}$ *to* $\frac{(10-1)0.286}{2.70}$ or 0.135 to 0.954.

A 95% confidence interval for the standard deviation is: $\sqrt{0.135} = .368$ *to* $\sqrt{0.954} = .977$.

Box 4-23: Directions for Calculating an F-Test to Compare Two Variances with an Example

Directions: Let $X_1, X_2, \ldots, X_m$ represent the m data points from population 1 and $Y_1, Y_2, \ldots, Y_n$ represent the n data points from population 2. To perform an F-test, proceed as follows.

STEP 1: Calculate the sample variances s_X^2 (for the X's) and s_Y^2 (for the Y's) (Section 2.2.3).

STEP 2: Calculate the variance ratios $F_X = s_X^2/s_Y^2$ and $F_Y = s_Y^2/s_X^2$. Let F equal the larger of these two values. If $F = F_x$, then let k = m - 1 and q = n - 1. If $F = F_y$, then let k = n -1 and q = m - 1.

STEP 3: Using Table A-9 of Appendix A of the F distribution, find the cutoff $U = f_{1-\alpha/2}(k, q)$. If F > U, conclude that the variances of the two populations are not the same.

Example: Manganese concentrations were collected from 2 wells. The data are Well X: 50, 73, 244, 202 ppm; and Well Y: 272, 171, 32, 250, 53 ppm. An F-test will be used to test if the variances are equal.

STEP 1: For Well X, $s_X^2 = 9076$. For Well Y, $s_Y^2 = 12125$.

STEP 2: $F_X = s_X^2/s_Y^2 = 9076 / 12125 = 0.749$. $F_Y = s_Y^2/s_X^2 = 12125 / 9076 = 1.336$. Since, $F_Y > F_X$, $F = F_Y = 1.336$, k = 5 -1 = 4 and q = 4 - 1 = 3.

STEP 3: Using Table A-9 of Appendix A of the F distribution with α = 0.05, $L = f_{1-.05/2}(4, 3) = 15.1$. Since 1.336 < 15.1, there is no evidence that the variability of the two wells is different.

to departures from normality. With long-tailed distributions, the test too often rejects equality (homogeneity) of the variances.

Bartlett's test requires the calculation of the variance for each sample, then calculation of a statistic associated with the logarithm of these variances. This statistic is compared to tables and if it exceeds the tabulated value, the conclusion is that the variances differ as a complete set. It does *not* mean that one is significantly different from the others, nor that one or more are larger (smaller) than the rest. It simply implies the variances are unequal as a group. Directions for Bartlett's test are given in Box 4-24 and an example is given in Box 4-25.

4.5.4 Levene's Test for the Equality of Two or More Variances

Levene's test provides an alternative to Bartlett's test for homogeneity of variance (testing for differences among the dispersions of several groups). Levene's test is less sensitive to departures from normality than Bartlett's test and has greater power than Bartlett's for non-normal data. In addition, Levene's test has power nearly as great as Bartlett's test for normally distributed data. However, Levene's test is more difficult to apply than Bartlett's test since it involves applying an analysis of variance (ANOVA) to the absolute deviations from the group means. Directions and an example of Levene's test are contained in Box 4-26 and Box 4-27, respectively.

Box 4-24: Directions for Bartlett's Test

Consider k groups with a sample size of n_i for each group. Let N represent the total number of samples, i.e., let $N = n_1 + n_2 + . . . + n_k$. For example, consider two wells where 4 samples have been taken from well 1 and 3 samples have been taken from well 2. In this case, k = 2, $n_1 = 4$, $n_2 = 3$, and N = 4 + 3 = 7.

STEP 1: For each of the k groups, calculate the sample variances, s_i^2 (Section 2.2.3).

STEP 2: Compute the pooled variance across groups: $s_p^2 = \frac{1}{(N-k)} \sum_{i=1}^{k} (n_i - 1) s_i^2$

STEP 3: Compute the test statistic: $TS = (N - k) \ln(s_p^2) - \sum_{i=1}^{k} (n_i - 1) \ln(s_i^2)$

where "ln" stands for natural logarithms.

STEP 4: Using a chi-squared table (Table A-8 of Appendix A), find the critical value for χ^2 with (k-1) degrees of freedom at a predetermined significance level. For example, for a significance level of 5% and 5 degrees of freedom, $\chi^2 = 11.1$. If the calculated value (*TS*) is greater than the tabulated value, conclude that the variances are not equal at that significance level.

Box 4-25: An Example of Bartlett's Test

Manganese concentrations were collected from 6 wells over a 4 month period. The data are shown in the following table. Before analyzing the data, it is important to determine if the variances of the six wells are equal. Bartlett's test will be used to make this determination.

STEP 1: For each of the 6 wells, the sample means and variances were calculated. These are shown in the bottom rows of the table below.

Sampling Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
January 1	50		272			
February 1	73		171			68
March 1	244	46	32	34	48	991
April 1	202	77	53	3940	54	54
n_i (N=17)	4	2	4	2	2	3
$\bar{x}_i$	142.25	61.50	132	1987	51.00	371.00
s_i^2	9076.37	480.49	12455	7628243	17.98	288348

STEP 2: $$s_p^2 = \frac{1}{(N-k)}\sum_{i=1}^{k}(n_i - 1)s_i^2 = \frac{1}{(17-6)}[(4-1)9076 + \ldots + (3-1)576696] = 751837.27$$

STEP 3:

$$TS = (17-6)\ \ln(751837.27) - [(4-1)\ln(9076) + \ldots + (3-1)\ln(288348)] = 43.16$$

STEP 4: The critical χ^2 value with 6 - 1 = 5 degrees of freedom at the 5% significance level is 11.1 (from Table A-8 of Appendix A). Since 43.16 is larger than 11.1, it is concluded that the six variances ($s_1^2, \ldots, s_6^2$) are not homogeneous at the 5% significance level.

Box 4-26: Directions for Levene's Test

Consider k groups with a sample size of n_i for the ith group. Let N represent the total number of samples, i.e., let $N = n_1 + n_2 + \ldots + n_k$. For example, consider two wells where 4 samples have been taken from well 1 and 3 samples have been taken from well 2. In this case, k = 2, $n_1 = 4$, $n_2 = 3$, and N = 4 + 3 = 7.

STEP 1: For each of the k groups, calculate the group mean, $\bar{x}_i$ (Section 2.2.2), i.e., calculate:

$$\bar{X}_1 = \frac{1}{n_1}\sum_{j=1}^{n_1} x_{1j}, \quad \bar{X}_2 = \frac{1}{n_2}\sum_{j=1}^{n_2} x_{2j}, \quad \ldots, \quad \bar{X}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} x_{kj}.$$

STEP 2: Compute the absolute residuals $z_{ij} = |X_{ij} - \bar{X}_i|$ where X_{ij} represents the j^th value of the i^th group. For each of the k groups, calculate the means, $\bar{z}_i$, of these residuals, i.e., calculate:

$$\bar{z}_1 = \frac{1}{n_1}\sum_{j=1}^{n_1} z_{1j}, \quad \bar{z}_2 = \frac{1}{n_2}\sum_{j=1}^{n_2} z_{2j}, \quad \ldots, \quad \bar{z}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} z_{kj}.$$

Also calculate the overall mean residual as $\bar{z} = \frac{1}{N}\sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij} = \frac{1}{N}\sum_{i=1}^{k} n_i \bar{z}_i.$

STEP 3: Compute the following sums of squares for the absolute residuals:

$$SS_{TOTAL} = \sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij}^2 - \frac{\bar{z}}{N}, \quad SS_{GROUPS} = \sum_{i=1}^{k}\frac{\bar{z}_i^2}{n_i} - \frac{\bar{z}}{N},$$ and $SS_{ERROR} = SS_{TOTAL} - SS_{GROUPS}$.

STEP 4: Compute $f = \dfrac{SS_{GROUPS}/(k-1)}{SS_{ERROR}/(N-k)}$

STEP 5: Using Table A-9 of Appendix A, find the critical value of the F-distribution with (k-1) numerator degrees of freedom, (N-k) denominator degrees of freedom, and a desired level of significance (α). For example, if $\alpha = 0.05$, the numerator degrees of freedom is 5, and the denominator degrees of freedom is 18, then using Table A-9, F = 2.77. If f is greater than F, reject the assumptions of equal variances.

Box 4-27: An Example of Levene's Test

Four months of data on arsenic concentration were collected from six wells at a Superfund site. This data set is shown in the table below. Before analyzing this data, it is important to determine if the variances of the six wells are equal. Levene's test will be used to make this determination.

STEP 1: The group mean for each well ($\bar{x}_i$) is shown in the last row of the table below.

Arsenic Concentration (ppm)						
Month	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
1	22.90	2.00	2.0	7.84	24.90	0.34
2	3.09	1.25	109.4	9.30	1.30	4.78
3	35.70	7.80	4.5	25.90	0.75	2.85
4	4.18	52.00	2.5	2.00	27.00	1.20
Group Means	$\bar{x}_1$=16.47	$\bar{x}_2$=15.76	$\bar{x}_3$=29.6	$\bar{x}_4$=11.26	$\bar{x}_5$=13.49	$\bar{x}_6$=2.29

STEP 2: To compute the absolute residuals z_{ij} in each well, the value 16.47 will be subtracted from Well 1 data, 15.76 from Well 2 data, 29.6 from Well 3 data, 11.26 from Well 4 data, 13.49 from Well 5 data, and 2.29 from Well 6 data. The resulting values are shown in the following table with the new well means ($\bar{z}_i$) and the total mean $\bar{z}$.

Residual Arsenic Concentration (ppm)						
Month	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
1	6.43	13.76	27.6	3.42	11.41	1.95
2	13.38	14.51	79.8	1.96	12.19	2.49
3	19.23	7.96	25.1	14.64	12.74	0.56
4	12.29	36.24	27.1	9.26	13.51	1.09
Residual Means	$\bar{z}_1$=12.83	$\bar{z}_2$=18.12	$\bar{z}_3$=39.9	$\bar{z}_4$=7.32	$\bar{z}_5$=12.46	$\bar{z}_6$=1.52
Total Residual Mean $\bar{z}$ = (1/6)(12.83 + 18.12 + 39.9 + 7.32 + 12.46 + 1.52) = 15.36						

STEP 3: The sum of squares are: SS_{TOTAL} = 6300.89, SS_{WELLS} = 3522.90, and SS_{ERROR} = 2777.99.

STEP 4: $$f = \frac{SS_{WELLS}/(k-1)}{SS_{ERROR}/(N-k)} = \frac{3522.9/(6-1)}{2777.99/(24-6)} = 4.56$$

STEP 5: Using Table A-9 of Appendix A, the F statistic for 5 and 18 degrees of freedom with α = 0.05 is 2.77. Since f=4.56 exceeds $F_{.05}$=2.77, the assumption of equal variances should be rejected.

4.6 TRANSFORMATIONS

Most statistical tests and procedures contain assumptions about the data to which they will be applied. For example, some common assumptions are that the data are normally distributed; variance components of a statistical model are additive; two independent data sets have equal variance; and a data set has no trends over time or space. If the data do not satisfy such assumptions, then the results of a statistical procedure or test may be biased or incorrect. Fortunately, data that do not satisfy statistical assumptions may often be converted or transformed mathematically into a form that allows standard statistical tests to perform adequately.

4.6.1 Types of Data Transformations

Any mathematical function that is applied to every point in a data set is called a transformation. Some commonly used transformations include:

Logarithmic (Log X or Ln X): This transformation may be used when the original measurement data follow a lognormal distribution or when the variance at each level of the data is proportional to the square of the mean of the data points at that level. For example, if the variance of data collected around 50 ppm is approximately 250, but the variance of data collected around 100 ppm is approximately 1000, then a logarithmic transformation may be useful. This situation is often characterized by having a constant coefficient of variation (ratio of standard deviation to mean) over all possible data values.

The logarithmic base (for example, either natural or base 10) needs to be consistent throughout the analysis. If some of the original values are zero, it is customary to add a small quantity to make the data value non-zero as the logarithm of zero does not exist. The size of the small quantity depends on the magnitude of the non-zero data and the consequences of potentially erroneous inference from the resulting transformed data. As a working point, a value of one tenth the smallest non-zero value could be selected. It does not matter whether a natural (ln) or base 10 (log) transformation is used because the two transformations are related by the expression ln(X) = 2.303 log(X). Directions for applying a logarithmic transformation with an example are given in Box 4-28.

Square Root (X): This transformation may be used when dealing with small whole numbers, such as bacteriological counts, or the occurrence of rare events, such as violations of a standard over the course of a year. The underlying assumption is that the original data follow a Poisson-like distribution in which case the mean and variance of the data are equal. It should be noted that the square root transformation overcorrects when very small values and zeros appear in the original data. In these cases, $\sqrt{X+1}$ is often used as a transformation.

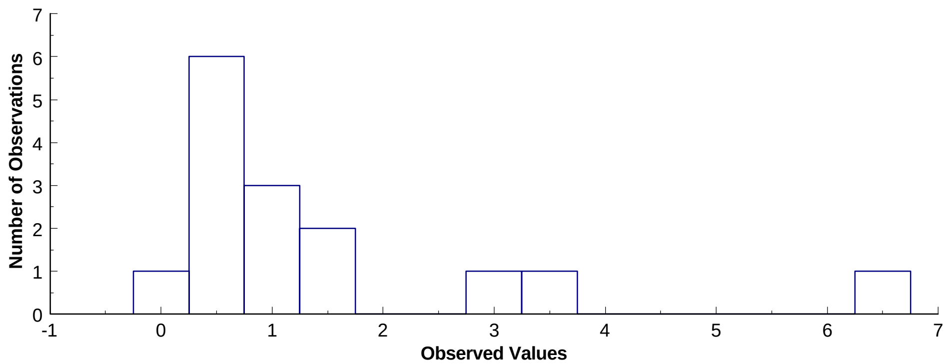
Box 4-28: Directions for Transforming Data and an Example

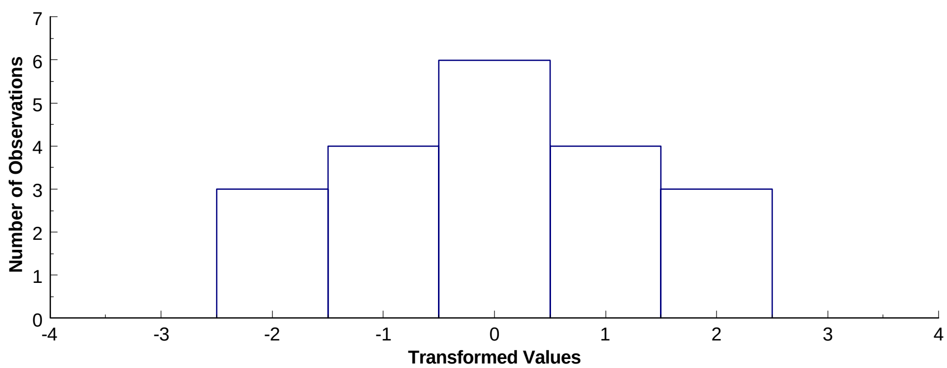
Let X_1, X_2, . . . , X_n represent the n data points. To apply a transformation, simply apply the transforming function to each data point. When a transformation is implemented to make the data satisfy some statistical assumption, it will need to be verified that the transformed data satisfy this assumption.

<u>Example: Transforming Lognormal Data</u>

A logarithmic transformation is particularly useful for pollution data. Pollution data are often skewed, thus the log-transformed data will tend to be symmetric. Consider the data set shown below with 15 data points. The frequency plot of this data (below) shows that the data are possibly lognormally distributed. If any analysis performed with this data assumes normality, then the data may be logarithmically transformed to achieve normality. The transformed data are shown in column 2. A frequency plot of the transformed data (below) shows that the transformed data appear to be normally distributed.

Observed X	→	Transformed ln(X)	Observed X	→	Transformed ln(X)
0.22	→	-1.51	0.47	→	-0.76
3.48	→	1.25	0.67	→	-0.40
6.67	→	1.90	0.75	→	-0.29
2.53	→	0.93	0.60	→	-0.51
1.11	→	0.10	0.99	→	-0.01
0.33	→	-1.11	0.90	→	-0.11
1.64	→	0.50	0.26	→	-1.35
1.37	→	0.31			





Inverse Sine (Arcsine X): This transformation may be used for binomial proportions based on count data to achieve stability in variance. The resulting transformed data are expressed in radians (angular degrees). Special tables must be used to transform the proportions into degrees.

Box-Cox Transformations: This transformation is a complex power transformation that takes the original data and raises each data observation to the power lambda (λ). A logarithmic transformation is a special case of the Box-Cox transformation. The rationale is to find λ such that the transformed data have the best possible additive model for the variance structure, the errors are normally distributed, and the variance is as constant as possible over all possible concentration values. The Maximum Likelihood technique is used to find λ such that the residual error from fitting the theorized model is minimized. In practice, the exact value of λ is often rounded to a convenient value for ease in interpretation (for example, $\lambda = -1.1$ would be rounded to -1 as it would then have the interpretation of a reciprocal transform). One of the drawbacks of the Box-Cox transformation is the difficulty in physically interpreting the transformed data.

4.6.2 Reasons for Transforming Data

By transforming the data, assumptions that are not satisfied in the original data can be satisfied by the transformed data. For instance, a right-skewed distribution can be transformed to be approximately Gaussian (normal) by using a logarithmic or square-root transformation. Then the normal-theory procedures can be applied to the transformed data. If data are lognormally distributed, then apply procedures to logarithms of the data. However, selecting the correct transformation may be difficult. If standard transformations do not apply, it is suggested that the data user consult a statistician.

Another important use of transformations is in the interpretation of data collected under conditions leading to an Analysis of Variance (ANOVA). Some of the key assumptions needed for analysis (for example, additivity of variance components) may only be satisfied if the data are transformed suitably. The selection of a suitable transformation depends on the structure of the data collection design; however, the interpretation of the transformed data remains an issue.

While transformations are useful for dealing with data that do not satisfy statistical assumptions, they can also be used for various other purposes. For example, transformations are useful for consolidating data that may be spread out or that have several extreme values. In addition, transformations can be used to derive a linear relationship between two variables, so that linear regression analysis can be applied. They can also be used to efficiently estimate quantities such as the mean and variance of a lognormal distribution. Transformations may also make the analysis of data easier by changing the scale into one that is more familiar or easier to work with.

Once the data have been transformed, all statistical analysis must be performed on the transformed data. No attempt should be made to transform the data back to the original form because this can lead to biased estimates. For example, estimating quantities such as means, variances, confidence limits, and regression coefficients in the transformed scale typically leads to biased estimates when transformed back into original scale. However, it may be difficult to understand or apply results of statistical analysis expressed in the transformed scale. Therefore, if the transformed data do not give noticeable benefits to the analysis, it is better to use the original data. There is no point in working with transformed data unless it adds value to the analysis.

4.7 VALUES BELOW DETECTION LIMITS

Data generated from chemical analysis may fall below the detection limit (DL) of the analytical procedure. These measurement data are generally described as not detected, or nondetects, (rather than as zero or not present) and the appropriate limit of detection is usually reported. In cases where measurement data are described as not detected, the concentration of the chemical is unknown although it lies somewhere between zero and the detection limit. Data that includes both detected and non-detected results are called censored data in the statistical literature.

There are a variety of ways to evaluate data that include values below the detection limit. However, there are no general procedures that are applicable in all cases. Some general guidelines are presented in Table 4-4. Although these guidelines are usually adequate, they should be implemented cautiously.

Table 4-4. Guidelines for Analyzing Data with Nondetects

Percentage of Nondetects	Section	Statistical Analysis Method
< 15%	4.7.1	Replace nondetects with DL/2, DL, or a very small number.
15% - 50%	4.7.2	Trimmed mean, Cohen's adjustment, Winsorized mean and standard deviation.
> 50% - 90%	4.7.3	Use tests for proportions (Section 3.2.2)

All of the suggested procedures for analyzing data with nondetects depend on the amount of data below the detection limit. For relatively small amounts below detection limit values, replacing the nondetects with a small number and proceeding with the usual analysis may be satisfactory. For moderate amounts of data below the detection limit, a more detailed adjustment is appropriate. In situations where relatively large amounts of data below the detection limit exist, one may need only to consider whether the chemical was detected as above some level or not. The interpretation of small, moderate, and large amounts of data below the DL is subjective. Table 4-4 provides percentages to assist the user in evaluating their particular situation. However, it should be recognized that these percentages are not hard and fast rules, but should be based on judgement.

In addition to the percentage of samples below the detection limit, sample size influences which procedures should be used to evaluate the data. For example, the case where 1 sample out of 4 is not detected should be treated differently from the case where 25 samples out of 100 are not detected. Therefore, this guidance suggests that the data analyst consult a statistician for the most appropriate way to evaluate data containing values below the detection level.

4.7.1 Less than 15% Nondetects - Substitution Methods

If a small proportion of the observations are not detected, these may be replaced with a small number, usually the detection limit divided by 2 (DL/2), and the usual analysis performed. As a guideline, if 15% or fewer of the values are not detected, replace them with the method detection limit divided by two and proceed with the appropriate analysis using these modified values. If simple substitution of values below the detection limit is proposed when more than 15% of the values are reported as not detected, consider using nonparametric methods or a test of proportions to analyze the data. If a more accurate method is to be considered, see Cohen's Method (Section 4.7.2.1).

4.7.2 Between 15-50% Nondetects

4.7.2.1 Cohen's Method

Cohen's method provides adjusted estimates of the sample mean and standard deviation that accounts for data below the detection level. The adjusted estimates are based on the statistical technique of maximum likelihood estimation of the mean and variance so that the fact that the nondetects are below the limit of detection but may not be zero is accounted for. The adjusted mean and standard deviation can then be used in the parametric tests described in Chapter 3 (e.g., the one sample t-test of Section 3.2.1). However, if more than 50% of the observations are not detected, Cohen's method should not be used. In addition, this method requires that the data without the nondetects be normally distributed and the detection limit is always the same. Directions for Cohen's method are contained in Box 4-29; an example is given in Box 4-30.

Box 4-29: Directions for Cohen's Method

Let $X_1, X_2, \ldots, X_n$ represent the n data points with the first m values representing the data points above the detection limit (DL). Thus, there are (n-m) data points are below the DL.

STEP 1: Compute the sample mean $\bar{x}_d$ from the data above the detection limit:

$$\bar{X}_d = \frac{1}{m}\sum_{i=1}^{m} X_i$$

STEP 2: Compute the sample variance s_d^2 from the data above the detection limit:

$$s_d^2 = \frac{\sum_{i=1}^{m} X_i^2 - \frac{1}{m}\left(\sum_{i=1}^{m} X_i\right)^2}{m-1}$$

STEP 3: Compute $h = \frac{(n-m)}{n}$ and $\gamma = \frac{s_d^2}{(\bar{X}_d - DL)^2}$

STEP 4: Use h and γ in Table A-10 of Appendix A to determine $\hat{\lambda}$. For example, if h = 0.4 and γ = 0.30, then $\hat{\lambda}$ = 0.6713. If the exact value of h and γ do not appear in the table, use double linear interpolation (Box 4-31) to estimate $\hat{\lambda}$.

STEP 5: Estimate the corrected sample mean, $\bar{x}$, and sample variance, s^2, to account for the data below the detection limit, as follows: $\bar{X} = \bar{X}_d - \hat{\lambda}(\bar{X}_d - DL)$ and $s^2 = s_d^2 + \hat{\lambda}(\bar{X}_d - DL)^2$.

Box 4-30: An Example of Cohen's Method

Sulfate concentrations were measured for 24 data points. The detection limit was 1,450 mg/L and 3 of the 24 values were below the detection level. The 24 values are 1850, 1760, < 1450 (ND), 1710, 1575, 1475, 1780, 1790, 1780, < 1450 (ND), 1790, 1800, < 1450 (ND), 1800, 1840, 1820, 1860, 1780, 1760, 1800, 1900, 1770, 1790, 1780 mg/L. Cohen's Method will be used to adjust the sample mean for use in a t-test to determine if the mean is greater than 1600 mg/L.

STEP 1: The sample mean of the m = 21 values above the detection level is $\bar{X}_d = 1771.9$

STEP 2: The sample variance of the 21 quantified values is s_d^2= 8593.69.

STEP 3: h = (24 - 21)/24 = 0.125 and γ = 8593.69/(1771.9 - 1450)^2 = 0.083

STEP 4: Table A-10 of Appendix A was used for h = 0.125 and γ = 0.083 to find the value of $\hat{\lambda}$. Since the table does not contain these entries exactly, double linear interpolation was used to estimate $\hat{\lambda}$ = 0.149839 (see Box 4-31).

STEP 5: The adjusted sample mean and variance are then estimated as follows:

$$\bar{X} = 1771.9 - 0.149839(1771.9 - 1450) = 1723.67 \text{ and}$$

$$s^2 = 8593.69 + 0.149839(1771.9 - 1450)^2 = 24119.95$$

Box 4-31: Double Linear Interpolation

The details of the double linear interpolation are provided to assist in the use of Table A-10 of Appendix A. The desired value for $\hat{\lambda}$ corresponds to γ = 0.083 and, h = 0.125 from Box 4-30, Step 3. The values from Table A-10 for interpolatation are:

γ	h = 0.10	h = 0.15
0.05	0.11431	0.17925
0.10	0.11804	0.18479

There are 0.05 units between 0.10 and 0.15 on the h-scale and 0.025 units between 0.10 and 0.125. Therefore, the value of interest lies (0.025/0.05)100% = 50% of the distance along the interval between 0.10 and 0.15. To linearly interpolate between tabulated values on the h axis for γ = 0.05, the range between the values must be calculated, 0.17925 - 0.11431 = 0.06494; the value that is 50% of the distance along the range must be computed, 0.06494 x 0.50 = 0.03247; and then that value must be added to the lower point on the tabulated values, 0.11431 + 0.03247 = 0.14678. Similarly for γ = 0.10, 0.18479 - 0.11804 = 0.06675, 0.06675 x 0.50 = 0.033375, and 0.11804 + 0.033375 = 0.151415.

On the γ-axis there are 0.033 units between 0.05 and 0.083 and there are 0.05 units between 0.05 and 0.10. The value of interest (0.083) lies (0.033/0.05 x 100) = 66% of the distance along the interval between 0.05 and 0.10, so 0.151415 - 0.14678 = 0.004635, 0.004635 * 0.66 = 0.003059. Therefore,

$$\hat{\lambda} = 0.14678 + 0.003059 = 0.149839.$$

4.7.2.2 Trimmed Mean

Trimming discards the data in the tails of a data set in order to develop an unbiased estimate of the population mean. For environmental data, nondetects usually occur in the left tail of the data so trimming the data can be used to adjust the data set to account for nondetects when estimating a mean. Developing a 100p% trimmed mean involves trimming p% of the data in both the lower and the upper tail. Note that p must be between 0 and .5 since p represents the portion deleted in both the upper and the lower tail. After np of the largest values and np of the smallest values are trimmed, there are n(1-2p) data values remaining. Therefore, the proportion trimmed is dependent on the total sample size (n) since a reasonable amount of samples must remain for analysis. For approximately symmetric distributions, a 25% trimmed mean (the midmean) is a good estimator of the population mean. However, environmental data are often skewed (non-symmetric) and in these cases a 15% trimmed mean performance may be a good estimator of the population mean. It is also possible to trim the data only to replace the nondetects. For example, if 3% of the data are below the detection limit, a 3% trimmed mean could be used to estimate the population mean. Directions for developing a trimmed mean are contained in Box 4-32 and an example is given in Box 4-33. A trimmed variance is rarely calculated and is of limited use.

4.7.2.3 Winsorized Mean and Standard Deviation

Winsorizing replaces data in the tails of a data set with the next most extreme data value. For environmental data, nondetects usually occur in the left tail of the data. Therefore, winsorizing can be used to adjust the data set to account for nondetects. The mean and standard deviation can then be computed on the new data set. Directions for winsorizing data (and revising the sample size) are contained in Box 4-34 and an example is given in Box 4-35

4.7.2.4 Atchison's Method

Previous adjustments to the mean and variance assumed that the data values really were present but could not be recorded or "seen" as they were below the detection limit. In other words, if the detection limit had been substantially lower, the data values would have been recorded. There are however, cases where the data values are below the detection limit because they are actually zero, the contaminant or chemical of concern being entirely absent. Such data sets are actually a mixture – partly the assumed distribution (for example, a normal distribution) and partly a number of zero values. Aitchison's Method is used in this situation to adjust the mean and variance for the zero values.

Box 4-32: Directions for Developing a Trimmed Mean

Let X_1, X_2, . . . , X_n represent the n data points. To develop a 100p% trimmed mean (0 < p < 0.5):

STEP 1: Let t represent the integer part of the product np. For example, if p = .25 and n = 17, np = (.25)(17) = 4.25, so t = 4.

STEP 2: Delete the t smallest values of the data set and the t largest values of the data set.

STEP 3: Compute the arithmetic mean of the remaining n - 2t values: $\bar{X} = \frac{1}{n-2t}\sum_{i=1}^{n-2t} X_i$

This value is the estimate of the population mean.

Box 4-33: An Example of the Trimmed Mean

Sulfate concentrations were measured for 24 data points. The detection limit was 1,450 mg/L and 3 of the 24 values were below this limit. The 24 values listed in order from smallest to largest are: < 1450 (ND), < 1450 (ND), < 1450 (ND), 1475, 1575, 1710, 1760, 1760, 1770, 1780, 1780, 1780, 1780, 1790, 1790, 1790, 1800, 1800, 1800, 1820, 1840, 1850, 1860, 1900 mg/L. A 15% trimmed mean will be used to develop an estimate of the population mean that accounts for the 3 nondetects.

STEP 1: Since np = (24)(.15) = 3.6, t = 3.

STEP 2: The 3 smallest values of the data set and the 3 largest values of the data set were deleted. The new data set is: 1475, 1575, 1710, 1760, 1760, 1770, 1780, 1780, 1780, 1780, 1790, 1790, 1790, 1800, 1800, 1800, 1820, 1840 mg/L.

STEP 3: Compute the arithmetic mean of the remaining n-2t values:

$$\bar{X} = \frac{1}{24-(2)(3)}(1475 + \ldots + 1840) = 1755.56$$

Therefore, the 15% trimmed mean is 1755.56 mg/L.

Box 4-34: Directions for Developing a Winsorized Mean and Standard Deviation

Let $X_1, X_2, \ldots, X_n$ represent the n data points and m represent the number of data points above the detection limit (DL), and hence n-m below the DL.

STEP 1: List the data in order from smallest to largest, including nondetects. Label these points $X_{(1)}, X_{(2)}, \ldots, X_{(n)}$ (so that $X_{(1)}$ is the smallest, $X_{(2)}$ is the second smallest, and $X_{(n)}$ is the largest).

STEP 2: Replace the n-m nondetects with $X_{(m+1)}$ and replace the n-m largest values with $X_{(n-m)}$.

STEP 3: Using the revised data set, compute the sample mean, $\bar{x}$, and the sample standard deviation, s:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad \text{and} \quad s = \sqrt{\frac{(\sum_{i=1}^{n} X_i^2) - n\bar{X}^2}{n-1}}$$

STEP 4: The Winsorized mean $\bar{x}_w$ is equal to $\bar{x}$. The Winsorized standard deviation is

$$s_w = \frac{s(n-1)}{(2m-n-1)}.$$

Box 4-35: An Example of a Winsorized Mean and Standard Deviation

Sulfate concentrations were measured for 24 data points. The detection limit was 1,450 mg/L and 3 of the 24 values were below the detection level. The 24 values listed in order from smallest to largest are: < 1450 (ND), < 1450 (ND), < 1450 (ND), 1475, 1575, 1710, 1760, 1760, 1770, 1780, 1780, 1780, 1780, 1790, 1790, 1790, 1800, 1800, 1800, 1820, 1840, 1850, 1860, 1900 mg/L.

STEP 1: The data above are already listed from smallest to largest. There are n=24 samples, 21 above DL, and n-m=3 nondetects.

STEP 2: The 3 nondetects were replaced with $X_{(4)}$ and the 3 largest values were replaced with $X_{(21)}$. The resulting data set is: 1475, 1475, 1475, 1475, 1575, 1710, 1760, 1760, 1770, 1780, 1780, 1780, 1780, 1790, 1790, 1790, 1800, 1800, 1800, 1820, 1840, 1840, 1840, 1840 mg/L

STEP 3: For the new data set, $\bar{x}$ = 1731 mg/L and s = 128.52 mg/L.

STEP 4: The Winsorized mean $\bar{x}_w$ = 1731 mg/L. The Winsorized sample standard deviation is:

$$s_w = \frac{128.52(24-1)}{2(21) - 24 - 1} = 173.88$$

Aitchison's method for adjusting the mean and variance of the above the detection level values works quite well provided the percentage of non-detects is between 15-50% of the total number of values. Care must be taken when using Aitchison's adjustment to the mean and standard deviation as the mean is reduced and variance increased. With such an effect it may become very difficult to use the adjusted data for tests of hypotheses or for predicative purposes. As a diagnostic tool, the relevance of Aitchison' adjustment can lead to an evaluation of the data to determine if two populations are being sampled simultaneously: one population being represented by a normal distribution, the other being simply blanks. In some circumstances, for example investigating a hazardous site, it may be possible to relate the position of the sample through a Posting Plot (Section 2.3.9) and determine if the target population has not been adequately stratified. Directions for Aitchison's method are contained in Box 4-36; an example (with a comparison to Cohen's method) is contained in Box 4-37.

Box 4-36: 11 Directions for Aitchison's Method to Adjust Means and Variances

Let $X_1, X_2, \ldots, X_m, \ldots, X_n$ represent the data points where the first m values are above the detection limit (DL) and the remaining (n-m) data points are below the DL

STEP 1: Using the data above the detection level, compute the sample mean,

$$\overline{X}_d = \frac{1}{m}\sum_{i=1}^{m} X_i \quad \text{and the sample variance,} \quad s_d^2 = \frac{\sum_{i=1}^{m} X_i^2 - \frac{1}{m}\left(\sum_{i=1}^{m} X_i\right)^2}{m-1}$$

STEP 2: Estimate the corrected sample mean, $\overline{X} = \frac{m}{n}\overline{X}_d$

and the sample variance $s^2 = \frac{m-1}{n-1}s_d^2 + \frac{m(n-m)}{n(n-1)}\overline{X}_d^2$

Box 4-37: An Example of Aitchison's Method

The following data consist of 10 Methylene Chloride samples: 1.9,1.3, <1, 2.0, 1.9, <1, <1, <1, 1.6, and 1.7. There are 7 values above the detection limit and 3 below, so m = 7 and n - m=3. Aitchison's method will be used to estimate the mean and sample variance of this data.

STEP 1: $\overline{X}_d = \frac{1}{7}\sum_{i=1}^{7} X_i = \frac{1}{7}(1.9 + 1.3 + 2.0 + 1.9 + 1.6 + 1.6 + 1.7) = 1.714$

and $s_d^2 = \frac{\sum_{i=1}^{7} X_i^2 - \frac{1}{7}\left(\sum_{i=1}^{7} X_i\right)^2}{7-1} = 0.05809$

STEP 2: The corrected sample mean is then $\overline{X} = \frac{7}{3}(1.714) = 1.2$

and the sample variance $s^2 = \frac{7-1}{10-1}(0.05809) + \frac{7(3)}{3(3-1)}(1.714) = 0.7242$

4.7.2.5 Selecting Between Atchison's Method or Cohen's Method

To determine if a data set is better adjusted by Cohen's method or Aitchison's method, a simple graphical procedure using Normal Probability Paper (Section 2.3) can be used. Examples for this procedures are given in Box 4-38 and an example is contained in Box 4-39.

Box 4-38: Directions for Selecting Between Cohen's Method or Aitchison's Method

Let X_1, X_2, . . .,X_m, . . . , X_n represent the data points with the first m values are above the detection limit (DL) and the remaining (n-m) data points are below the DL.

STEP 1: Use Box 2-19 to construct a Normal Probability Plot of all the data but only plot the values belonging to those above the detection level. This is called the Censored Plot.

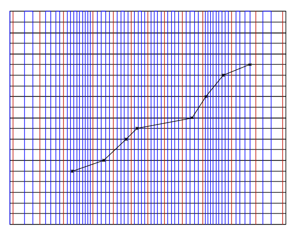
STEP 2: Use Box 2-19 to construct a Normal Probability Plot of only those values above the detection level. This called the Detects only Plot.

STEP 3: If the Censored Plot is more linear than the Detects Only Plot, use Cohen's Method to estimate the sample mean and variance. If the Detects Only Plot is more linear than the Censored Plot, then use Aitchison's Method to estimate the sample mean and variance.

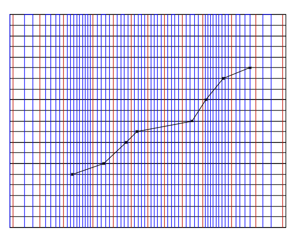
Box 4-39: Example of Determining Between Cohen's Method and Aitchison's Method

In this example, 10 readings of Chlorobenzene were obtained from a monitoring well and submitted for consideration for a permit: < 1, 1.9, 1.4, 1.5, < 1, 1.2, <1, 1.3, 1.9, 2.1 ppm. The data can be thought to be independent readings.

Step 1: Using the directions in Box 2-19 the following is the Censored Plot:



STEP 2: Using the directions in Box 2-19 the following is the Detects only Plot:



STEP 3: Since the Censored Plots is more linear than the Detects Only Plot, Cohen's Method should be used to estimate the sample mean and variance.

4.7.3 Greater than 50% Nondetects - Test of Proportions

If more than 50% of the data are below the detection limit but at least 10% of the observations are quantified, tests of proportions may be used to test hypotheses using the data. Thus, if the parameter of interest is a mean, consider switching the parameter of interest to some percentile greater than the percent of data below the detection limit. For example, if 67% of the data are below the DL, consider switching the parameter of interest to the 75th percentile. Then the method described in 3.2.2 can be applied to test the hypothesis concerning the 75th percentile. It is important to note that the tests of proportions may not be applicable for composite samples. In this case, the data analyst should consult a statistician before proceeding with analysis.

If very few quantified values are found, a method based on the Poisson distribution may be used as an alternative approach. However, with a large proportion of nondetects in the data, the data analyst should consult with a statistician before proceeding with analysis.

4.7.4 Recommendations

If the number of sample observations is small ($n<20$), maximum likelihood methods can produce biased results since it is difficult to assure that the underlying distribution appropriate and the solutions to the likelihood equation for the parameters of interest are statistically consistent only if the number of samples is large. Additionally, most methods will yield estimated parameters with large estimation variance, which reduces the power to detect import differences from standards or between populations. While these methods can be applied to small data sets, the user should be cautioned that they will only be effective in detecting large departures from the null hypothesis.

If the degree of censoring (the percentage of data below the detection limit) is relatively low, reasonably good estimates of means, variances and upper percentiles can be obtained. However, if the rate of censoring is very high (greater than 50%) then little can be done statistically except to focus on some upper quantile of the contaminant distribution, or on some proportion of measurements above a certain critical level that is at or above the censoring limit.

When the numerical standard is at or below one of the censoring levels and a one-sample test is used, the most useful statistical method is to test whether the proportion of a population is above (below) the standard is too large, or to test whether and upper quantile of the population distribution is above the numerical standard. Table 4-5 gives some recommendation on which statistical parameter to use when censoring is present in data sets for different sizes of the coefficient of variation (Section 2.2.3).

When comparing two data sets with different censoring levels (i.e., different detection limits), it is recommended that all data be censored at the highest censoring value present and a non parametric test such as the Wilcoxon Rank Sum Test (Section 3.3.3.1) used to compare the two data sets. There is a corresponding loss of statistical power but this can be minimized through the use of large samples.

Table 4-5. Guidelines for Recommended Parameters for Different Coefficient of Variations and Censoring

Assumed Coefficient of Variation (CV)	Proportion of Data Below the Detection Limit	
	Low (<30%)	**High (>30%)**
Large: CV > 1.5	Mean or Upper Percentile	Upper Percentile
Medium: 0.5 < CV < 1.5	Mean or Upper Percentile	Upper Percentile
Small: CV < 0.5	Mean or Median	Median

4.8 INDEPENDENCE

The assumption of independence of data is key to the validity of the false rejection and false acceptance error rates associated with the selected statistical test. When data are truly independent between themselves, the correlation between data points is by definition zero and the selected statistical tests work with the desired chosen decision error rates (given appropriate the assumptions have been satisfied). When correlation (usually positive) exists, the effectiveness of statistical tests is diminished. Environmental data are particularly susceptible to correlation problems due to the fact that such environmental data are collected under a spatial pattern (for example a grid) or sequentially over time (for example, daily readings from a monitoring station).

The reason non-independence is an issue for statistical testing situations is that if observations are positively correlated over time or space, then the effective sample size for a test tends to be smaller than the actual sample size – i.e., each additional observation does not provide as much "new" information because its value is partially determined by (or a function of) the value of adjacent observations. This smaller effective sample size means that the degrees of freedom for the test statistic is less, or equivalently, the test is not as powerful as originally thought. In addition to affecting the false acceptance error rate, applying the usual tests to correlated data tends to result in a test whose actual significance level (false rejection error rate) is larger than the nominal error rate.

When observations are correlated, estimates of the variance that are used in test statistic formulas are often understated. For example, consider the mean of a series of n temporally-ordered observations. If these observations are independent, then the variance of the mean is σ^2/n, where σ^2 is the variance of individual observations (see Section 2.2.3). However, if the observations are not independent and the correlation between successive observations is ρ (for example, the correlation between the first and second observation is ρ, between first and third observations is ρ^2, between first and fourth observations is ρ^3, etc.), then the variance of the mean increases to

$$VAR(\overline{X}) = \boldsymbol{s}^{2}(1+q), \text{where } q = \frac{2}{n}\sum_{k=1}^{n-1}(n-t)\boldsymbol{r}^{k}$$

which will tend to be larger than σ^2/n if the correlations (on average) are positive. If one conducts a t-test at the significance level, using the usual formula for the estimated variance (Box 2-3), then the actual significance level can be approximately double what was expected even for relatively low values of ρ.

One of the most effective ways to determine statistical independence is through use of the Rank von Neumann Test. Directions for this test are given in Box 4-40 and an example in contained in Box 4-41. Compared to other tests of statistical independence, the rank von Neumann test has been shown to be more powerful over a wide variety of cases. It is also a reasonable test when the data really follow a Normal distribution. In that case, the efficiency of the test is always close to 90 percent when compared to the von Neumann ratio computed on the original data instead of the ranks. This means that very little effectiveness is lost by always using the ranks in place of the original concentrations; the rank von Neumann ration should still correctly detect non-independent data.

Box 4-40: Directions for the Rank von Neumann Test

Let $X_1, X_2, \ldots, X_n$ represent the data values collected in sequence over equally spaced periods of time.

Step 1. Order the data measurements from smallest to largest and assign a unique rank (r^i) to each measurement (See Box 3-20 Then list the observations and their corresponding ranks in the order that sampling occurred(i.e., by sampling event or time order.)

Step 2. Using the list of ranks, r_i, for the sampling periods i=1, 2, ..., n, compute the rank von Neumann ratio:

$$v = \frac{\sum_{i=2}^{n}(r_i - r_{i-1})^2}{n(n^2-1)/12}$$

Step 3: Use Table A-15 of Appendix A to determine the lower critical point of the rank von Neumann ration using the sample size, n, and the desired significance level, α. If the computed ratio, v, is smaller than this critical point, conclude that the data series is strongly auto correlated. If not, the data may be mildly correlated, but there is no statistically significant evidence to reject the hypothesis of independence. Therefore, the data should be regarded as independent in subsequent statistical testing.

Note: if the rank von Neumann ratio test indicates significant evidence of dependence in the data, a statistician should be consulted before further analysis is performed.

Box 4-41: An Example of the Rank von Neumann Test

The following are hourly readings from a discharge monitor: hourly readings from a discharge monitor.

Time:	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Reading	6.5	6.6	6.7	6.4	6.3	6.4	6.2	6.2	6.3	6.6	6.8	6.9	7.0
Rank	7	8.5	10	5.5	3.5	5.5	1.5	1.5	3.5	8.5	11	12	13

Step 1: The ranks are displayed in the table above and the time periods were labeled 1 through 13.

Step 2:
$$v = \frac{\sum_{i=2}^{n} (r_i - r_{i-1})^2}{n(n^2 - 1)/12} = \frac{(8.5 - 7)^2 + (10 - 8.5)^2 + \ldots + (13 - 12)^2}{13(13^2 - 1)/12} = 0.473$$

Step 3: Using Table A-15 of Appendix A with $\alpha = 0.05$, the lower critical point is 1.17. Since v = 0.473 < 1.17, the hypothesis that the data are independent must be rejected.

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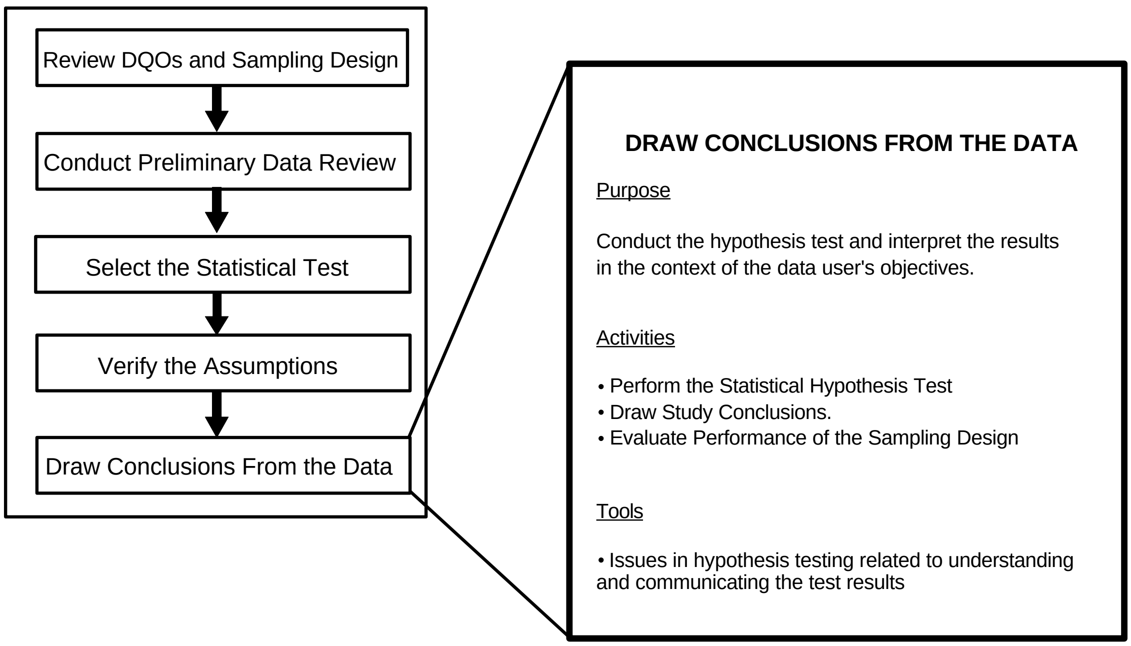
CHAPTER 5

STEP 5: DRAW CONCLUSIONS FROM THE DATA

THE DATA QUALITY ASSESSMENT PROCESS



Step 5: Draw Conclusions from the Data

! Perform the calculations for the statistical hypothesis test.
  - P Perform the calculations and document them clearly.
  - P If anomalies or outliers are present in the data set, perform the calculations with and without the questionable data.

! Evaluate the statistical test results and draw conclusions.
  - P If the null hypothesis is rejected, then draw the conclusions and document the analysis.
  - P If the null hypothesis is not rejected, verify whether the tolerable limits on false acceptance decision errors have been satisfied. If so, draw conclusions and document the analysis; if not, determine corrective actions, if any.
  - P Interpret the results of the test.

! Evaluate the performance of the sampling design if the design is to be used again.
  - P Evaluate the statistical power of the design over the full range of parameter values; consult a statistician as necessary.

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CHAPTER 5
STEP 5: DRAW CONCLUSIONS FROM THE DATA

5.1 OVERVIEW AND ACTIVITIES

In this final step of the DQA, the analyst performs the statistical hypothesis test and draws conclusions that address the data user's objectives. This step represents the culmination of the planning, implementation, and assessment phases of the data operations. The data user's planning objectives will have been reviewed (or developed retrospectively) and the sampling design examined in Step 1. Reports on the implementation of the sampling scheme will have been reviewed and a preliminary picture of the sampling results developed in Step 2. In light of the information gained in Step 2, the statistical test will have been selected in Step 3. To ensure that the chosen statistical methods are valid, the key underlying assumptions of the statistical test will have been verified in Step 4. Consequently, all of the activities conducted up to this point should ensure that the calculations performed on the data set and the conclusions drawn here in Step 5 address the data user's needs in a scientifically defensible manner. This chapter describes the main activities that should be conducted during this step. The actual procedures for implementing some commonly used statistical tests are described in Step 3, Select the Statistical Test.

5.1.1 Perform the Statistical Hypothesis Test

The goal of this activity is to conduct the statistical hypothesis test. Step-by-step directions for several commonly used statistical tests are described in Chapter 3. The calculations for the test should be clearly documented and easily verifiable. In addition, the documentation of the results of the test should be understandable so that the results can be communicated effectively to those who may hold a stake in the resulting decision. If computer software is used to perform the calculations, ensure that the procedures are adequately documented, particularly if algorithms have been developed and coded specifically for the project.

The analyst should always exercise best professional judgment when performing the calculations. For instance, if outliers or anomalies are present in the data set, the calculations should be performed both with and without the questionable data to see what effect they may have on the results.

5.1.2 Draw Study Conclusions

The goal of this activity is to translate the results of the statistical hypothesis test so that the data user may draw a conclusion from the data. The results of the statistical hypothesis test will be either:

(a) *reject the null hypothesis*, in which case the analyst is concerned about a possible false rejection decision error; or

(b) *fail to reject the null hypothesis*, in which case the analyst is concerned about a possible false acceptance decision error.

In case (a), the data have provided the evidence needed to reject the null hypothesis, so the decision can be made with sufficient confidence and without further analysis. This is because the statistical test based on the classical hypothesis testing philosophy, which is the approach described in prior chapters, inherently controls the false rejection decision error rate within the data user's tolerable limits, provided that the underlying assumptions of the test have been verified correctly.

In case (b), the data do not provide sufficient evidence to reject the null hypothesis, and the data must be analyzed further to determine whether the data user's tolerable limits on false acceptance decision errors have been satisfied. One of two possible conditions may prevail:

(1) The data do not support rejecting the null hypothesis and the false acceptance decision error limits were satisfied. In this case, the conclusion is drawn in favor of the null hypothesis, since the probability of committing a false acceptance decision error is believed to be sufficiently small in the context of the current study (see Section 5.2).

(2) The data do not support rejecting the null hypothesis, and the false acceptance decision error limits were *not* satisfied. In this case, the statistical test was not powerful enough to satisfy the data user's performance criteria. The data user may choose to tolerate a higher false acceptance decision error rate than previously specified and draw the conclusion in favor of the null hypothesis, or instead take some form of corrective action, such as obtaining additional data before drawing a conclusion and making a decision.

When the test fails to reject the null hypothesis, the most thorough procedure for verifying whether the false acceptance decision error limits have been satisfied is to compute the estimated power of the statistical test, using the variability observed in the data. Computing the power of the statistical test across the full range of possible parameter values can be complicated and usually requires specialized software. Power calculations are also necessary for evaluating the performance of a sampling design. Thus, power calculations will be discussed further in Section 5.1.3.

A simpler method can be used for checking the performance of the statistical test. Using an estimate of variance obtained from the actual data or upper 95% confidence limit on variance, the sample size required to satisfy the data user's objectives can be calculated retrospectively. If this theoretical sample size is less than or equal to the number of samples actually taken, then the test is sufficiently powerful. If the required number of samples is greater than the number actually collected, then additional samples would be required to satisfy the data user's performance criteria for the statistical test. An example of this method is contained in Box 5-1. The equations

Box 5-1: Checking Adequacy of Sample Size for a One-Sample t-Test for Simple Random Sampling

In Box 3-1, the one-sample t-test was used to test the hypothesis H_0: $\mu \leq 95$ ppm vs. H_A: $\mu > 95$ ppm. DQOs specified that the test should limit the false rejection error rate to 5% and the false acceptance error rate to 20% if the true mean were 105 ppm. A random sample of size n = 9 had sample mean $\bar{x}$ = 99.38 ppm and standard deviation s = 10.41 ppm. The null hypothesis was not rejected. Assuming that the true value of the standard deviation was equal to its sample estimate 10.41 ppm, it was found that a sample size of 9 would be required, which validated the sample size of 9 which had actually been used.

The distribution of the sample standard deviation is skewed with a long right tail. It follows that the chances are greater than 50% that the sample standard deviation will underestimate the true standard deviation. In such a case it makes sense to build in some conservatism, for example, by using an upper 90% confidence limit for σ in Step 5 of Box 3-12. Using Box 4-22 and n - 1 = 8 degrees of freedom, it is found that L = 3.49, so that an upper 90% confidence limit for the true standard deviation is

$$s\sqrt{[(n-1)/L]} = 10.41\sqrt{8/3.49} = 15.76$$

Using this value for s in Step 5 of Box 3-1 leads to the sample size estimate of 17. Hence, a sample size of at least 17 should be used to be 90% sure of achieving the DQOs. Since it is generally desirable to avoid the need for additional sampling, it is advisable to conservatively estimate sample size in the first place. In cases where DQOs depend on a variance estimate, this conservatism is achieved by intentionally overestimating the variance.

required to perform these calculations have been provided in the detailed step-by-step instructions for each hypothesis test procedure in Chapter 3.

5.1.3 Evaluate Performance of the Sampling Design

If the sampling design is to be used again, either in a later phase of the current study or in a similar study, the analyst will be interested in evaluating the overall performance of the design. To evaluate the sampling design, the analyst performs a statistical power analysis that describes the estimated power of the statistical test over the range of possible parameter values. The power of a statistical test is the probability of rejecting the null hypothesis when the null hypothesis is false. The estimated power is computed for all parameter values under the alternative hypothesis to create a power curve. A power analysis helps the analyst evaluate the adequacy of the sampling design when the true parameter value lies in the vicinity of the action level (which may not have been the outcome of the current study). In this manner, the analyst may determine how well a statistical test performed and compare this performance with that of other tests.

The calculations required to perform a power analysis can be relatively complicated, depending on the complexity of the sampling design and statistical test selected. Box 5-2 illustrates power calculations for a test of a single proportion, which is one of the simpler cases. A further discussion of power curves (performance curves) is contained in the *Guidance for Data Quality Objectives (QA/G-4)* (EPA 1994).

Box 5-2: Example of Power Calculations for the One-Sample Test of a Single Proportion

This box illustrates power calculations for the test of H_0: P $\geq$ .20 vs. H_A: P < .20, with a false rejection error rate of 5% when P=.20 presented in Boxes 3-10 and 3-11 The power of the test will be calculated assuming P_1 = .15 and before any data are available. Since nP_1 and $n(1-P_1)$ both exceed 4, the sample size is large enough for the normal approximation, and the test can be carried out as in steps 3 and 4 of Box 3-10

STEP 1: Determine the general conditions for rejection of the null hypothesis. In this case, the null hypothesis is rejected if the sample proportion is sufficiently smaller than P_0. (Clearly, a sample proportion above P_0 cannot cast doubt on H_0.) By steps 3 and 4 of Box 3-10 and 3-3 H_0 is rejected if

$$\frac{p + .5/n - P_0}{\sqrt{P_0 Q_0 / n}} < -z_{1-\alpha}.$$

Here p is the sample proportion, $Q_0 = 1 - P_0$, n is the sample size, and $z_{1-\alpha}$ is the critical value such that 100(1-α)% of the standard normal distribution is below $z_{1-\alpha}$. This inequality is true if

$$p + .5/n < P_0 - z_{1-\alpha}\sqrt{P_0 Q_0 / n}.$$

STEP 2: Determine the specific conditions for rejection of the null hypothesis if P_1 (=1-Q_1) is the true value of the proportion P. The same operations as are used in step 3 of Box 3-10 are performed on both sides of the above inequality. However, P_0 is replaced by P_1 since it is assumed that P_1 is the true proportion. These operations make the normal approximation applicable. Hence, rejection occurs if

$$\frac{p + .5/n - P_1}{\sqrt{P_1^{/} Q_1 / n}} < \frac{P_0 - P_1 - z_{1-\alpha}\sqrt{P_0 Q_0 / n}}{\sqrt{P_1 Q_1 / n}} = \frac{.20 - .15 - 1.645\sqrt{(.2)(.8)/85}}{\sqrt{(.15)(.85)/85}} = -0.55$$

STEP 3: Find the probability of rejection if P_1 is the true proportion. By the same reasoning that led to the test in steps 3 and 4 of Boxes 3-10 and 3-11 the quantity on the left-hand side of the above inequality is a standard normal variable. Hence the power at P_1 = .15 (i.e., the probability of rejection of H_0 when .15 is the true proportion) is the probability that a standard normal variable is less than -0.55. In this case, the probability is approximately 0.3 (using the last line from Table A-1 of Appendix A) which is fairly small.

5.2 INTERPRETING AND COMMUNICATING THE TEST RESULTS

Sometimes difficulties may arise in interpreting or explaining the results of a statistical test. One reason for such difficulties may stem from inconsistencies in terminology; another may be due to a lack of understanding of some of the basic notions underlying hypothesis tests. As an example, in explaining the results to a data user, an analyst may use different terminology than that appearing in this guidance. For instance, rather than saying that the null hypothesis was or was not rejected, analysts may report the result of a test by saying that their computer output shows a p-value of 0.12. What does this mean? Similar problems of interpretation may occur when the data user attempts to understand the practical significance of the test results or to explain the test results to others. The following paragraphs touch on some of the philosophical issues related to hypothesis testing which may help in understanding and communicating the test results.

5.2.1 Interpretation of p-Values

The classical approach for hypothesis tests is to prespecify the significance level of the test, i.e., the Type I decision error rate α. This rate is used to define the decision rule associated with the hypothesis test. For instance, in testing whether the population mean μ exceeds a threshold level (e.g., 100 ppm), the test statistic may depend on $\bar{x}$, an estimate of μ. Obtaining an estimate $\bar{x}$ that is greater than 100 ppm may occur simply by chance even if the true mean μ is less than or equal to 100; however, if $\bar{x}$ is "much larger" than 100 ppm, then there is only a small chance that the null hypothesis H_0 ($\mu \leq 100$ ppm) is true. Hence the decision rule might take the form "reject H_0 if $\bar{x}$ exceeds 100 + C", where C is a positive quantity that depends on α (and on the variability of $\bar{x}$). If this condition is met, then the result of the statistical test is reported as "reject H_0"; otherwise, the result is reported as "do not reject H_0."

An alternative way of reporting the result of a statistical test is to report its p-value, which is defined as the probability, assuming the null hypothesis to be true, of observing a test result at least as extreme as that found in the sample. Many statistical software packages report p-values, rather than adopting the classical approach of using a prespecified false rejection error rate. In the above example, for instance, the p-value would be the probability of observing a sample mean as large as $\bar{x}$ (or larger) if in fact the true mean was equal to 100 ppm. Obviously, in making a decision based on the p-value, one should reject H_0 when p is small and not reject it if p is large. Thus the relationship between p-values and the classical hypothesis testing approach is that one rejects H_0 if the p-value associated with the test result is less than α. If the data user had chosen the false rejection error rate as 0.05 *a priori* and the analyst reported a p-value of 0.12, then the data user would report the result as "do not reject the null hypothesis;" if the p-value had been reported as 0.03, then that person would report the result as "reject the null hypothesis." An advantage of reporting p-values is that they provide a measure of the strength of evidence for or against the null hypothesis, which allows data users to establish their own false rejection error rates. The significance level can be interpreted as that p-value (α) that divides "do not reject H_O" from "reject H_O."

5.2.2 "Accepting" vs. "Failing to Reject" the Null Hypothesis

As noted in the paragraphs above, the classical approach to hypothesis testing results in one of two conclusions: "reject H_0" (called a significant result) or "do not reject H_0" (a nonsignificant result). In the latter case one might be tempted to equate "do not reject H_0" with "accept H_0." This terminology is not recommended, however, because of the philosophy underlying the classical testing procedure. This philosophy places the burden of proof on the alternative hypothesis, that is, the null hypothesis is rejected only if the evidence furnished by the data convinces us that the alternative hypothesis is the more likely state of nature. If a nonsignificant result is obtained, it provides evidence that the null hypothesis *could* sufficiently account for the observed data, but it does not imply that the hypothesis is the only hypothesis that could be supported by the data. In other words, a highly nonsignificant result (e.g., a p-value of 0.80) may indicate that the null hypothesis provides a reasonable model for explaining the data, but it does not necessarily imply that the null hypothesis is true. It may, for example, simply indicate that the sample size was not large enough to establish convincingly that the alternative hypothesis was more likely. When the phrase "accept H_O" is encountered, it must be considered as "accepted with the preceding caveats."

5.2.3 Statistical Significance vs. Practical Significance

There is an important distinction between these two concepts. Statistical significance simply refers to the result of the hypothesis test: Was the null hypothesis rejected? The likelihood of achieving a statistically significant result depends on the true value of the population parameter being tested (for example, μ), how much that value deviates from the value hypothesized under the null hypothesis (for example, μ_0), and on the sample size. This dependence on (μ - μ_0) is depicted by the power curve associated with the test (Section 5.1.3). A steep power curve can be achieved by using a large sample size; this means that there will be a high likelihood of detecting even a small difference. On the other hand, if small sample sizes are used, the power curve will be less steep, meaning that only a very large difference between μ and μ_0 will be detectable with high probability. Hence, suppose one obtains a statistically significant result but has no knowledge of the power of the test. Then it is possible, in the case of the steep power curve, that one may be declaring significance (claiming $\mu > \mu_0$, for example) when the actual difference, from a practical standpoint, may be inconsequential. Or, in the case of the slowly increasing power curve, one may not find a significant result even though a "large" difference between μ and μ_0 exists. Neither of these situations is desirable: in the former case, there has been an excess of resources expended, whereas in the latter case, a false acceptance error is likely and has occurred.

But how large a difference between the parameter and the null value is of real importance? This relates to the concept of practical significance. Ideally, this question is asked and answered as part of the DQO process during the planning phase of the study. Knowing the magnitude of the difference that is regarded as being of practical significance is important during the design stage because this allows one, to the extent that prior information permits, to determine a sampling plan of type and size that will make the magnitude of that difference commensurate with a difference that can be detected with high probability. From a purely statistical design perspective, this can be considered to be main purpose of the DQO process. With such planning, the likelihood of encountering either of the undesirable situations mentioned in the prior paragraph can be reduced. Box 5-3 contains an example of a statistically significant but fairly inconsequential difference.

5.2.4 Impact of Bias on Test Results

Bias is defined as the difference between the expected value of a statistic and a population parameter. It is relevant when the statistic of interest (e.g., a sample average $\bar{x}$) is to be used as an estimate of the parameter (e.g., the population mean μ). For example, the population parameter of interest may be the average concentration of dioxin within the given bounds of a hazardous waste site, and the statistic might be the sample average as obtained from a random sample of points within those bounds. The expected value of a statistic can be interpreted as supposing one repeatedly implemented the particular sampling design a very large number of times and calculated the statistic of interest in each case. The average of the statistic's values would then be regarded as its expected value. Let E denote the expected value of $\bar{x}$ and denote the relationship between the expected value and the parameter, μ, as $E = \mu + b$ where b is the bias. For instance, if the bias occurred due to incomplete recovery of an analyte (and no adjustment is made), then $b = (R-100)\mu/100$, where R denotes the percent recovery. Bias may also occur for other reasons, such as lack of coverage of the entire target population (e.g., if only the drums within a storage site that are easily accessible are eligible for inclusion in the sample, then inferences to the entire group of drums may be biased). Moreover, in cases of incomplete coverage, the magnitude and direction of the bias may be unknown. An example involving comparison of the biases of two measurement methods is contained in Box 5-4.

Box 5-3: Example of a Comparison of Two Variances which is Statistically but not Practically Significant

The quality control (QC) program associated with a measurement system provides important information on performance and also yields data which should be taken into account in some statistical analyses. The QC program should include QC check samples, i.e., samples of known composition and concentration which are run at regular frequencies. The term precision refers to the consistency of a measurement method in repeated applications under fixed conditions and is usually equated with a standard deviation. The appropriate standard deviation is one which results from applying the system to the same sample over a long period of time.

This example concerns two methods for measuring ozone in ambient air, an approved method and a new candidate method. Both methods are used once per week on a weekly basis for three months. Based on 13 analyses with each method of the mid-range QC check sample at 100 ppb, the null hypothesis of the equality of the two variances will be tested with a false rejection error rate of 5% or less. (If the variances are equal, then the standard deviations are equal.) Method 1 had a sample mean of 80 ppb and a standard deviation of 4 ppb. Method 2 had a mean of 90 ppb and a standard deviation of 8 ppb. The Shapiro-Wilks test did not reject the assumption of normality for either method. Applying the F-test of Box 4-23, the F ratio is $8^2/4^2 = 2$. Using 12 degrees of freedom for both the numerator and denominator, the F ratio must exceed 3.28 in order to reject the hypothesis of equal variances (Table A-9 of Appendix A). Since 4 > 3.28, the hypothesis of equal variances is rejected, and it is concluded that method 1 is significantly more precise than method 2.

In an industrialized urban environment, the true ozone levels at a fixed location and time of day are known to vary over a period of months with a coefficient of variation of at least 100%. This means that the ratio of the standard deviation (SD) to the mean at a given location is at least 1. For a mean of 100 ppb, the standard deviation over time for true ozone values at the location would be at least 100 ppb. Relative to this degree of variability, a difference between measurement error standard deviations of 4 or 8 ppb is negligible. The overall variance, incorporating the true process variability and measurement error, is obtained by adding the individual variances. For instance, if measurement error standard deviation is 8 ppb, then the total variance is (100 ppb)(100 ppb) + (8 ppb)(8 ppb). Taking the square root of the variance gives a corresponding total standard deviation of 100.32 ppb. For a measurement error standard deviation of 4 ppb, the total standard deviation would be 100.08 ppb. From a practical standpoint, the difference in precision between the two methods is insignificant for the given application, despite the finding that there is a statistically significant difference between the variances of the two methods.

Box 5-4: Example of a Comparison of Two Biases

This example is a continuation of the ozone measurement comparison described in Box 5-3. Let $\bar{X}$ and s_X denote the sample mean and standard deviation of measurement method 1 applied to the QC check sample, and let $\bar{Y}$ and s_Y denote the sample mean and standard deviation of method 2. Then $\bar{X}$ = 80 ppb, s_X = 4 ppb, $\bar{Y}$ = 90 ppb and s_Y = 8 ppb. The estimated biases are $\bar{X}$ - T = 80 - 100 = -20 ppb for method 1, and $\bar{Y}$ - T = 90-100 = 10 ppb for method 2, since 100 ppb is the true value T. That is, method 1 seems to underestimate by 20 ppb, and method 2 seems to underestimate by 10 ppb. Let μ_1 and μ_2 be the underlying mean concentrations for measurement methods 1 and 2 applied to the QC check sample. These means correspond to the average results which would obtain by applying each method a large number of times to the QC check sample, over a long period of time.

A two-sample t-test (Boxes 3-14 and 3-16) can be used to test for a significant difference between these two biases. In this case, a two-tailed test of the null hypothesis H_0: $\mu_1 - \mu_2 = 0$ against the alternative H_A: $\mu_1 - \mu_2 \neq 0$ is appropriate, because there is no *a priori* reason (in advance of data collection) to suspect that one measurement method is superior to the other. (In general, hypotheses should not be tailored to data.) Note that the difference between the two biases is the same as the difference ($\mu_1 - \mu_2$) between the two underlying means of the measurement methods. The test will be done to limit the false rejection error rate to 5% if the two means are equal.

STEP 1: $\bar{X}$ = 80 ppb, s_X = 4 ppb, $\bar{Y}$ = 90 ppb, s_Y = 8 ppb.

STEP 2: From Box 5-3, it is known that the methods have significantly different variances, so that Sattherthwaite's t-test should be used. Therefore,

$$s_{NE} = \sqrt{\frac{s_X^2}{m} + \frac{s_Y^2}{n}} = \sqrt{\frac{4^2}{13} + \frac{8^2}{13}} = 2.48$$

STEP 3:

$$f = \frac{\left[\frac{s_X^2}{m} + \frac{s_Y^2}{n}\right]^2}{\left[\frac{s_X^4}{m^2(m-1)} + \frac{s_Y^4}{n^2\,(n-1)}\right]} = \frac{\left[\frac{4^2}{13} + \frac{8^2}{13}\right]^2}{\left[\frac{4^4}{13^2\;12} + \frac{8^4}{13^2\;12}\right]} = 17.65.$$

Rounding down to the nearest integer gives f = 17. For a two-tailed test, the critical value is $t_{1-\alpha/2} = t_{.975}$ = 2.110, from Table A-1 of Appendix A.

STEP 4:

$$t = \frac{\bar{X} - \bar{Y}}{S_{NE}} = \frac{80 - 90}{2.48} = -4.032$$

STEP 5: For a two-tailed test, compare *t* with $t_{1-\alpha/2}$ = 2.11. Since 4.032 > 2.11, reject the null hypothesis and conclude that there is a significant difference between the two method biases, in favor of method 2.

This box illustrates a situation involving two measurement methods where one method is more precise, but also more biased, than the other. If no adjustment for bias is made, then for many purposes, the less biased, more variable method is preferable. However, proper bias adjustment can make both methods unbiased, so that the more precise method becomes the preferred method. Such adjustments can be based on QC check sample results, if the QC check samples are regarded as representative of environmental samples involving sufficiently similar analytes and matrices.

In the context of hypothesis testing, the impact of bias can be quite severe in some circumstances. This can be illustrated by comparing the power curve of a test when bias is not present with a power curve for the same test when bias is present. The basic influence of bias is to shift the former "no bias" curve to the right or left, depending on the direction of the bias. If the bias is constant, then the second curve will be an exact translation of the former curve; if not, there will be a change in the shape of the second curve in addition to the translation. If the existence of the bias is unknown, then the former power curve will be regarded as the curve that determines the properties of the test when in fact the second curve will be the one that actually represents the test's power.

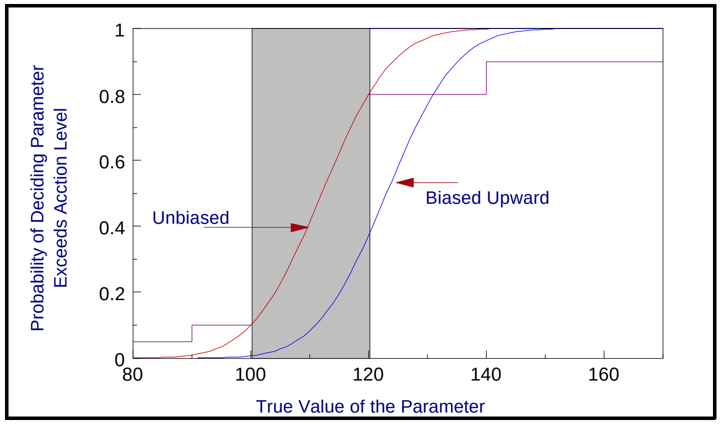

Figure 5-1. Illustration of Unbiased versus Biased Power Curves

For example, in Figure 5-1 when the true value of the parameter is 120, the "no bias" power is 0.72 but the true power (the biased power) is only 0.4, a substantial difference. Since bias is not impacted by changing the sample size, while the precision of estimates and the power of tests increases with sample size, the relative importance of bias becomes more pronounced when the sample size increases (i.e., when one makes the power curve steeper). Similarly, if the same magnitude of bias exists for two different sites, then the impact on testing errors will be more severe for the site having the smaller inherent variability in the characteristic of interest (i.e., when bias represents a larger portion of total variability).

To minimize the effects of bias: identify and document sources of potential bias; adopt measurement procedures (including specimen collection, handling, and analysis procedures) that minimize the potential for bias; make a concerted effort to quantify bias whenever possible; and make appropriate compensation for bias when possible.

5.2.5 Quantity vs. Quality of Data

The above conclusions imply that, *if compensation for bias cannot be made and if statistically-based decisions are to be made*, then there will be situations in which serious consideration should be given to using an imprecise (and perhaps relatively inexpensive) chemical method having negligible bias as compared to using a very precise method that has even a moderate degree of bias. The tradeoff favoring the imprecise method is especially relevant when the inherent variability in the population is very large relative to the random measurement error.

For example, suppose a mean concentration for a given spatial area (site) is of interest and that the coefficient of variation (CV) characterizing the site's variability is 100%. Let method A denote an imprecise method, with measurement-error CV of 40%, and let method B denote a highly precise method, with measurement-error CV of 5%. The overall variability, or total variability, can essentially be regarded as the sum of the spatial variability and the measurement variability. These are obtained from the individual CVs in the form of variances. As CV equals standard deviation divided by mean, it follows that the site standard deviation is then the CV times the mean. Thus, for the site, the variance is 1.00^2 x mean^2; for method A, the variance is 0.40^2 x mean^2; and for method B, the variance is 0.05^2 x mean^2. The overall variability when using method A is then (1.00^2 x mean^2) + (0.40^2 x mean^2) = 1.16 x mean^2, and when using method B, the variance is (1.00^2 x mean^2) + (0.05^2 x mean^2) = 1.0025 mean^2. It follows that the overall CV when using each method is then (1.077 x mean) / mean = 107.7% for method A, and (1.001 x mean) / mean = 100.1% for method B.

Now consider a sample of 25 specimens from the site. The *precision* of the sample mean can then be characterized by the relative standard error (RSE) of the mean (which for the simple random sample situation is simply the overall CV divided by the square root of the sample size). For Method A, RSE = 21.54%; for method B, RSE = 20.02%. Now suppose that the imprecise method (Method A) is unbiased, while the precise method (Method B) has a 10% bias (e.g., an analyte percent recovery of 90%). An overall measure of error that reflects how well the sample mean estimates the site mean is the relative root mean squared error (RRMSE):

$$RRMSE = \sqrt{(RB)^2 + (RSE)^2}$$

where RB denotes the relative bias (RB = 0 for Method A since it is unbiased and RB = ±10% for Method B since it is biased) and RSE is as defined above. The overall error in the estimation of the population mean (the RRMSE) would then be 21.54% for Method A and 22.38% for Method B. If the relative bias for Method B was 15% rather than 10%, then the RRMSE for Method A would be 21.54% and the RRMSE for Method B would be 25.02%, so the method difference is even more pronounced. While the above illustration is portrayed in terms of estimation of a mean based on a simple random sample, the basic concepts apply more generally.

This example serves to illustrate that a method that may be considered preferable from a chemical point of view [e.g., 85 or 90% recovery, 5% relative standard deviation (RSD)] may not perform as well in a statistical application as a method with less bias and greater imprecision (e.g., zero bias, 40% RSD), especially when the inherent site variability is large relative to the measurement-error RSD.

5.2.6 "Proof of Safety" vs. "Proof of Hazard"

Because of the basic hypothesis testing philosophy, the null hypothesis is generally specified in terms of the *status quo* (e.g., no change or action will take place if null hypothesis is not rejected). Also, since the classical approach exercises direct control over the false rejection error rate, this rate is generally associated with the error of most concern (for further discussion of this point, see Section 1.2). One difficulty, therefore, may be obtaining a consensus on which error should be of most concern. It is not unlikely that the Agency's viewpoint in this regard will differ from the viewpoint of the regulated party. In using this philosophy, the Agency's ideal approach is not only to set up the direction of the hypothesis in such a way that controlling the false rejection error protects the health and environment but also to set it up in a way that encourages quality (high precision and accuracy) and minimizes expenditure of resources in situations where decisions are relatively "easy" (e.g., all observations are far from the threshold level of interest).

In some cases, how one formulates the hypothesis testing problem can lead to very different sampling requirements. For instance, following remediation activities at a hazardous waste site, one may seek to answer "Is the site clean?" Suppose one attempts to address this question by comparing a mean level from samples taken after the remediation with a threshold level (chosen to reflect "safety"). If the threshold level is near background levels that might have existed in the absence of the contamination, then it may be very difficult (i.e., require enormous sample sizes) to "prove" that the site is "safe." This is because the concentrations resulting from even a highly efficient remediation under such circumstances would not be expected to deviate greatly from such a threshold. A better approach for dealing with this problem may be to compare the remediated site with a reference ("uncontaminated") site, assuming that such a site can be determined.

To avoid excessive expense in collecting and analyzing samples for a contaminant, compromises will sometimes be necessary. For instance, suppose that a significance level of 0.05 is to be used; however, the affordable sample size may be expected to yield a test with power of only 0.40 at some specified parameter value chosen to have practical significance (see Section 5.2.3). One possible way that compromise may be made in such a situation is to relax the significance level, for instance, using $\alpha = 0.10$, 0.15, or 0.20. By relaxing this false rejection rate, a higher power (i.e., a lower false acceptance rate β) can be achieved. An argument can be made, for example, that one should develop sampling plans and determine sample sizes in such a way that both the false rejection and false acceptance errors are treated simultaneously and in a balanced manner (for example, designing to achieve $\alpha = \beta = 0.15$) instead of using the traditional approach of fixing the false rejection error rate at 0.05 or 0.01 and letting β be determined by the sample size. This approach of treating the false rejection and false acceptance errors simultaneously is taken in the DQO Process and it is recommended that several different scenarios of α and β be investigated before a decision on specific values for α and β are selected.

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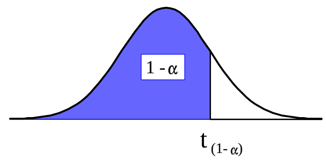
APPENDIX A

STATISTICAL TABLES

LIST OF TABLES

TABLE A-1: CRITICAL VALUES OF STUDENT'S t DISTRIBUTION



Degrees of Freedom	1 - α								
	.70	.75	.80	.85	.90	.95	.975	.99	.995
1	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
2	0.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
3	0.584	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841
4	0.569	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604
5	0.559	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032
6	0.553	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707
7	0.549	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499
8	0.546	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355
9	0.543	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250
10	0.542	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169
11	0.540	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106
12	0.539	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055
13	0.538	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012
14	0.537	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977
15	0.536	0.691	0.866	1.074	1.34	1.753	2.131	2.602	2.947
16	0.535	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921
17	0.534	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898
18	0.534	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878
19	0.533	0.6880	0.861	1.066	1.328	1.729	2.093	2.539	2.861
20	0.533	.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845
21	0.532	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831
22	0.532	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819
23	0.532	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807
24	0.531	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797
25	0.531	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787
26	0.531	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779
27	0.531	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771
28	0.530	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763
29	0.530	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756
30	0.530	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750
40	0.529	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704
60	0.527	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660
120	0.526	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617
∞	0.524	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576

Note: The last row of the table (∞ degrees of freedom) gives the critical values for a standard normal distribution (z), e.g., $t_{\infty,\ 0.95} = z_{0.95} = 1.645$.

TABLE A-2: CRITICAL VALUES FOR THE STUDENTIZED RANGE TEST

	Level of Significance α					
	0.01		0.05		0.10	
n	*a*	*b*	*a*	*b*	*a*	*b*
3	1.737	2.000	1.758	1.999	1.782	1.997
4	1.87	2.445	1.98	2.429	2.04	2.409
5	2.02	2.803	2.15	2.753	2.22	2.712
6	2.15	3.095	2.28	3.012	2.37	2.949
7	2.26	3.338	2.40	3.222	2.49	3.143
8	2.35	3.543	2.50	3.399	2.59	3.308
9	2.44	3.720	2.59	3.552	2.68	3.449
10	2.51	3.875	2.67	3.685	2.76	3.57
11	2.58	4.012	2.74	3.80	2.84	3.68
12	2.64	4.134	2.80	3.91	2.90	3.78
13	2.70	4.244	2.86	4.00	2.96	3.87
14	2.75	4.34	2.92	4.09	3.02	3.95
15	2.80	4.44	2.97	4.17	3.07	4.02
16	2.84	4.52	3.01	4.24	3.12	4.09
17	2.88	4.60	3.06	4.31	3.17	4.15
18	2.92	4.67	3.10	4.37	3.21	4.21
19	2.96	4.74	3.14	4.43	3.25	4.27
20	2.99	4.80	3.18	4.49	3.29	4.32
25	3.15	5.06	3.34	4.71	3.45	4.53
30	3.27	5.26	3.47	4.89	3.59	4.70
35	3.38	5.42	3.58	5.04	3.70	4.84
40	3.47	5.56	3.67	5.16	3.79	4.96
45	3.55	5.67	3.75	5.26	3.88	5.06
50	3.62	5.77	3.83	5.35	3.95	5.14
55	3.69	5.86	3.90	5.43	4.02	5.22
60	3.75	5.94	3.96	5.51	4.08	5.29
65	3.80	6.01	4.01	5.57	4.14	5.35
70	3.85	6.07	4.06	5.63	4.19	5.41
75	3.90	6.13	4.11	5.68	4.24	5.46
80	3.94	6.18	4.16	5.73	4.28	5.51
85	3.99	6.23	4.20	5.78	4.33	5.56
90	4.02	6.27	4.24	5.82	4.36	5.60
95	4.06	6.32	4.27	5.86	4.40	5.64
100	4.10	6.36	4.31	5.90	4.44	5.68
150	4.38	6.64	4.59	6.18	4.72	5.96
200	4.59	6.84	4.78	6.39	4.90	6.15
500	5.13	7.42	5.47	6.94	5.49	6.72
1000	5.57	7.80	5.79	7.33	5.92	7.11

TABLE A-3: CRITICAL VALUES FOR THE EXTREME VALUE TEST (DIXON'S TEST)

	Level of Significance α		
n	**0.10**	**0.05**	**0.01**
3	0.886	0.941	0.988
4	0.679	0.765	0.889
5	0.557	0.642	0.780
6	0.482	0.560	0.698
7	0.434	0.507	0.637
8	0.479	0.554	0.683
9	0.441	0.512	0.635
10	0.409	0.477	0.597
11	0.517	0.576	0.679
12	0.490	0.546	0.642
13	0.467	0.521	0.615
14	0.492	0.546	0.641
15	0.472	0.525	0.616
16	0.454	0.507	0.595
17	0.438	0.490	0.577
18	0.424	0.475	0.561
19	0.412	0.462	0.547
20	0.401	0.450	0.535
21	0.391	0.440	0.524
22	0.382	0.430	0.514
23	0.374	0.421	0.505
24	0.367	0.413	0.497
25	0.360	0.406	0.489

TABLE A-4: CRITICAL VALUES FOR DISCORDANCE TEST

n	Level of Significance α	
	0.01	**0.05**
3	1.155	1.153
4	1.492	1.463
5	1.749	1.672
6	1.944	1.822
7	2.097	1.938
8	2.221	2.032
9	2.323	2.110
10	2.410	2.176
11	2.485	2.234
12	2.550	2.285
13	2.607	2.331
14	2.659	2.371
15	2.705	2.409
16	2.747	2.443
17	2.785	2.475
18	2.821	2.504
19	2.854	2.532
20	2.884	2.557
21	2.912	2.580
22	2.939	2.603
23	2.963	2.624
24	2.987	2.644
25	3.009	2.663
26	3.029	2.681
27	3.049	2.698
28	3.068	2.714
29	3.085	2.730
30	3.103	2.745
31	3.119	2.759
32	3.135	2.773

n	Level of Significance α	
	0.01	**0.05**
33	3.150	2.786
34	3.164	2.799
35	3.178	2.811
36	3.191	2.823
37	3.204	2.835
38	3.216	2.846
39	3.228	2.857
40	3.240	2.866
41	3.251	2.877
42	3.261	2.887
43	3.271	2.896
44	3.282	2.905
45	3.292	2.914
46	3.302	2.923
47	3.310	2.931
48	3.319	2.940
49	3.329	2.948
50	3.336	2.956

TABLE A-5: APPROXIMATE CRITICAL VALUES λ_r FOR ROSNER'S TEST

n	r	α 0.05	α 0.01
25	1	2.82	3.14
	2	2.80	3.11
	3	2.78	3.09
	4	2.76	3.06
	5	2.73	3.03
	10	2.59	2.85
26	1	2.84	3.16
	2	2.82	3.14
	3	2.80	3.11
	4	2.78	3.09
	5	2.76	3.06
	10	2.62	2.89
27	1	2.86	3.18
	2	2.84	3.16
	3	2.82	3.14
	4	2.80	3.11
	5	2.78	3.09
	10	2.65	2.93
28	1	2.88	3.20
	2	2.86	3.18
	3	2.84	3.16
	4	2.82	3.14
	5	2.80	3.11
	10	2.68	2.97
29	1	2.89	3.22
	2	2.88	3.20
	3	2.86	3.18
	4	2.84	3.16
	5	2.82	3.14
	10	2.71	3.00
30	1	2.91	3.24
	2	2.89	3.22
	3	2.88	3.20
	4	2.86	3.18
	5	2.84	3.16
	10	2.73	3.03
31	1	2.92	3.25
	2	2.91	3.24
	3	2.89	3.22
	4	2.88	3.20
	5	2.86	3.18
	10	2.76	3.06

n	r	α 0.05	α 0.01
32	1	2.94	3.27
	2	2.92	3.25
	3	2.91	3.24
	4	2.89	3.22
	5	2.88	3.20
	10	2.78	3.09
33	1	2.95	3.29
	2	2.94	3.27
	3	2.92	3.25
	4	2.91	3.24
	5	2.89	3.22
	10	2.80	3.11
34	1	2.97	3.30
	2	2.95	3.29
	3	2.94	3.27
	4	2.92	3.25
	5	2.91	3.24
	10	2.82	3.14
35	1	2.98	3.32
	2	2.97	3.30
	3	2.95	3.29
	4	2.94	3.27
	5	2.92	3.25
	10	2.84	3.16
36	1	2.99	3.33
	2	2.98	3.32
	3	2.97	3.30
	4	2.95	3.29
	5	2.94	3.27
	10	2.86	3.18
37	1	3.00	3.34
	2	2.99	3.33
	3	2.98	3.32
	4	2.97	3.30
	5	2.95	3.29
	10	2.88	3.20
38	1	3.01	3.36
	2	3.00	3.34
	3	2.99	3.33
	4	2.98	3.32
	5	2.97	3.30
	10	2.91	3.22

n	r	α 0.05	α 0.01
39	1	3.03	3.37
	2	3.01	3.36
	3	3.00	3.34
	4	2.99	3.33
	5	2.98	3.32
	10	2.91	3.24
40	1	3.04	3.38
	2	3.03	3.37
	3	3.01	3.36
	4	3.00	3.34
	5	2.99	3.33
	10	2.92	3.25
41	1	3.05	3.39
	2	3.04	3.38
	3	3.03	3.37
	4	3.01	3.36
	5	3.00	3.34
	10	2.94	3.27
42	1	3.06	3.40
	2	3.05	3.39
	3	3.04	3.38
	4	3.03	3.37
	5	3.01	3.36
	10	2.95	3.29
43	1	3.07	3.41
	2	3.06	3.40
	3	3.05	3.39
	4	3.04	3.38
	5	3.03	3.37
	10	2.97	3.30
44	1	3.08	3.43
	2	3.07	3.41
	3	3.06	3.40
	4	3.05	3.39
	5	3.04	3.38
	10	2.98	3.32
45	1	3.09	3.44
	2	3.08	3.43
	3	3.07	3.41
	4	3.06	3.40
	5	3.05	3.39
	10	2.99	3.33

TABLE A-5: APPROXIMATE CRITICAL VALUES λ_r FOR ROSNER'S TEST

n	r	α	
		0.05	0.01
46	1	3.09	3.45
	2	3.09	3.44
	3	3.08	3.43
	4	3.07	3.41
	5	3.06	3.40
	10	3.00	3.34
47	1	3.10	3.46
	2	3.09	3.45
	3	3.09	3.44
	4	3.08	3.43
	5	3.07	3.41
	10	3.01	3.36
48	1	3.11	3.46
	2	3.10	3.46
	3	3.09	3.45
	4	3.09	3.44
	5	3.08	3.43
	10	3.03	3.37
49	1	3.12	3.47
	2	3.11	3.46
	3	3.10	3.46
	4	3.09	3.45
	5	3.09	3.44
	10	3.04	3.38
50	1	3.13	3.48
	2	3.12	3.47
	3	3.11	3.46
	4	3.10	3.46
	5	3.09	3.45
	10	3.05	3.39
60	1	3.20	3.56
	2	3.19	3.55
	3	3.19	3.55
	4	3.18	3.54
	5	3.17	3.53
	10	3.14	3.49

n	r	α	
		0.05	0.01
70	1	3.26	3.62
	2	3.25	3.62
	3	3.25	3.61
	4	3.24	3.60
	5	3.24	3.60
	10	3.21	3.57
80	1	3.31	3.67
	2	3.30	3.67
	3	3.30	3.66
	4	3.29	3.66
	5	3.29	3.65
	10	3.26	3.63
90	1	3.35	3.72
	2	3.34	3.71
	3	3.34	3.71
	4	3.34	3.70
	5	3.33	3.70
	10	3.31	3.68
100	1	3.38	3.75
	2	3.38	3.75
	3	3.38	3.75
	4	3.37	3.74
	5	3.37	3.74
	10	3.35	3.72
150	1	3.52	3.89
	2	3.51	3.89
	3	3.51	3.89
	4	3.51	3.88
	5	3.51	3.88
	10	3.50	3.87
200	1	3.61	3.98
	2	3.60	3.98
	3	3.60	3.97
	4	3.60	3.97
	5	3.60	3.97
	10	3.59	3.96

n	r	α	
		0.05	0.01
250	1	3.67	4.04
	5	3.67	4.04
	10	3.66	4.03
300	1	3.72	4.09
	5	3.72	4.09
	10	3.71	4.09
350	1	3.77	4.14
	5	3.76	4.13
	10	3.76	4.13
400	1	3.80	4.17
	5	3.80	4.17
	10	3.80	4.16
450	1	3.84	4.20
	5	3.83	4.20
	10	3.83	4.20
500	1	3.86	4.23
	5	3.86	4.23
	10	3.86	4.22

TABLE A-6: QUANTILES OF THE WILCOXON SIGNED RANKS TEST

n	$w_{.01}$	$w_{.05}$	$w_{.10}$	$w_{.20}$
4	0	0	1	3
5	0	1	3	4
6	0	3	4	6
7	1	4	6	9
8	2	6	9	12
9	4	9	11	15
10	6	11	15	19
11	8	14	18	23
12	10	18	22	28
13	13	22	27	33
14	16	26	32	39
15	20	31	37	45
16	24	36	43	51
17	28	42	49	58
18	33	48	56	66
19	38	54	63	74
20	44	61	70	82

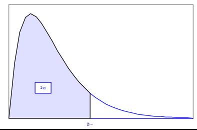
TABLE A-7: CRITICAL VALUES FOR THE RANK-SUM TEST

n	α	*m* = 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	**0.05**	0	0	0	1	1	1	2	2	2	2	3	3	4	4	4	4	5	5	5
	0.10	0	1	1	2	2	2	3	3	4	4	5	5	5	6	6	7	7	8	8
3	**0.05**	0	1	1	2	3	3	4	5	5	6	6	7	8	8	9	10	10	11	12
	0.10	1	2	2	3	4	5	6	6	7	8	9	10	11	11	12	13	14	15	16
4	**0.05**	0	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19
	0.10	1	2	4	5	6	7	8	10	11	12	13	14	16	17	18	19	21	22	23
5	**0.05**	1	2	3	5	6	7	9	10	12	13	14	16	17	19	20	21	23	24	26
	0.10	2	3	5	6	8	9	11	13	14	16	18	19	21	23	24	26	28	29	31
6	**0.05**	1	3	4	6	8	9	11	13	15	17	18	20	22	24	26	27	29	31	33
	0.10	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	35	37	39
7	**0.05**	1	3	5	7	9	12	14	16	18	20	22	25	27	29	31	34	36	38	40
	0.10	2	5	7	9	12	14	17	19	22	24	27	29	32	34	37	39	42	44	47
8	**0.05**	2	4	6	9	111	14	16	19	21	24	27	29	32	34	37	40	42	45	48
	0.10	3	6	8	11	4	17	20	23	25	28	31	34	37	40	43	46	49	52	55
9	**0.05**	2	5	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55
	0.10	3	6	10	13	16	19	23	26	29	32	36	39	42	46	49	53	56	59	63
10	**0.05**	2	5	8	12	15	18	21	25	28	32	35	38	42	45	49	52	56	59	63
	0.10	4	7	11	14	18	22	25	29	33	37	40	44	48	52	55	59	63	67	71
11	**0.05**	2	6	9	13	17	20	24	28	32	35	39	43	47	51	55	58	62	66	70
	0.10	4	8	12	16	20	24	28	32	37	41	45	49	53	58	62	66	70	74	79
12	**0.05**	3	6	10	14	18	22	27	31	35	39	43	48	52	56	61	65	69	73	78
	0.10	5	9	13	18	22	27	31	36	40	45	50	54	59	64	68	73	78	82	87
13	**0.05**	3	7	11	16	20	25	29	34	38	43	48	52	57	62	66	71	76	81	85
	0.10	5	10	14	19	24	29	34	39	44	49	54	59	64	69	75	80	85	90	95
14	**0.05**	4	8	12	17	22	27	32	37	42	47	52	57	62	67	72	78	83	88	93
	0.10	5	11	16	21	26	32	37	42	48	53	59	64	70	75	81	86	92	98	103
15	**0.05**	4	8	13	19	24	29	34	40	45	51	56	62	67	73	78	84	89	95	101
	0.10	6	11	17	23	28	34	40	46	52	58	64	69	75	81	87	93	99	105	111
16	**0.05**	4	9	15	20	26	31	37	43	49	55	61	66	72	78	84	90	96	102	108
	0.10	6	12	18	24	30	37	43	49	55	62	68	75	81	87	94	100	107	113	120
17	**0.05**	4	10	16	21	27	34	40	46	52	58	65	71	78	84	90	97	103	110	116
	0.10	7	13	19	26	32	39	46	53	59	66	73	80	86	93	100	107	114	121	128

TABLE A-7: CRITICAL VALUES FOR THE RANK-SUM TEST

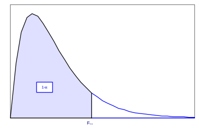
n	α	*m* 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
18	**0.05**	5	10	17	23	29	36	42	49	56	62	69	76	83	89	96	103	110	117	124
	0.10	7	14	21	28	35	42	49	56	63	70	78	85	92	99	107	114	121	129	136
19	**0.05**	5	11	18	24	31	38	45	52	59	66	73	81	88	95	102	110	117	124	131
	0.10	8	15	22	29	37	44	52	59	67	74	82	90	98	105	113	121	129	136	144
20	**0.05**	5	12	19	26	33	40	48	55	63	70	78	85	93	101	108	116	124	131	139
	0.10	8	16	23	31	39	47	55	63	71	79	87	95	103	111	120	128	136	144	152

TABLE A-8: PERCENTILES OF THE CHI-SQUARE DISTRIBUTION



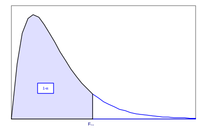
v	1 - α									
	.005	.010	.025	.050	.100	.900	.950	.975	.990	.995
1	$0.0^{4}393$	$0.0^{3}157$	$0.0^{3}982$	$0.0^{2}393$	0.0158	2.71	3.84	5.02	6.63	7.88
2	0.0100	0.0201	0.0506	0.103	0.211	4.61	5.99	7.38	9.21	10.60
3	0.072	0.115	0.216	0.352	0.584	6.25	7.81	9.35	11.34	12.84
4	0.207	0.297	0.484	0.711	1.064	7.78	9.49	11.14	13.28	14.86
5	0.412	0.554	0.831	1.145	1.61	9.24	11.07	12.83	15.09	16.75
6	0.676	0.872	1.24	1.64	2.20	10.64	12.59	14.45	16.81	18.55
7	0.989	1.24	1.69	2.17	2.83	12.02	14.07	16.01	18.48	20.28
8	1.34	1.65	2.18	2.73	3.49	13.36	15.51	17.53	20.09	21.96
9	1.73	2.09	2.70	3.33	4.17	14.68	16.92	19.02	21.67	23.59
10	2.16	2.56	3.25	3.94	4.87	15.99	18.31	20.48	23.21	25.19
11	2.60	3.05	3.82	3.57	5.58	17.28	19.68	21.92	24.73	26.76
12	3.07	3.57	4.40	5.23	6.30	18.55	21.03	23.34	26.22	28.30
13	3.57	4.11	5.01	5.89	7.04	19.81	22.36	24.74	27.69	29.82
14	4.07	4.66	5.63	6.57	7.79	21.06	23.68	26.12	29.14	31.32
15	4.60	5.23	6.26	7.26	8.55	22.31	25.00	27.49	30.58	32.80
16	5.14	5.81	6.91	7.96	9.31	23.54	26.30	28.85	32.00	34.27
17	5.70	6.41	7.56	8.67	10.09	24.77	27.59	30.19	33.41	35.72
18	6.26	7.01	8.23	9.39	10.86	25.99	28.87	31.53	34.81	37.16
19	6.84	7.63	8.91	10.12	11.65	27.20	30.14	32.85	36.19	38.58
20	7.43	8.26	9.59	10.85	12.44	28.41	31.41	34.17	37.57	40.00
21	8.03	8.90	10.28	11.59	13.24	29.62	32.67	35.48	38.93	41.40
22	8.64	9.54	10.98	12.34	14.04	30.81	33.92	36.78	40.29	42.80
23	9.26	10.20	11.69	13.09	14.85	32.01	35.17	38.08	41.64	44.18
24	9.89	10.86	12.40	13.85	15.66	33.20	36.42	39.36	42.98	45.56
25	10.52	11.52	13.12	14.61	16.47	34.38	37.65	40.65	44.31	46.93
26	11.16	12.20	13.84	15.38	17.29	35.56	38.89	41.92	45.64	48.29
27	11.81	12.88	14.57	16.15	18.11	36.74	40.11	43.19	46.96	49.64
28	12.46	13.56	15.31	16.93	18.94	37.92	41.34	44.46	48.28	50.99
29	13.12	14.26	16.05	17.71	19.77	39.09	42.56	45.72	49.59	52.34
30	13.79	14.95	16.79	18.49	20.60	40.26	43.77	46.98	50.89	53.67
40	20.71	22.16	24.43	26.51	29.05	51.81	55.76	59.34	63.69	66.77
50	27.99	29.71	32.36	34.76	37.69	63.17	67.50	71.42	76.15	79.49
60	35.53	37.48	40.48	43.19	46.46	74.40	79.08	83.30	88.38	91.95
70	43.28	45.44	48.76	51.74	53.33	85.53	90.53	95.02	100.4	104.2
80	51.17	53.54	57.15	60.39	64.28	96.58	101.9	106.6	112.3	116.3
90	59.20	61.75	65.65	69.13	73.29	107.6	113.1	118.1	124.1	128.3
100	67.33	70.06	74.22	77.93	82.36	118.5	124.3	129.6	135.8	140.2

TABLE A-9: PERCENTILES OF THE F DISTRIBUTION



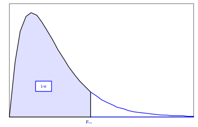
Degrees Freedom for Denom-inator		Degrees of Freedom for Numerator																	
		1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	60	120	∞
1	.50	1.00	1.50	1.71	1.82	1.89	1.94	1.98	2.00	2.03	2.04	2.07	2.09	2.12	2.13	2.15	2.17	2.18	2.20
	.90	39.9	49.5	53.6	55.8	57.2	58.2	58.9	59.4	59.9	60.2	60.7	61.2	61.7	62.0	62.3	62.8	63.1	63.3
	.95	161	200	216	225	230	234	237	239	241	242	244	246	248	249	250	252	253	254
	.975	648	800	864	900	922	937	948	957	963	969	977	985	993	997	1001	1010	1014	1018
	.99	4052	5000	5403	5625	5764	5859	5928	5981	6022	6056	6106	6157	6209	6235	6261	6313	6339	6366
2	.50	0.667	1.00	1.13	1.21	1.25	1.28	1.30	1.32	1.33	1.34	1.36	1.38	1.39	1.40	1.41	1.43	1.43	1.44
	.90	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.48	9.49
	.95	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5
	.975	38.5	39.0	39.2	39.2	39.3	39.3	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.5	39.5	39.5	39.5	39.5
	.99	98.5	99.0	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.5	99.5	99.5	99.5	99.5
3	.50	0.585	0.881	1.00	1.06	1.10	1.13	1.15	1.16	1.17	1.18	1.20	1.21	1.23	1.23	1.24	1.25	1.26	1.27
	.90	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.22	5.20	5.18	5.18	5.17	5.15	5.14	5.13
	.95	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.57	8.55	8.53
	.975	17.4	16.0	15.4	15.1	14.9	14.7	14.6	14.5	14.5	14.4	14.3	14.3	14.2	14.1	14.1	14.0	13.9	13.9
	.99	34.1	30.8	29.5	28.7	28.2	27.9	27.7	27.5	27.3	27.2	27.1	26.9	26.7	26.6	26.5	26.3	26.2	26.1
4	.50	0.549	0.828	0.941	1.00	1.04	1.06	1.08	1.09	1.10	1.11	1.13	1.14	1.15	1.16	1.16	1.18	1.18	1.19
	.90	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94	3.92	3.90	3.87	3.84	3.83	3.82	3.79	3.78	3.76
	.95	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.69	5.66	5.63
	.975	12.2	10.6	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.75	8.66	8.56	8.51	8.46	8.36	8.31	8.26
	.99	21.2	18.0	16.7	16.0	15.5	15.2	15.0	14.8	14.7	14.5	14.4	14.2	14.0	13.9	13.8	13.7	13.6	13.5
	.999	74.1	61.2	56.2	53.4	51.7	50.5	49.7	49.0	48.5	48.1	47.4	46.8	46.1	45.8	45.4	44.7	44.4	44.1

TABLE A-9: PERCENTILES OF THE F DISTRIBUTION



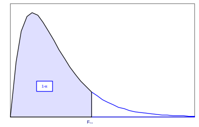
Degrees Freedom for Denom-inator		Degrees of Freedom for Numerator																	
		1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	60	120	∞
5	.50	0.528	0.799	0.907	0.965	1.00	1.02	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.12	1.12	1.14	1.14	1.15
	.90	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.39	3.27	3.24	3.21	3.19	3.17	3.14	3.12	3.11
	.95	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.43	4.40	4.37
	.975	10.0	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.52	6.43	6.33	6.28	6.23	6.12	6.07	6.02
	.99	16.3	13.3	12.1	11.4	11.0	10.7	10.5	10.3	10.2	10.1	9.89	9.72	9.55	9.47	9.38	9.20	9.11	9.02
	.999	47.2	37.1	33.2	31.1	29.8	28.8	28.2	27.6	27.2	26.9	26.4	25.9	25.4	25.1	24.9	24.3	24.1	23.8
6	.50	0.515	0.780	0.886	0.942	0.977	1.00	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12	1.12
	.90	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96	2.94	2.90	2.87	2.84	2.82	2.80	2.76	2.74	2.72
	.95	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.74	3.70	3.67
	.975	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.37	5.27	5.17	5.12	5.07	4.96	4.90	4.85
	.99	22.8	10.9	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.23	7.06	6.97	6.88
	.999	35.5	27.0	23.7	21.9	20.8	20.0	19.5	19.0	18.7	18.4	18.0	17.6	17.1	16.9	16.7	16.2	16.0	15.7
7	.50	0.506	.0767	0.871	0.926	0.960	0.983	1.00	1.01	1.02	1.03	1.04	1.05	1.07	1.07	1.08	1.09	1.10	1.10
	.90	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.67	2.63	2.59	2.58	2.56	2.51	2.49	2.47
	.95	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.30	3.27	3.23
	.975	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.67	4.57	4.47	4.42	4.36	4.25	4.20	4.14
	.99	12.2	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	5.99	5.82	5.74	5.65
	.999	29.2	21.7	18.8	17.2	16.2	15.5	15.0	14.6	14.5	14.1	13.7	13.3	12.9	12.7	12.5	12.1	11.9	11.7
8	.50	0.499	0.757	0.860	0.915	0.948	0.971	0.988	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.08	1.09
	.90	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.50	2.46	2.42	2.40	2.38	2.34	2.32	2.29
	.95	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.01	2.97	2.93
	.975	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.20	4.10	4.00	3.95	3.89	3.78	3.73	3.67
	.99	11.3	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.20	5.03	4.95	4.86
	.999	25.4	18.5	15.8	14.4	13.5	12.9	12.4	12.0	11.8	11.5	11.2	10.8	10.5	10.3	10.1	9.73	9.53	9.33

TABLE A-9: PERCENTILES OF THE F DISTRIBUTION



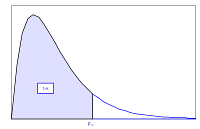
Degrees Freedom for Denom-inator		Degrees of Freedom for Numerator																	
		1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	60	120	∞
9	.50	0.494	0.749	0.852	0.906	0.939	0.962	0.978	0.990	1.00	1.01	1.01	1.03	1.04	1.05	1.05	1.07	1.07	1.08
	.90	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.38	2.34	2.30	2.28	2.25	2.21	2.18	2.16
	.95	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.79	2.75	2.71
	.975	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.87	3.77	3.67	3.61	3.56	3.45	3.39	3.33
	.99	10.6	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.65	4.48	4.40	4.31
	.999	22.9	16.4	13.9	12.6	11.7	11.1	10.7	10.4	10.1	9.89	9.57	9.24	8.90	8.72	8.55	8.19	8.00	7.81
10	.50	0.490	0.743	0.845	0.899	0.932	0.954	0.971	0.983	0.992	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.06	1.07
	.90	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.28	2.24	2.20	2.18	2.16	2.11	2.08	2.06
	.95	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.74	2.70	2.62	2.58	2.54
	.975	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.62	3.52	3.42	3.37	3.31	3.20	3.14	3.08
	.99	10.0	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.25	4.08	4.00	3.91
	.999	21.0	14.9	12.6	11.3	10.5	9.93	9.52	9.20	8.96	8.75	8.45	8.13	7.80	7.64	7.47	7.12	6.94	6.76
12	.50	0.484	0.735	0.835	0.888	0.921	0.943	0.959	0.972	0.981	0.989	1.00	1.01	1.02	1.03	1.03	1.05	1.05	1.06
	.90	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.15	2.10	2.06	2.04	2.01	1.96	1.93	1.90
	.95	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.38	2.34	2.30
	.975	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.28	3.18	3.07	3.02	2.96	2.85	2.79	2.72
	.99	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.70	3.54	3.45	3.36
	.999	18.6	13.0	10.8	9.63	8.89	8.38	8.00	7.71	7.48	7.29	7.00	6.71	6.40	6.25	6.09	5.76	5.59	5.42
15	.50	0.478	0.726	0.826	0.878	0.911	0.933	0.949	0.960	0.970	0.977	0.989	1.00	1.01	1.02	1.02	1.03	1.04	1.05
	.90	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	2.02	1.97	1.92	1.90	1.87	1.82	1.79	1.76
	.95	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.16	2.11	2.07
	.975	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	2.96	2.86	2.76	2.70	2.64	2.52	2.46	2.40
	.99	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.21	3.05	2.96	2.87
	.999	16.6	11.3	9.34	8.25	7.57	7.09	6.74	6.47	6.26	6.08	5.81	5.54	5.25	5.10	4.95	4.64	4.48	4.31

TABLE A-9: PERCENTILES OF THE F DISTRIBUTION



Degrees Freedom for Denom-inator	Degrees of Freedom for Numerator																	
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	60	120	∞
20 .50	0.472	0.718	0.816	0.868	0.900	0.922	0.938	0.950	0.959	0.966	0.977	0.989	1.00	1.01	1.01	1.02	1.03	1.03
.90	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.89	1.84	1.79	1.77	1.74	1.68	1.64	1.61
.95	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.95	1.90	1.84
.975	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.68	2.57	2.46	2.41	2.35	2.22	2.16	2.09
.99	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.78	2.61	2.52	2.42
.999	14.8	9.95	8.10	7.10	6.46	6.02	5.69	5.44	5.24	5.08	4.82	4.56	4.29	4.15	4.00	3.70	3.54	3.38
24 .50	0.469	0.714	0.812	0.863	0.895	0.917	0.932	0.944	0.953	0.961	0.972	0.983	0.994	1.00	1.01	1.02	1.02	1.03
.90	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91	1.88	1.83	1.78	1.73	1.70	1.67	1.61	1.57	1.53
.95	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.84	1.79	1.73
.975	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70	2.64	2.54	2.44	2.33	2.27	2.21	2.08	2.01	1.94
.99	7.82	6.66	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.58	2.40	2.31	2.21
.999	14.0	9.34	7.55	6.59	5.98	5.55	5.23	4.99	4.80	4.64	4.39	4.14	3.87	3.74	3.59	3.29	3.14	2.97
30 .50	0.466	0.709	0.807	0.858	0.890	0.912	0.927	0.939	0.948	0.955	0.966	0.978	0.989	0.994	1.00	1.01	1.02	1.02
.90	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85	1.82	1.77	1.72	1.62	1.64	1.61	1.54	1.50	1.46
.95	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.74	1.68	1.62
.975	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.41	2.31	2.20	2.14	2.07	1.94	1.87	1.79
.99	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.39	2.21	2.11	2.01
.999	13.3	8.77	7.05	6.12	5.53	5.12	4.82	4.58	4.39	4.24	4.00	3.75	3.49	3.36	3.22	2.92	2.76	2.59
60 .50	0.461	0.701	0.798	0.849	0.880	0.901	0.917	0.928	0.937	0.945	0.956	0.967	0.978	0.983	0.989	1.00	1.01	1.01
.90	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.66	1.60	1.54	1.51	1.48	1.40	1.35	1.29
.95	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.53	1.47	1.39
.975	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.17	2.06	1.94	1.88	1.82	1.67	1.58	1.48
.99	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.03	1.84	1.73	1.60
.999	12.0	7.77	6.17	5.31	4.76	4.37	4.09	3.86	3.69	3.54	3.32	3.08	2.83	2.69	2.55	2.25	2.08	1.89

TABLE A-9: PERCENTILES OF THE F DISTRIBUTION



Degrees Freedom for Denom-inator	Degrees of Freedom for Numerator																	
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	60	120	∞
120 . 90	2.75	2.35	2.13	1.99	1.90	1.82	1.77	1.72	1.68	1.65	1.60	1.55	1.48	1.45	1.41	1.32	1.26	1.19
.95	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.43	1.35	1.25
.975	5.15	3.80	3.23	2.89	2.67	2.52	2.39	2.30	2.22	2.16	2.05	1.95	1.82	1.76	1.69	1.53	1.43	1.31
.99	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.86	1.66	1.53	1.38
.999	11.4	7.32	5.78	4.95	4.42	4.04	3.77	3.55	3.38	3.24	3.02	2.78	2.53	2.40	2.26	1.95	1.77	1.54
∞ .90	2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63	1.60	1.55	1.49	1.42	1.38	1.34	1.24	1.17	1.00
.95	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.32	1.22	1.00
.975	5.02	3.69	3.12	2.79	2.57	22.41	2.29	2.19	2.11	2.05	1.94	1.83	1.71	1.64	1.57	1.39	1.27	1.00
.99	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.70	1.47	1.32	1.00
.999	10.8	6.91	5.42	4.62	4.10	3.74	3.47	3.27	3.10	2.96	2.74	2.51	2.27	2.13	1.99	1.66	1.45	1.00

TABLE A-10: VALUES OF THE PARAMETER $\hat{\lambda}$ FOR COHEN'S ESTIMATES ADJUSTING FOR NONDETECTED VALUES

γ	h .01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.15	.20
.00	.010100	.020400	.030902	.041583	.052507	.063625	.074953	.08649	.09824	.11020	.17342	.24268
.05	.010551	.021294	.032225	.043350	.054670	.066159	.077909	.08983	.10197	.11431	.17925	.25033
.10	.010950	.022082	.033398	.044902	.056596	.068483	.080563	.09285	.10534	.11804	.18479	.25741
.15	.011310	.022798	.034466	.046318	.058356	.070586	.083009	.09563	.10845	.12148	.18985	.26405
.20	.011642	.023459	.035453	.047829	.059990	.072539	.085280	.09822	.11135	.12469	.19460	.27031
.25	.011952	.024076	.036377	.048858	.061522	.074372	.087413	.10065	.11408	.12772	.19910	.27626
.30	.012243	.024658	.037249	.050018	.062969	.076106	.089433	.10295	.11667	.13059	.20338	.28193
.35	.012520	.025211	.038077	.051120	.064345	.077736	.091355	.10515	.11914	.13333	.20747	.28737
.40	.012784	.025738	.038866	.052173	.065660	.079332	.093193	.10725	.12150	.13595	.21129	.29250
.45	.013036	.026243	.039624	.053182	.066921	.080845	.094958	.10926	.12377	.13847	.21517	.29765
.50	.013279	.026728	.040352	.054153	.068135	.082301	.096657	.11121	.12595	.14090	.21882	.30253
.55	.013513	.027196	.041054	.055089	.069306	.083708	.098298	.11208	.12806	.14325	.22225	.30725
.60	.013739	.027849	.041733	.055995	.070439	.085068	.099887	.11490	.13011	.14552	.22578	.31184
.65	.013958	.028087	.042391	.056874	.071538	.086388	.10143	.11666	.13209	.14773	.22910	.31630
.70	.014171	.028513	.043030	.057726	.072505	.087670	.10292	.11837	.13402	.14987	.23234	.32065
.75	.014378	.029927	.043652	.058556	.073643	.088917	.10438	.12004	.13590	.15196	.23550	.32489
.80	.014579	.029330	.044258	.059364	.074655	.090133	.10580	.12167	.13775	.15400	.23858	.32903
.85	.014773	.029723	.044848	.060153	.075642	.091319	.10719	.12225	.13952	.15599	.24158	.33307
.90	.014967	.030107	.045425	.060923	.075606	.092477	.10854	.12480	.14126	.15793	.24452	.33703
.95	.015154	.030483	.045989	.061676	.077549	.093611	.10987	.12632	.14297	.15983	.24740	.34091
1.00	.015338	.030850	.046540	.062413	.078471	.094720	.11116	.12780	.14465	.16170	.25022	.34471

γ	h .25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.80	.90
.00	.31862	.4021	.4941	.5961	.7096	.8388	.9808	1.145	1.336	1.561	2.176	3.283
.05	.32793	.4130	.5066	.6101	.7252	.8540	.9994	1.166	1.358	1.585	2.203	3.314
.10	.33662	.4233	.5184	.6234	.7400	.8703	1.017	1.185	1.379	1.608	2.229	3.345
.15	.34480	.4330	.5296	.6361	.7542	.8860	1.035	1.204	1.400	1.630	2.255	3.376
.20	.35255	.4422	.5403	.6483	.7673	.9012	1.051	1.222	1.419	1.651	2.280	3.405
.25	.35993	.4510	.5506	.6600	.7810	.9158	1.067	1.240	1.439	1.672	2.305	3.435
.30	.36700	.4595	.5604	.6713	.7937	.9300	1.083	1.257	1.457	1.693	2.329	3.464
.35	.37379	.4676	.5699	.6821	.8060	.9437	1.098	1.274	1.475	1.713	2.353	3.492
.40	.38033	.4735	.5791	.6927	.8179	.9570	1.113	1.290	1.494	1.732	2.376	3.520
.45	.38665	.4831	.5880	.7029	.8295	.9700	1.127	1.306	1.511	1.751	2.399	3.547
.50	.39276	.4904	.5967	.7129	.8408	.9826	1.141	1.321	1.528	1.770	2.421	3.575
.55	.39679	.4976	.6061	.7225	.8517	.9950	1.155	1.337	1.545	1.788	2.443	3.601
.60	.40447	.5045	.6133	.7320	.8625	1.007	1.169	1.351	1.561	1.806	2.465	3.628
.65	.41008	.5114	.6213	.7412	.8729	1.019	1.182	1.368	1.577	1.824	2.486	3.654
.70	.41555	.5180	.6291	.7502	.8832	1.030	1.195	1.380	1.593	1.841	2.507	3.679
.75	.42090	.5245	.6367	.7590	.8932	1.042	1.207	1.394	1.608	1.851	2.528	3.705
.80	.42612	.5308	.6441	.7676	.9031	1.053	1.220	1.408	1.624	1.875	2.548	3.730
.85	.43122	.5370	.6515	.7781	.9127	1.064	1.232	1.422	1.639	1.892	2.568	3.754
.90	.43622	.5430	.6586	.7844	.9222	1.074	1.244	1.435	1.653	1.908	2.588	3.779
.95	.44112	.5490	.6656	.7925	.9314	1.085	1.255	1.448	1.668	1.924	2.607	3.803
1.00	.44592	.5548	.6724	.8005	.9406	1.095	1.287	1.461	1.882	1.940	2.626	3.827

TABLE A-11: PROBABILITIES FOR THE SMALL-SAMPLE MANN-KENDALL TEST FOR TREND

S	n = 4	n = 5	n = 8	n = 9	S	n = 6	n = 7	n = 10
0	0.625	0.592	0.548	0.540	1	0.500	0.500	0.500
2	0.375	0.408	0.452	0.460	3	0.360	0.386	0.431
4	0.167	0.242	0.360	0.381	5	0.235	0.281	0.364
6	0.042	0.117	0.274	0.306	7	0.136	0.191	0.300
8		0.042	0.199	0.238	9	0.068	0.119	0.242
10		0.0083	0.138	0.179	11	0.028	0.068	0.190
12			0.089	0.130	13	0.0083	0.035	0.146
14			0.054	0.090	15	0.0014	0.015	0.108
16			0.031	0.060	17		0.0054	0.078
18			0.016	0.038	19		0.0014	0.054
20			0.0071	0.022	21		0.00020	0.036
22			0.0028	0.012	23			0.023
24			0.00087	0.0063	25			0.014
26			0.00019	0.0029	27			0.0083
28			0.000025	0.0012	29			0.0046
30				0.00043	31			0.0023
32				0.00012	33			0.0011
34				0.000025	35			0.00047
36				0.0000028	37			0.00018
					39			0.000058
					41			0.000015
					43			0.0000028
					45			0.00000028

TABLE A-12. QUANTILES FOR THE WALD-WOLFOWITZ TEST FOR RUNS

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
4	4	-	-	3
	5	-	-	3
	6	-	3	4
	7	-	3	4
	8	-	3	4
	9	-	3	4
	10	-	4	5
	11	3	4	5
	12	3	4	5
	13	3	4	5
	14	3	5	6
	15	3	5	6
	16	4	5	6
	17	4	5	6
	18	4	5	6
	19	4	5	6
	20	4	5	6

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
5	5	3	4	4
	6	3	4	4
	7	3	4	5
	8	3	4	5
	9	3	4	5
	10	4	4	5
	11	4	5	6
	12	4	5	6
	13	4	5	6
	14	5	6	6
	15	5	6	7
	16	5	6	7
	17	5	6	7
	18	5	6	7
	19	5	6	7
	20	5	6	7

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
6	6	3	4	5
	7	4	5	6
	8	4	5	6
	9	4	5	6
	10	4	6	7
	11	5	6	7
	12	5	6	7
	13	5	7	8
	14	5	7	8
	15	5	7	8
	16	6	7	8
	17	6	7	8
	18	6	7	8
	19	6	7	8
	20	6	7	8

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
7				
	8	4	5	6
	9	4	5	6
	10	4	6	7
	11	5	6	7
	12	5	6	7
	13	5	7	7
	14	5	7	8
	15	6	7	8
	16	6	7	8
	17	6	8	8
	18	7	8	9
	19	7	8	9
	20	7	8	9

TABLE A-12. QUANTILES FOR THE WALD-WOLFOWITZ TEST FOR RUNS

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
8	8	5	6	6
	9	5	6	7
	10	5	7	7
	11	6	7	8
	12	6	7	8
	13	6	7	8
	14	6	8	8
	15	6	8	9
	16	7	8	9
	17	7	8	9
	18	7	9	10
	19	7	9	10
	20	7	9	10

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
9	9	5	6	7
	10	6	7	8
	11	6	7	8
	12	6	7	8
	13	7	8	9
	14	7	8	9
	15	7	9	9
	16	7	9	10
	17	8	9	10
	18	8	9	10
	19	8	10	11
	20	8	10	11

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
10	10	7	8	9
	11	7	8	9
	12	7	8	9
	13	7	9	10
	14	8	9	10
	15	8	9	10
	16	8	9	11
	17	8	10	11
	18	9	10	11
	19	9	11	12
	20	9	11	12

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
11	11	7	8	9
	12	7	8	9
	13	7	9	10
	14	8	9	10
	15	8	9	10
	16	8	10	11
	17	9	10	11
	18	9	10	11
	19	9	11	12
	20	9	11	12

12	12	7	9	10
	13	8	10	10
	14	8	10	10
	15	8	10	11
	16	9	11	12
	17	9	11	12

13	13	9	10	11
	14	9	11	12
	15	10	11	12
	16	10	11	12
	17	10	11	12
	18	10	11	13

14	14	9	11	12
	15	9	11	12
	16	10	11	13
	17	10	12	13
	18	10	12	13
	19	11	13	14

15	15	8	10	11
	16	9	11	12
	17	10	12	13
	18	10	12	14
	19	11	13	15
	20	12	14	16

TABLE A-12. QUANTILES FOR THE WALD-WOLFOWITZ TEST FOR RUNS

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
	18	9	11	12
	19	10	12	13
	20	10	12	13
16	16	10	12	13
	17	11	13	14
	18	11	13	14
	19	12	14	15
	20	13	14	16
20	20	143	16	17

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
	19	10	12	13
	20	11	12	13
17	17	11	13	14
	18	11	13	15
	19	12	14	16
	20	12	14	16

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
	20	11	13	14
18	18	13	14	16
	19	13	14	16
	20	14	15	16

n	m	$W_{0.01}$	$W_{0.05}$	$W_{0.10}$
19	19	14	16	17
	20	14	16	17

When n or m is greater than 20 the Wp quantile is given by:

$$Wp = \left(1 + \frac{2mn}{m+n}\right) + Zp\sqrt{\frac{2mn(2mn-m-n)}{(m+n)^2(m+n-1)}}$$

where Zp is the appropriate quantile from the standard normal (see last row of Table A-1).

TABLE A-13. MODIFIED QUANTILE TEST CRITICAL NUMBERS LEVEL OF SIGNIFICANCE ( ) APPROXIMATELY 0.10

	n = number of measurements population 1															
m = number of measurements population 2		5	6	7	8	90	10	11	12	13	14	15	16	17	18	19	20
	5	3	3	4	4	5	5	5	6	6	7	7	7	8	8	8	8
	6	3	3	3	4	4	4	4	5	5	6	6	7	7	8	8	8
	7	2	2	3	3	4	4	4	4	5	5	6	6	6	7	7	7
	8	2	2	3	3	3	4	4	4	4	5	5	5	5	6	6	6
	9	2	2	3	3	3	3	4	4	4	4	5	5	5	5	5	6
	10	2	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5
	11	2	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5
	12	2	2	2	2	2	2	3	3	3	3	4	4	4	4	5	5
	13	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4	4
	14	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4
	15	2	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4
	16	2	2	2	2	2	2	2	2	2	2	3	3	3	3	4	4
	17	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
	18	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
	19	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	20	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3

TABLE A-13. MODIFIED QUANTILE TEST CRITICAL NUMBERS (CONTINUED)
LEVEL OF SIGNIFICANCE ( ) APPROXIMATELY 0.10

	n = number of measurements population 1																
m = number of measurements population 2			30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	25	3	4	4	5	5	5	6	6	7	7	8	8	8	9	9	10
	30	3	3	4	4	5	5	5	6	6	6	7	7	7	8	8	8
	35	3	3	3	4	4	4	5	5	5	6	6	6	6	7	7	7
	40	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6	7
	45	3	3	3	3	4	4	4	4	4	5	5	5	5	6	6	6
	50	2	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6
	55	2	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5
	60	2	2	3	3	3	3	3	4	4	4	4	4	4	5	5	5
	65	2	2	3	3	3	3	3	3	4	4	4	4	4	4	5	5
	70	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	4
	75	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4
	80	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4
	85	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4	4
	90	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4
	95	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4
	100	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4

TABLE A-13. MODIFIED QUANTILE TEST CRITICAL NUMBERS (CONTINUED) LEVEL OF SIGNIFICANCE (∝) APPROXIMATELY 0.05

	n = number of measurements population 1																
m = number of measurements population 2		5	6	7	8	90	10	11	12	13	14	15	16	17	18	19	20
	5	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10	10
	6	4	4	4	5	5	5	5	6	6	7	7	8	8	9	9	9
	7	3	4	4	4	5	5	5	5	6	6	7	7	7	8	8	8
	8	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7
	9	3	3	3	4	4	4	5	5	5	5	6	6	6	6	6	6
	10	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6
	11	3	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6
	12	3	3	3	3	3	3	4	4	4	4	5	5	5	5	6	6
	13	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5
	14	2	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5
	15	2	2	3	3	3	3	3	3	3	4	4	4	4	5	5	5
	16	2	2	2	3	3	3	3	3	3	3	4	4	4	4	5	5
	17	2	2	2	2	3	3	3	3	3	3	3	4	4	4	4	4
	18	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4	4
	19	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4
	20	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4

TABLE A-13. MODIFIED QUANTILE TEST CRITICAL NUMBERS (CONTINUED)
LEVEL OF SIGNIFICANCE (∝) APPROXIMATELY 0.05

	n = number of measurements population 1																
m = number of measurements population 2			30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	25	4	4	5	6	7	7	8	8	8	9	9	10	10	11	11	12
	30	4	4	5	5	6	6	7	7	8	8	9	9	9	10	10	11
	35	3	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10
	40	3	4	4	4	5	5	5	6	6	7	7	7	8	8	8	9
	45	3	4	4	4	4	5	5	5	6	6	6	7	7	7	8	8
	50	3	3	4	4	4	4	5	5	5	5	6	6	6	7	7	7
	55	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6	7
	60	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6
	65	2	3	3	3	3	4	4	4	4	5	5	5	5	5	6	6
	70	2	3	3	3	3	3	4	4	4	4	5	5	5	5	5	6
	75	2	3	3	3	3	3	3	4	4	4	5	5	5	5	5	5
	80	2	3	3	3	3	3	3	3	4	4	4	5	5	5	5	5
	85	2	2	3	3	3	3	3	3	3	4	4	4	5	5	5	5
	90	2	2	2	3	3	3	3	3	3	3	4	4	4	5	5	5
	95	2	2	2	2	3	3	3	3	3	3	3	4	4	4	5	5
	100	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4	5

TABLE A-14. DUNNETT'S TEST (ONE TAILED)
TOTAL NUMBER OF INVESTIGATED GROUPS (K - 1)

Degrees of Freedom		α	2	3	4	5	6	7	8	9	10	12	14	16
	2	.05	3.80	4.34	4.71	5.08	5.24	5.43	5.60	5.75	5.88	6.11	6.29	6.45
		.10	2.54	2.92	3.20	3.40	3.57	3.71	3.83	3.94	4.03	4.19	4.32	4.44
	3	.05	2.94	3.28	3.52	3.70	3.85	3.97	4.08	4.17	4.25	4.39	4.51	4.61
		.10	2.13	2.41	2.61	2.76	2.87	2.97	3.06	3.13	3.20	3.31	3.41	3.49
	4	.05	2.61	2.88	3.08	3.22	3.34	3.44	3.52	3.59	3.66	3.77	3.86	3.94
		.10	1.96	2.20	2.37	2.50	2.60	2.68	2.75	2.82	2.87	2.97	3.05	3.11
	5	.05	2.44	2.68	2.85	2.98	3.08	3.16	3.24	3.30	3.36	3.45	3.53	3.60
		.10	1.87	2.09	2.24	2.36	2.45	2.53	2.59	2.65	2.70	2.78	2.86	2.92
	6	.05	2.34	2.56	2.71	2.83	2.92	3.00	3.06	3.12	3.17	3.26	3.33	3.48
		.10	1.82	2.02	2.17	2.27	2.36	2.43	2.49	2.54	2.59	2.67	2.74	2.79
	7	.05	2.27	2.48	2.82	2.73	2.81	2.89	2.95	3.00	3.05	3.13	3.20	3.26
		.10	1.78	1.98	2.11	2.22	2.30	2.37	2.42	2.47	2.52	2.59	2.66	2.71
	8	.05	2.22	2.42	2.55	2.66	2.74	2.81	2.87	2.92	2.96	3.04	3.11	3.16
		.10	1.75	1.94	2.08	2.17	2.25	2.32	2.38	2.42	2.47	2.54	2.60	2.65
	9	.05	2.18	2.37	2.50	2.60	2.68	2.75	2.81	2.86	2.90	2.97	3.04	3.09
		.10	1.73	1.92	2.05	2.14	2.22	2.28	2.34	2.39	2.43	2.50	2.56	2.61
	10	.05	2.15	2.34	2.47	2.56	2.64	2.70	2.76	2.81	2.85	2.92	2.98	3.03
		.10	1.71	1.90	2.02	2.12	2.19	2.26	2.31	2.35	2.40	2.46	2.52	2.57
	12	.05	2.11	2.29	2.41	2.50	2.58	2.64	2.69	2.74	2.78	2.84	2.90	2.95
		.10	1.69	1.87	1.99	2.08	2.16	2.22	2.27	2.31	2.35	2.42	2.47	2.52
	16	.05	2.06	2.23	2.34	2.43	2.50	2.56	2.61	2.65	2.69	2.75	2.81	2.85
		.10	1.66	1.83	1.95	2.04	2.11	2.17	2.22	2.26	2.30	2.36	2.41	2.46

TABLE A-14. DUNNETT'S TEST (ONE TAILED) (CONTINUED)
TOTAL NUMBER OF INVESTIGATED GROUPS (K - 1)

Degrees of Freedom	α	2	3	4	5	6	7	8	9	10	12	14	16
20	.05	2.03	2.19	2.30	2.39	2.46	2.51	2.56	2.60	2.64	2.70	2.75	2.80
	.10	1.64	1.81	1.93	2.01	2.08	2.14	2.19	2.23	2.26	2.33	2.38	2.42
24	.05	2.01	2.17	2.28	2.36	2.43	2.48	2.53	2.57	2.60	2.66	2.72	2.76
	.10	1.63	2.80	1.91	2.00	2.06	2.12	2.17	2.21	2.24	2.30	2.35	2.40
30	.05	1.99	2.15	2.25	2.34	2.40	2.45	2.50	2.54	2.57	2.63	2.68	2.72
	.10	1.62	1.79	1.90	1.98	2.05	2.10	2.15	2.19	2.22	2.28	2.33	2.37
40	.05	1.97	2.13	2.23	2.31	2.37	2.42	2.47	2.51	2.54	2.60	2.65	2.69
	.10	1.61	1.77	1.88	1.96	2.03	2.08	2.13	2.17	2.20	2.26	2.31	2.35
50	.05	1.96	2.11	2.22	2.29	2.32	2.41	2.45	2.49	2.52	2.58	2.63	2.67
	.10	1.61	1.77	1.88	1.96	2.02	2.07	2.12	2.16	2.19	2.25	2.30	2.34
60	.05	1.95	2.10	2.21	2.28	2.34	2.40	2.44	2.48	2.51	2.57	2.61	2.65
	.10	1.60	1.76	1.87	1.95	2.01	2.06	2.11	2.15	2.18	2.24	2.29	2.33
70	.05	1.95	2.10	2.21	2.28	2.34	2.40	2.44	2.48	2.51	2.56	2.61	2.65
	.10	1.60	1.76	1.87	1.95	2.01	2.06	2.11	2.15	2.18	2.24	2.29	2.33
80	.05	1.94	2.10	2.20	2.28	2.34	2.39	2.43	2.47	2.50	2.55	2.60	2.64
	.10	1.60	1.76	1.87	1.95	2.01	2.06	2.10	2.15	2.18	2.23	2.28	2.32
90	.05	1.94	2.09	2.20	2.27	2.33	2.39	2.43	2.47	2.50	2.55	2.60	2.63
	.10	1.60	1.76	1.86	1.94	2.00	2.06	2.10	2.14	2.17	2.23	2.28	2.31
100	.05	1.93	2.08	2.18	2.27	2.33	2.38	2.42	2.46	2.49	2.54	2.59	2.63
	.10	1.59	1.75	1.85	1.93	1.99	2.05	2.09	2.14	2.17	2.22	2.27	2.31
120	.05	1.93	2.08	2.18	2.26	2.32	2.37	2.41	2.45	2.48	2.53	2.58	2.62
	.10	1.59	1.75	1.85	1.93	1.99	2.05	2.09	2.13	2.16	2.22	2.27	2.31
∞	.05	1.92	2.06	2.16	2.23	2.29	2.34	2.38	2.42	2.45	2.50	2.55	2.58
	.10	1.58	1.73	1.84	1.92	1.98	2.03	2.07	2.11	2.14	2.20	2.24	2.28

TABLE A-15. APPROXIMATE α-LEVEL CRITICAL POINTS FOR RANK VON NEUMANN RATIO TEST

n/α	.050	.100
4		
5	0.70	0.60
6	0.80	0.97
7	0.86	1.11
8	0.93	1.14
9	0.98	1.18
10	1.04	1.23
11	1.08	1.26
12	1.11	1.29
13	1.14	1.32
14	1.17	1.34
15	1.19	1.36
16	1.21	1.38
17	1.24	1.40
18	1.26	1.41
19	1.27	1.43
20	1.29	1.44
21	1.31	1.45
22	1.32	1.46
23	1.33	1.48
24	1.35	1.49
25	1.36	1.50
26	1.37	1.51
27	1.38	1.51
28	1.39	1.52
29	1.40	1.53
30	1.41	1.54
32	1.43	1.55
34	1.45	1.57
36	1.46	1.58
38	1.48	1.59
40	1.49	1.60
42	1.50	1.61
44	1.51	1.62
46	1.52	1.63
48	1.53	1.63
50	1.54	1.64
55	1.56	1.66
60	1.58	1.67
65	1.60	1.68
70	1.61	1.70
75	1.62	1.71
80	1.64	1.71
85	1.65	1.72
90	1.66	1.73
95	1.66	1.74
100	1.67	1.74

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APPENDIX B

REFERENCES

APPENDIX B: REFERENCES

This appendix provides references for the topics and procedures described in this document. The references are broken into three groups: Primary, Basic Statistics Textbooks, and Secondary. This classification does not refer in any way to the subject matter content but to the relevance to the intended audience for this document, ease in understanding statistical concepts and methodologies, and accessability to the non-statistical community. Primary references are those thought to be of particular benefit as hands-on material, where the degree of sophistication demanded by the writer seldom requires extensive training in statistics; most of these references should be on an environmental statistician's bookshelf. Users of this document are encouraged to send recommendations on additional references to the address listed in the Foreword.

Some sections within the chapters reference materials found in most introductory statistics books. This document uses Walpole and Myers (1985), Freedman, Pisani, Purves, and Adhakari (1991), Mendenhall (1987), and Dixon and Massey (1983). Table B-1 (at the end of this appendix) lists specific chapters in these books where topics contained in this guidance may be found. This list could be extended much further by use of other basic textbooks; this is acknowledged by the simple statement that further information is available from introductory text books.

Some important books specific to the analysis of environmental data include: Gilbert (1987), an excellent all-round handbook having strength in sampling, estimation, and hot-spot detection; Gibbons (1994), a book specifically concentrating on the application of statistics to groundwater problems with emphasis on method detection limits, censored data, and the detection of outliers; and Madansky (1988), a slightly more theoretical volume with important chapters on the testing for Normality, transformations, and testing for independence. In addition, Ott (1995) describes modeling, probabilistic processes, and the Lognormal distribution of contaminants, and Berthouex and Brown (1994) provide an engineering approach to problems including estimation, experimental design and the fitting of models.

B.1 CHAPTER 1

Chapter 1 establishes the framework of qualitative and quantitative criteria against which the data that has been collected will be assessed. The most important feature of this chapter is the concept of the test of hypotheses framework which is described in any introductory textbook. A non-technical exposition of hypothesis testing is also to be found in U.S. EPA (1994a, 1994b) which provides guidance on planning for environmental data collection. An application of the DQO Process to geostatistical error management may be found in Myers (1997).

A full discussion of sampling methods with the attendant theory are to be found in Gilbert (1987) and a shorter discussion may be found in U.S. EPA (1989). Cochran (1966) and Kish (1965) also provide more advanced theoretical concepts but may require the assistance of a statistician for full comprehension. More sophisticated sampling designs such as composite sampling, adaptive sampling, and ranked set sampling, will be discussed in future Agency guidance.

B.2 CHAPTER 2

Standard statistical quantities and graphical representations are discussed in most introductory statistics books. In addition, Berthouex & Brown (1994) and Madansky (1988) both contain thorough discussions on the subject. There are also several textbooks devoted exclusively to graphical representations, including Cleveland (1993), which may contain the most applicable methods for environmental data, Tufte (1983), and Chambers, Cleveland, Kleiner and Tukey (1983).

Two EPA sources for temporal data that keep theoretical discussions to a minimum are U.S. EPA (1992a) and U.S. EPA (1992b). For a more complete discussion on temporal data, specifically time series analysis, see Box and Jenkins (1970), Wei (1990), or Ostrum (1978). These more complete references provide both theory and practice; however, the assistance of a statistician may be needed to adapt the methodologies for immediate use. Theoretical discussions of spatial data may be found in Journel and Huijbregts (1978), Cressie (1993), and Ripley (1981).

B.3 CHAPTER 3

The hypothesis tests covered in this edition of the guidance are well known and straight-forward; basic statistics texts cover these subjects. Besides basic statistical text books, Berthouex & Brown (1994), Hardin and Gilbert (1993), and U.S. EPA (1989, 1994c) may be useful to the reader. In addition, there are some statistics books devoted specifically to hypothesis testing, for example, see Lehmann (1991). These books may be too theoretical for most practitioners, and their application to environmental situations may not be obvious.

The statement in this document that the sign test requires approximately 1.225 times as many observations as the Wilcoxon rank sum test to achieve a given power at a given significance level is attributable to Lehmann (1975).

B.4 CHAPTER 4

This chapter is essentially a compendium of statistical tests drawn mostly from the primary references and basic statistics textbooks. Gilbert (1987) and Madansky (1988) have an excellent collection of techniques and U.S. EPA (1992a) contains techniques specific to water problems.

For Normality (Section 4.2), Madansky (1988) has an excellent discussion on tests as does Shapiro (1986). For trend testing (Section 4.3), Gilbert (1987) has an excellent discussion on statistical tests and U.S. EPA (1992b) provides adjustments for trends and seasonality in the calculation of descriptive statistics.

There are several very good textbooks devoted to the treatment of outliers (Section 4.4). Two authoritative texts are Barnett and Lewis (1978) and Hawkins (1980). Additional information is also to be found in Beckman and Cook (1983) and Tietjen and Moore (1972). Several useful software programs are available on the statistical market including U.S. EPA's *GEO-EASE* and *Scout*, both developed by the Environmental Monitoring Systems Laboratory, Las Vegas, Nevada and described in U.S. EPA (1991) and U.S. EPA (1993b), respectively.

Tests for dispersion (Section 4.5) are described in the basic textbooks and examples are to be found in U.S. EPA (1992a). Transformation of data (Section 4.6) is a sensitive topic and thorough discussions may be found in Gilbert (1987), and Dixon and Massey (1983). Equally sensitive is the analysis of data where some values are recorded as non-detected (Section 4.7); Gibbons (1994) and U.S. EPA (1992a) have relevant discussions and examples.

B.5 CHAPTER 5

Chapter 5 discusses some of the philosophical issues related to hypothesis testing which may help in understanding and communicating the test results. Although there are no specific references for this chapter, many topics (e.g., the use of p-values) are discussed in introductory textbooks. Future editions of this guidance will be expanded by incorporating practical experiences from the environmental community into this chapter.

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United States Environmental Protection Agency	**Office of Research and Development Washington, D.C. 20460**	**EPA/600/R-98/018 February 1998**

EPA GUIDANCE FOR QUALITY ASSURANCE PROJECT PLANS

EPA QA/G-5

FOREWORD

The U.S. Environmental Protection Agency (EPA) has developed the Quality Assurance Project Plan (QAPP) as an important tool for project managers and planners to document the type and quality of data needed for environmental decisions and to use as the blueprint for collecting and assessing those data from environmental programs. The development, review, approval, and implementation of the QAPP is part of the mandatory Agency-wide Quality System that requires all organizations performing work for EPA to develop and operate management processes and structures for ensuring that data or information collected are of the needed and expected quality for their desired use. The QAPP is an integral part of the fundamental principles of quality management that form the foundation of the Agency's Quality System and the requirements for a QAPP are contained in EPA QA/R-5, *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations.*

This document is one of the *U.S. Environmental Protection Agency Quality System Series* requirements and guidance documents. These documents describe the EPA policies and procedures for planning, implementing, and assessing the effectiveness of the Quality System. Requirements documents (identified as EPA/R-*x*) establish criteria and mandatory specifications for quality assurance (QA) and quality control (QC) activities. Guidance documents (identified as EPA QA/G-*x*) provide suggestions and recommendations of a nonmandatory nature for using the various components of the Quality System. This guidance document contains advice and recommendations on how to meet the requirements of EPA QA/R-5. In addition to this guidance document on writing a QAPP, other EPA documents are available to assist the QAPP writer; these are discussed in Appendix A. Effective use of this document assumes that appropriate management systems for QA and QC have been established by the implementing organization and are operational. For requirements and guidance on the structure of this management system, refer to Appendix A.

Questions regarding this document or other documents from the Quality System Series may be directed to:

U.S. EPA
Quality Staff (2811R)
Office of Environmental Information
401 M Street, SW
Washington, DC 20460

Phone: (202) 564-6830
Fax: (202) 565-2441

All requirements and guidance documents are available on the EPA’s Quality Staff website:

http://www.epa.gov/quality

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LIST OF ACRONYMS

ACS	American Chemical Society
ADQ	Audit of Data Quality
CFR	Code of Federal Regulations
DQA	Data Quality Assessment
DQI	Data Quality Indicator
DQO	Data Quality Objective
EPA	Environmental Protection Agency
ISO	International Organization for Standardization
MSR	Management Systems Review
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
PARCC	Precision, Accuracy, Representativeness, Comparability, and Completeness
PE	Performance Evaluation
QA	Quality Assurance
QAD	Quality Assurance Division
QAMS	Quality Assurance Management Staff (now QAD)
QAPP	Quality Assurance Project Plan
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
SOP	Standard Operating Procedure
SRM	Standard Reference Material
TSA	Technical Systems Audit

CHAPTER I

INTRODUCTION

OVERVIEW

This document presents detailed guidance on how to develop a Quality Assurance Project Plan (QAPP) for environmental data operations performed by or for the U.S. Environmental Protection Agency (EPA). This guidance discusses how to address and implement the specifications in *Requirements for QA Project Plans for Environmental Data Operations* (EPA QA/R-5).

The QAPP is the critical planning document for any environmental data collection operation because it documents how quality assurance (QA) and quality control (QC) activities will be implemented during the life cycle of a program, project, or task. The QAPP is the blueprint for identifying how the quality system of the organization performing the work is reflected in a particular project and in associated technical goals. QA is a system of management activities designed to ensure that the data produced by the operation will be of the type and quality needed and expected by the data user. QA is acknowledged to be a management function emphasizing systems and policies, and it aids the collection of data of needed and expected quality appropriate to support management decisions in a resource-efficient manner.

In order to obtain environmental data for decision making, a project should be conducted in three phases: planning, implementation, and assessment. The first phase involves the development of Data Quality Objectives (DQOs) using the DQO Process or a similar structural systematic planning process. The DQOs provide statements about the expectations and requirements of the *data user* (such as the decision maker). In the second phase, the QAPP translates these requirements into measurement performance specifications and QA/QC procedures for the *data suppliers* to provide the information needed to satisfy the data user's needs. This guidance links the results of the DQO Process with the QAPP to complete documentation of the planning process. Once the data have been collected and validated in accordance with the elements of the QAPP, the data should be evaluated to determine whether the DQOs have been satisfied. In the assessment phase, the Data Quality Assessment (DQA) Process applies statistical tools to determine whether the data meet the assumptions made during planning and whether the total error in the data is small enough to support a decision within tolerable decision error rates expressed by the decision maker. Plans for data validation and DQA are discussed in the final sections of the QAPP. Thus, the activities addressed and documented in the QAPP cover the entire project life cycle, integrating elements of the planning, implementation, and assessment phases.

A QAPP is composed of four sections of project-related information called “groups,” which are subdivided into specific detailed “elements.” The degree to which each QAPP element should be addressed will be dependent on the specific project and can range from “not applicable” to extensive documentation. This document provides a discussion and background of the elements of a QAPP that will typically be necessary. There is no Agency-wide template for QAPP format; however, QAD encourages organizational consistency in the presentation and content of the elements contained within the QAPP. The final decision on the specific need for these elements for project-specific QAPPs will be made by the overseeing or sponsoring EPA organization(s). The Agency encourages the specific tailoring of implementation documents within the EPA’s general QA framework on a project-specific basis.

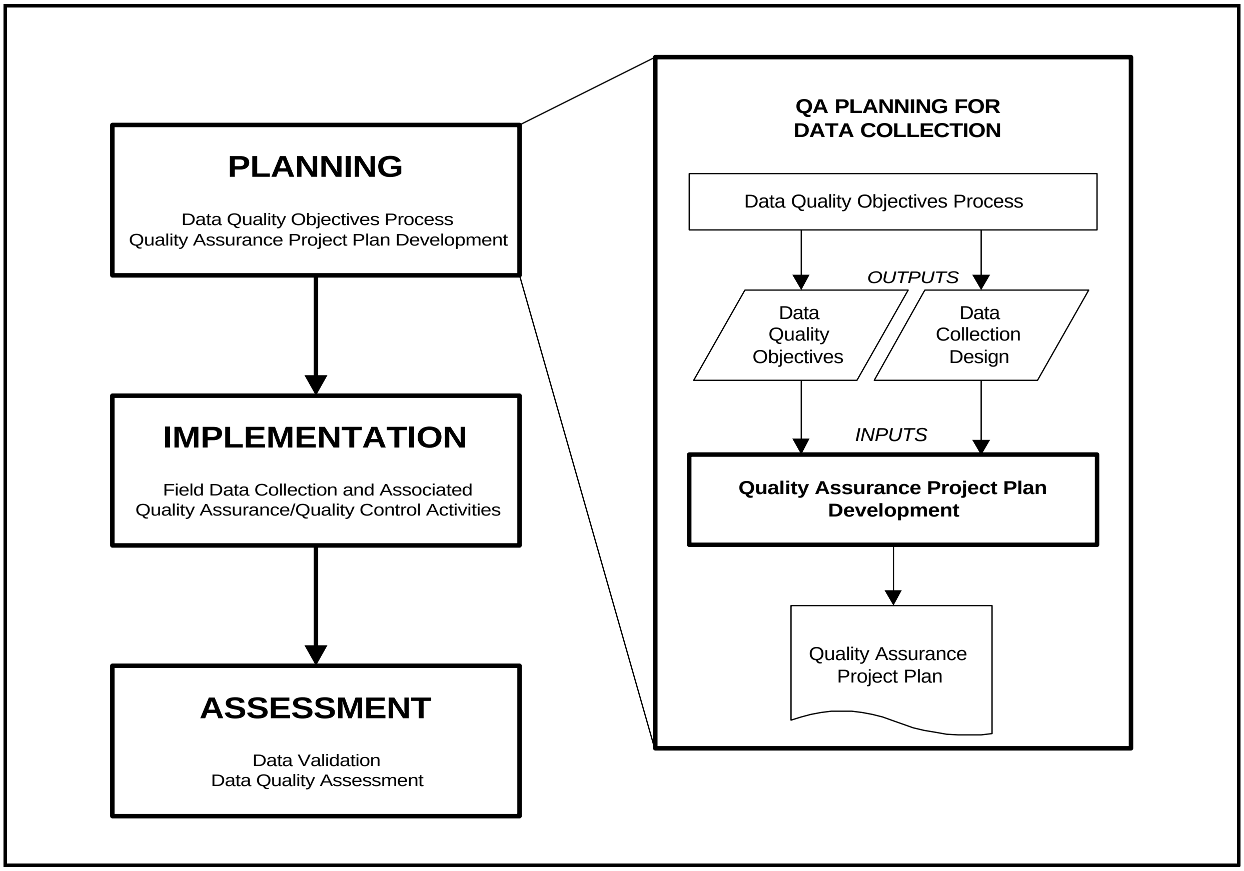

Figure 1. QA Planning and the Data Life Cycle.

PURPOSE OF QA PLANNING

The EPA Quality System is a structured and documented management system describing the policies, objectives, principles, organization, responsibilities, accountability, and implementation plan of an organization for ensuring quality in its work processes, products, and services. The Agency's Quality System is described in EPA QA/G-0, *The EPA Quality System.*

EPA policy requires that all projects involving the generation, acquisition, and use of environmental data be planned and documented and have an Agency-approved QAPP prior to the start of data collection. The primary purpose of the QAPP is to provide an overview of the project, describe the need for the measurements, and define QA/QC activities to be applied to the project, all within a single document. The QAPP should be detailed enough to provide a clear description of every aspect of the project and include information for every member of the project staff, including samplers, lab staff, and data reviewers. The QAPP facilitates communication among clients, data users, project staff, management, and external reviewers. Effective implementation of the QAPP assists project managers in keeping projects on schedule and within the resource budget. Agency QA policy is described in the Quality Manual and EPA QA/R-1, *EPA Quality System Requirements for Environmental Programs.*

CHAPTER II

QAPP REQUIREMENTS

EPA POLICY ON QAPPS

It is EPA's internal policy requirement[1] that the collection of environmental data by or for the Agency be supported by a QA program, or quality system. The authority for this requirement for work done for EPA through extramural agreements may be found in 48 CFR, Chapter 15, Part 1546 for contractors, and 40 CFR, Parts 30, 31, and 35 for financial assistance recipients, and may be included in negotiated interagency agreements and consent agreements in enforcement actions.

A key component of this mandatory quality system is the development, review, approval, and implementation of the QAPP. A QAPP must address all of the elements contained in QA/R-5 unless otherwise specified by the EPA QA Manager responsible for the data collection. The format of the QAPP is decided by the QA approving authority prior to preparation of the QAPP.

The QAPP is the logical product of the planning process for any data collection, as it documents how QA and QC activities will be planned and implemented. To be complete, the QAPP must meet certain specifications for detail and coverage, but the extent of detail is dependent on the type of project, the data to be collected, and the decisions to be made. Overall, the QAPP must provide sufficient detail to demonstrate that:

- the project's technical and quality objectives are identified and agreed upon,
- the intended measurements or data acquisition methods are consistent with project objectives,
- the assessment procedures are sufficient for determining if data of the type and quality needed and expected are obtained, and
- any potential limitations on the use of the data can be identified and documented.

Documents prepared prior to the QAPP (e.g., standard operating procedures [SOPs], test plans, and sampling plans) can be appended or, in some cases, incorporated by reference.

QAPP GROUPS AND ELEMENTS

The elements of a QAPP are categorized into "groups" according to their function. Specifications for each element are found in *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5). Summaries of each requirement of the elements from that document are contained in a box at the beginning of each specific element description. The elements of a QAPP are:

Group A: Project Management

This group of QAPP elements covers the general areas of project management, project history and objectives, and roles and responsibilities of the participants. The following 9 elements ensure that

[1]EPA Order 5360.1, *Policy and Program Requirements to Implement the Mandatory Quality Assurance Program*, was issued originally in April 1984 and will be revised in 1998.

the project's goals are clearly stated, that all participants understand the goals and the approach to be used, and that project planning is documented:

- A1 Title and Approval Sheet
- A2 Table of Contents and Document Control Format
- A3 Distribution List
- A4 Project/Task Organization and Schedule
- A5 Problem Definition/Background
- A6 Project/Task Description
- A7 Quality Objectives and Criteria for Measurement Data
- A8 Special Training Requirements/Certification
- A9 Documentation and Records

Group B: Measurement/Data Acquisition

This group of QAPP elements covers all of the aspects of measurement system design and implementation, ensuring that appropriate methods for sampling, analysis, data handling, and QC are employed and will be thoroughly documented:

- B1 Sampling Process Design (Experimental Design)
- B2 Sampling Methods Requirements
- B3 Sample Handling and Custody Requirements
- B4 Analytical Methods Requirements
- B5 Quality Control Requirements
- B6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements
- B7 Instrument Calibration and Frequency
- B8 Inspection/Acceptance Requirements for Supplies and Consumables
- B9 Data Acquisition Requirements (Non-Direct Measurements)
- B10 Data Management

Group C: Assessment/Oversight

The purpose of assessment is to ensure that the QAPP is implemented as prescribed. This group of QAPP elements addresses the activities for assessing the effectiveness of the implementation of the project and the associated QA/QC activities:

- C1 Assessments and Response Actions
- C2 Reports to Management

Group D: Data Validation and Usability

Implementation of Group D elements ensures that the individual data elements conform to the specified criteria, thus enabling reconciliation with the project’s objectives. This group of elements covers the QA activities that occur after the data collection phase of the project has been completed:

- D1 Data Review, Validation, and Verification Requirements
- D2 Validation and Verification Methods
- D3 Reconciliation with Data Quality Objectives

QAPP RESPONSIBILITIES

QAPPs may be prepared by EPA organizations and by groups outside EPA including contractors, assistance agreement holders, or other Federal agencies under interagency agreements. Generally, all QAPPs prepared by non-EPA organizations must be approved by EPA for implementation. Writing a QAPP is often a collaborative effort within an organization, or among organizations, and depends on the technical expertise, writing skills, knowledge of the project, and availability of the staff. Organizations are encouraged to involve technical project staff and the QA Manager or the QA Officer in this effort to ensure that the QAPP has adequate detail and coverage.

None of the environmental data collection work addressed by the QAPP may be started until the initial QAPP has been approved by the EPA Project Officer and the EPA QA Manager and then distributed to project personnel except under circumstances requiring immediate action to protect human health and the environment or to operations conducted under police power. In some cases, EPA may grant conditional or partial approval to a QAPP to permit some work to begin while noncritical deficiencies in it are being resolved. However, the QA Manager should be consulted to determine the length of time and nature of the work that may continue and the type of work that may be performed under a conditionally approved QAPP. Some organizations have defined and outlined these terms as:

- *Approval:* No remaining identified deficiencies exist in the QAPP and the project may commence.

- *Partial Approval:* Some activities identified in the QAPP still contain critical deficiencies while other activities are acceptable. If the acceptable activities are not contingent upon the completion of the activities with the deficiencies, a partial approval may be granted to allow those activities to proceed. Work will continue to resolve the portions of the QAPP that contain deficiencies.

- *Conditional Approval:* Approval of the QAPP or portions thereof will be granted upon agreement to implement specific conditions, specific language, etc. by entities required to approve the QAPP in order to expedite the initiation of field work. In most situations, the *conditional approval* is upgraded to final *approval* upon receipt, review, and sign off by all entities of the revised/additional QAPP pages.

The organizational group performing the work is responsible for implementing the approved QAPP. This responsibility includes ensuring that all personnel involved in the work have copies of or access to the approved QAPP along with all other necessary planning documents. In addition, the group must ensure that these personnel understand their requirements prior to the start of data generation activities.

Moreover, organizations are responsible for keeping the QAPP current when changes to technical aspects of the project change. QAPPs must be revised to incorporate such changes and the QAPP must be re-examined to determine the impact of the changes. Any revisions to the QAPP must be re-approved and distributed to all participants in the project.

CHAPTER III

QAPP ELEMENTS

A PROJECT MANAGEMENT

The following project management elements address the procedural aspects of project development and what to include in the QAPP project background, task description, and quality objectives elements. Summaries from R-5 are contained in the text box following the title of each element.

A1 TITLE AND APPROVAL SHEET

Include title of plan; name of the organization(s); and names, titles, signatures of appropriate approving officials, and their approval dates.

The title and approval sheet includes the title of the QAPP; the name(s) of the organization(s) implementing the project; and the names, titles, and signatures, and the signature dates of the appropriate approving officials. The approving officials typically include: the organization's Technical Project Manager, the organization's Quality Assurance Officer or Manager, the EPA (or other funding agency) Technical Project Manager/Project Officer, Laboratory Directors, Laboratory QA Officers, the EPA (or other funding agency) Quality Assurance Officer or Manager, and other key staff, such as the QA Officer of the prime contractor when a QAPP is prepared by a subcontractor organization.

The purpose of the approval sheet is to enable officials to document their approval of the QAPP. The title page (along with the organization chart) also identifies the key project officials for the work. The title and approval sheet should also indicate the date of the revision and a document number, if appropriate.

A2 TABLE OF CONTENTS AND DOCUMENT CONTROL FORMAT

List sections, figures, tables, references, and appendices.

The table of contents lists all the elements, references, and appendices contained in a QAPP, including a list of tables and a list of figures that are used in the text. The major headings for most QAPPs should closely follow the list of required elements; an example is shown in Figure 2. While the exact format of the QAPP does not have to follow the sequence given here, it is generally more convenient to do so, and it provides a standard format to the QAPP reviewer. Moreover, consistency in the format makes the document more familiar to users, who can expect to find a specific item in the same place in every QAPP.

The table of contents of the QAPP may include a document control component. This information should appear in the upper right-hand corner of each page of the QAPP when document control format is desired. For example:

Project No. or Name ___________ Element or Section No. _________ Revision No. _________________ Revision Date _______________ Section/Element Page ___ of _____

This component, together with the distribution list (see element A3), facilitates control of the document to help ensure that the most current QAPP is in use by all project participants. Each revision of the QAPP should have a different revision number and date.

A3 DISTRIBUTION LIST

List all the individuals and their organizations who will receive copies of the approved QAPP and any subsequent revisions. Include all persons who are responsible for implementation (including managers), the QA managers, and representatives of all groups involved.

All the persons and document files designated to receive copies of the QAPP, and any planned future revisions, need to be listed in the QAPP. This list, together with the document control information, will help the project manager ensure that all key personnel in the implementation of the QAPP have up-to-date copies of the plan. A typical distribution list appears in Figure 2.

A4 PROJECT/TASK ORGANIZATION

Identify the individuals or organizations participating in the project and discuss their specific roles and responsibilities. Include principal data users, the decision makers, the project QA manager, and all persons responsible for implementation.

Ensure that the project QA manager is independent of the unit generating the data.

Provide a concise organization chart showing the relationships and the lines of communication among all project participants; other data users who are outside of the organization generating the data; and any subcontractor relationships relevant to environmental data operations.

A4.1 Purpose/Background

The purpose of the project organization is to provide EPA and other involved parties with a clear understanding of the role that each party plays in the investigation or study and to provide the lines of authority and reporting for the project.

A4.2 Roles and Responsibilities

The specific roles, activities, and responsibilities of participants, as well as the internal lines of authority and communication within and between organizations, should be detailed. The position of the QA Manager or QA Officer should be described. Include the principal data users, the decision maker, project manager, QA manager, and all persons responsible for implementation of the QAPP. Also included should be the person responsible for maintaining the QAPP and any individual approving

CONTENTS

Section

Distribution List

N. Wentworth, EPA/ORD (Work Assignment Manager)*
B. Waldron, EPA/ORD (QA Manager)
J. Warren, State University (Principal Investigator)
T. Dixon, State University (QA Officer)
G. Johnson, State University (Field Activities)
F. Haeberer, State University (Laboratory Activities)
B. Odom, State University (Data Management)
E. Renard, ABC Laboratories (Subcontractor Laboratory)
P. Lafornara, ABC Laboratories (QA Manager Subcontractor Laboratory)

*indicates approving authority

Figure 2. An Example of a Table of Contents and a Distribution List

deliverables other than the project manager. A concise chart showing the project organization, the lines of responsibility, and the lines of communication should be presented; an example is given in Figure 3. For complex projects, it may be useful to include more than one chart—one for the overall project (with at least the primary contact) and others for each organization. Where direct contact between project managers and data users does not occur, such as between a project consultant for a potentially responsible party and the EPA risk assessment staff, the organization chart should show the route by which information is exchanged.

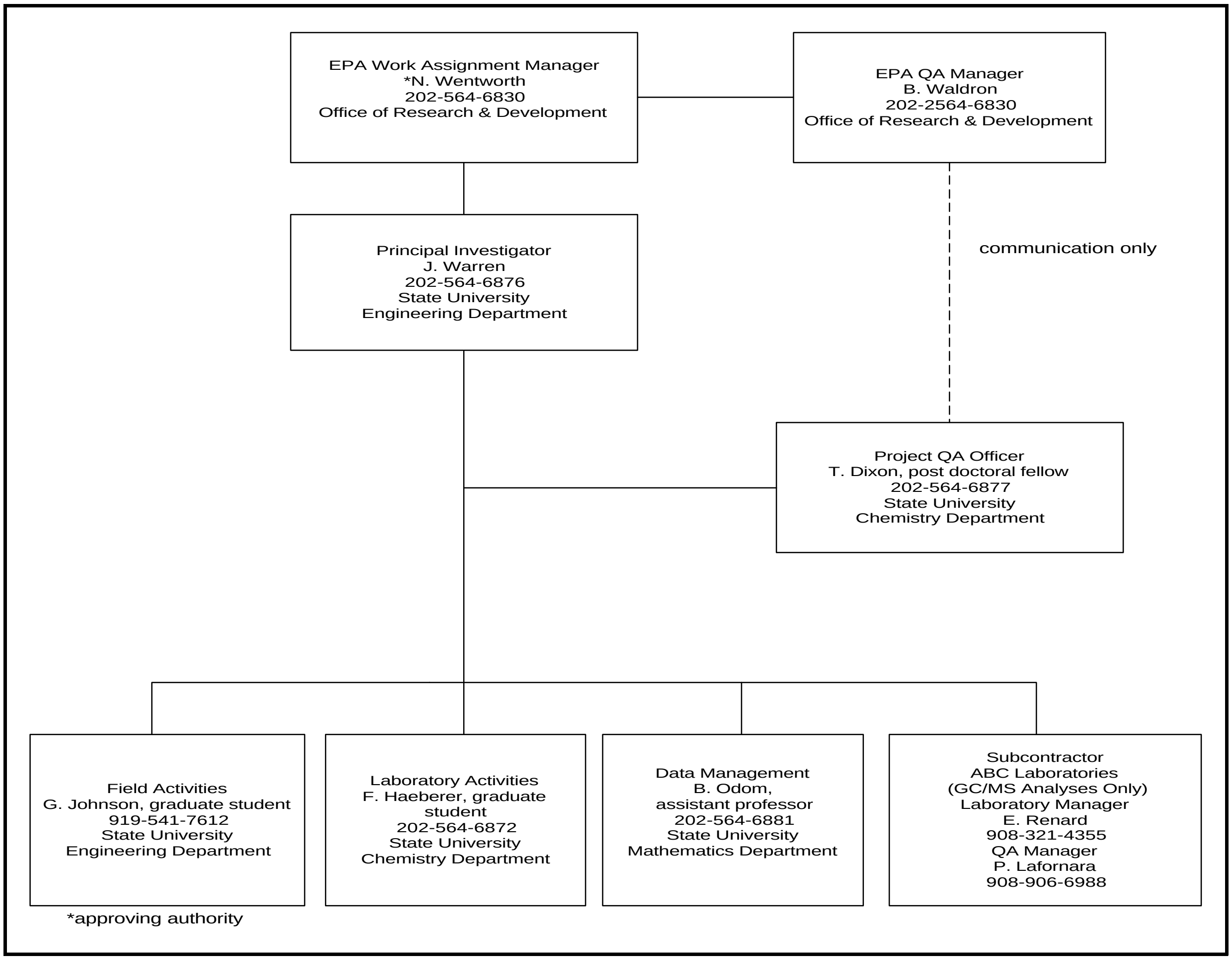

Figure 3. An Example of a Project Organization Chart

A5 PROBLEM DEFINITION/BACKGROUND

State the specific problem to be solved or decision to be made and include sufficient background information to provide a historical and scientific perspective for this particular project.

A5.1 Purpose/Background

The background information provided in this element will place the problem in historical perspective, giving readers and users of the QAPP a sense of the project's purpose and position relative to other project and program phases and initiatives.

A5.2 Problem Statement and Background

This discussion must include enough information about the problem, the past history, any previous work or data, and any other regulatory or legal context to allow a technically trained reader to make sense of the project objectives and activities. This discussion should include:

- a description of the problem as currently understood, indicating its importance and programmatic, regulatory, or research context;
- a summary of existing information on the problem, including any conflicts or uncertainties that are to be resolved by the project;
- a discussion of initial ideas or approaches for resolving the problem there were considered before selecting the approach described in element A6, "Project/Task Description"; and
- the identification of the principal data user or decision maker (if know).

Note that the problem statement is the first step of the DQO Process and the decision specification is the second step of the DQO Process.

A6 PROJECT/TASK DESCRIPTION AND SCHEDULE

Provide a description of the work to be performed and the schedule for implementation. Include measurements that will be made during the course of the project; applicable technical, regulatory, or program-specific quality standards, criteria, or objectives; any special personnel and equipment requirements; assessment tools needed; a schedule for work to be performed; and project and quality records required, including types of reports needed.

A6.1 Purpose/Background

The purpose of the project/task description element is to provide the participants with a background understanding of the project and the types of activities to be conducted, including the measurements that will be taken and the associated QA/QC goals, procedures, and timetables for collecting the measurements.

A6.2 Description of the Work to be Performed

(1) **Measurements that are expected during the course of the project.** Describe the characteristic or property to be studied and the measurement processes and techniques that will be used to collect data.

(2) **Applicable technical quality standards or criteria.** Cite any relevant regulatory standards or criteria pertinent to the project. For example, if environmental data are collected to test for compliance with a permit limit standard, the standard should be cited and the numerical limits should be given in the QAPP. The DQO Process refers to these limits as "action levels," because the type of action taken by the decision maker will depend on whether the measured levels exceed the limit (Step 5 of the DQO Process).

(3) **Any special personnel and equipment requirements that may indicate the complexity of the project.** Describe any special personnel or equipment required for the specific type of work being planned or measurements being taken.

(4) **The assessment techniques needed for the project.** The degree of quality assessment activity for a project will depend on the project's complexity, duration, and objectives. A discussion of the timing of each planned assessment and a brief outline of the roles of the different parties to be involved should be included.

(5) **A schedule for the work performed.** The anticipated start and completion dates for the project should be given. In addition, this discussion should include an approximate schedule of important project milestones, such as the start of environmental measurement activities.

(6) **Project and quality records required, including the types of reports needed.** An indication of the most important records should be given.

A7 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

Describe the project quality objectives and measurement performance criteria.

A7.1 Purpose/Background

The purpose of this element is to document the DQOs of the project and to establish performance criteria for the mandatory systematic planning process and measurement system that will be employed in generating the data.

A7.2 Specifying Quality Objectives

This element of the QAPP should discuss the desired quality of the final results of the study to ensure that the data user's needs are met. The Agency strongly recommends using the DQO Process (see Figure 4), a systematic procedure for planning data collection activities, to ensure that the right type, quality, and quantity of data are collected to satisfy the data user's needs. DQOs are qualitative and quantitative statements that:

- clarify the intended use of the data,
- define the type of data needed to support the decision,
- identify the conditions under which the data should be collected, and
- specify tolerable limits on the probability of making a decision error due to uncertainty in the data.

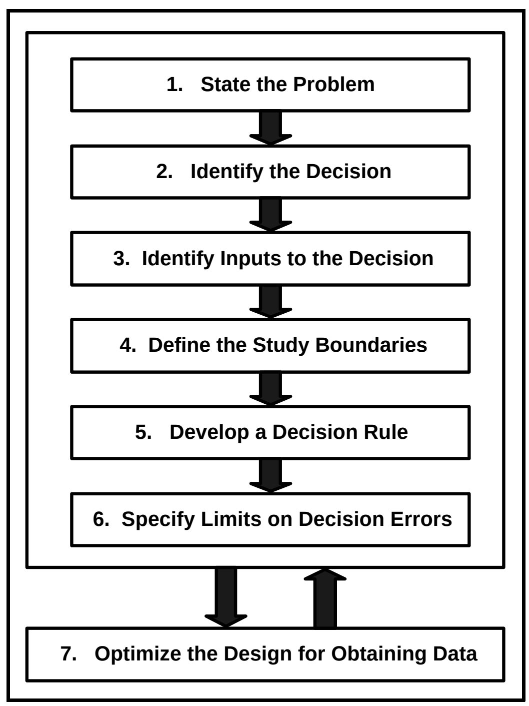

Figure 4. The DQO Process

Data Quality Indicators (DQIs) can be evolved from DQOs for a sampling activity through the use of the DQO Process (Appendix D). Figure 4 shows the seven steps of the DQO Process, which is explained in detail in EPA QA/G-4, *Guidance for the Data Quality Objectives Process.*

Appendix A.4 provides a crosswalk between the requirements of the QAPP and the DQO outputs. The QAPP should include a reference for a full discussion of the proposed DQOs.

For exploratory research, sometimes the goal is to develop questions that may be answered by subsequent work. Therefore, researchers may modify activities advocated in QA/G-4 to define decision errors (see EPA QA/G-4R, *Data Quality Objectives for Researchers*).

A7.3 Specifying Measurement Performance Criteria

While the quality objectives state what the data user's needs are, they do not provide sufficient information about how these needs can be satisfied. The specialists who will participate in generating the data need to know the measurement performance criteria that must be satisfied to achieve the overall quality objectives. One of the most important features of the QAPP is that it links the data user's quality objectives to verifiable measurement performance criteria. Although the level of rigor with which this is done and documented will vary widely, this linkage represents an important advancement in the implementation of QA. Once the measurement performance criteria have been established, sampling and analytical methods criteria can be specified under the elements contained in Group B.

A8 SPECIAL TRAINING REQUIREMENTS/CERTIFICATION

Identify and describe any specialized training or certification requirements and discuss how such training will be provided and how the necessary skills will be assured and documented.

A8.1 Purpose/Background

The purpose of this element is to ensure that any specialized training requirements necessary to complete the projects are known and furnished and the procedures are described in sufficient detail to ensure that specific training skills can be verified, documented, and updated as necessary.

A8.2 Training

Requirements for specialized training for nonroutine field sampling techniques, field analyses, laboratory analyses, or data validation should be specified. Depending on the nature of the environmental data operation, the QAPP may need to address compliance with specifically mandated training requirements. For example, contractors or employees working at a Superfund site need specialized training as mandated by the Occupational Safety and Health (OSHA) regulations. If hazardous materials are moved offsite, compliance with the training requirements for shipping hazardous materials as mandated by the Department of Transportation (DOT) in association with the International Air Transportation Association may be necessary. This element of the QAPP should show that the management and project teams are aware of specific health and safety needs as well as any other organizational safety plans.

A8.3 Certification

Usually, the organizations participating in the project that are responsible for conducting training and health and safety programs are also responsible for ensuring certification. Training and certification should be planned well in advance for necessary personnel prior to the implementation of the project.

All certificates or documentation representing completion of specialized training should be maintained in personnel files.

A9 DOCUMENTATION AND RECORDS

Itemize the information and records that must be included in the data report package and specify the desired reporting format for hard copy and electronic forms, when used.

Identify any other records and documents applicable to the project, such as audit reports, interim progress reports, and final reports, that will be produced.

Specify or reference all applicable requirements for the final disposition of records and documents, including location and length of retention period.

A9.1 Purpose/Background

This element defines which records are critical to the project and what information needs to be included in reports, as well as the data reporting format and the document control procedures to be used. Specification of the proper reporting format, compatible with data validation, will facilitate clear, direct communication of the investigation.

A9.2 Information Included in the Reporting Packages

The selection of which records to include in a data reporting package must be determined based on how the data will be used. Different "levels of effort" require different supporting QA/QC documentation. For example, organizations conducting basic research have different reporting requirements from organizations collecting data in support of litigation or in compliance with permits. When possible, field and laboratory records should be integrated to provide a continuous reporting track. The following are examples of different records that may be included in the data reporting package.

A9.2.1 <u>Field Operation Records</u>

The information contained in these records documents overall field operations and generally consists of the following:

- *Sample collection records.* These records show that the proper sampling protocol was performed in the field. At a minimum, this documentation should include the names of the persons conducting the activity, sample number, sample collection points, maps and diagrams, equipment/method used, climatic conditions, and unusual observations. Bound field notebooks are generally used to record raw data and make references to prescribed procedures and changes in planned activities. They should be formatted to include pre-numbered pages with date and signature lines.

- *Chain-of-custody records*. Chain-of-custody records document the progression of samples as they travel from the original sampling location to the laboratory and finally to their disposal area. (See Appendix C for an example of a chain-of-custody checklist.)

- *QC sample records.* These records document the generation of QC samples, such as field, trip, and equipment rinsate blanks and duplicate samples. They also include documentation on sample integrity and preservation and include calibration and standards' traceability documentation capable of providing a reproducible reference point. Quality control sample records should contain information on the frequency, conditions, level of standards, and instrument calibration history.

- *General field procedures.* General field procedures record the procedures used in the field to collect data and outline potential areas of difficulty in gathering specimens.

- *Corrective action reports.* Corrective action reports show what methods were used in cases where general field practices or other standard procedures were violated and include the methods used to resolve noncompliance.

If applicable, to show regulatory compliance in disposing of waste generated during the data operation, procedures manifest and testing contracts should be included in the field procedures section.

A9.2.2 Laboratory Records

The following list describes some of the laboratory-specific records that should be compiled if available and appropriate:

- *Sample Data.* These records contain the times that samples were analyzed to verify that they met the holding times prescribed in the analytical methods. Included should be the overall number of samples, sample location information, any deviations from the SOPs, time of day, and date. Corrective action procedures to replace samples violating the protocol also should be noted.

- *Sample Management Records.* Sample management records document sample receipt, handling and storage, and scheduling of analyses. The records verify that the chain-of-custody and proper preservation were maintained, reflect any anomalies in the samples (such as receipt of damaged samples), note proper log-in of samples into the laboratory, and address procedures used to ensure that holding time requirements were met.

- *Test Methods.* Unless analyses are performed exactly as prescribed by SOPs, this documentation will describe how the analyses were carried out in the laboratory. This includes sample preparation and analysis, instrument standardization, detection and reporting limits, and test-specific QC criteria. Documentation demonstrating laboratory proficiency with each method used could be included.

- *QA/QC Reports.* These reports will include the general QC records, such as initial demonstration of capability, instrument calibration, routine monitoring of analytical performance, calibration verification, etc. Project-specific information from the QA/QC checks such as blanks (field, reagent, rinsate, and method), spikes (matrix, matrix spike replicate, analysis matrix spike, and surrogate spike), calibration check samples (zero check, span check, and mid-range check), replicates, splits, and so on should be included in these reports to facilitate data quality analysis.

A9.2.3 <u>Data Handling Records</u>

These records document protocols used in data reduction, verification, and validation. Data reduction addresses data transformation operations such as converting raw data into reportable quantities and units, use of significant figures, recording of extreme values, blank corrections, etc. Data verification ensures the accuracy of data transcription and calculations, if necessary, by checking a set of computer calculations manually. Data validation ensures that QC criteria have been met.

A9.3 Data Reporting Package Format and Documentation Control

The format of all data reporting packages must be consistent with the requirements and procedures used for data validation and data assessment described in Sections B, C, and D of the QAPP. All individual records that represent actions taken to achieve the objective of the data operation and the performance of specific QA functions are potential components of the final data reporting package. This element should discuss how these various components will be assembled to represent a concise and accurate record of all activities impacting data quality. The discussion should detail the recording medium for the project, guidelines for hand-recorded data (e.g., using indelible ink), procedures for correcting data (e.g., single line drawn through errors and initialed by the responsible person), and documentation control. Procedures for making revisions to technical documents should be clearly specified and the lines of authority indicated.

A9.4 Data Reporting Package Archiving and Retrieval

The length of storage for the data reporting package may be governed by regulatory requirements, organizational policy, or contractual project requirements. This element of the QAPP should note the governing authority for storage of, access to, and final disposal of all records.

A9.5 References

Kanare, Howard M. 1985. *Writing the Laboratory Notebook.* Washington, DC: American Chemical Society.

U.S. Environmental Protection Agency. 1993. *Guidance on Evaluation, Resolution, and Documentation of Analytical Problems Associated with Compliance Monitoring.* EPA/821/B-93/001.

B MEASUREMENT/DATA ACQUISITION

B1 SAMPLING PROCESS DESIGN (EXPERIMENTAL DESIGN)

Describe the experimental design or data collection design for the project. **Classify all measurements as critical or non-critical.**

B1.1 Purpose/Background

The purpose of this element is to describe all the relevant components of the experimental design; define the key parameters to be estimated; indicate the number and type of samples expected; and describe where, when, and how samples are to be taken. The level of detail should be sufficient that a person knowledgeable in this area could understand how and why the samples will be collected. This element provides the main opportunity for QAPP reviewers to ensure that the "right" samples will be taken. Strategies such as stratification, compositing, and clustering should be discussed, and diagrams or maps showing sampling points should be included. Most of this information should be available as outputs from the final steps of the planning (DQO) process.

In addition to describing the design, this element of the QAPP should discuss the following:

- a schedule for project sampling activities,
- a rationale for the design (in terms of meeting DQOs),
- the sampling design assumptions,
- the procedures for locating and selecting environmental samples,
- a classification of measurements as critical or noncritical, and
- the validation of any nonstandard sampling/measurement methods.

Elements B1.2 through B1.8 address these subjects.

B1.2 Scheduled Project Activities, Including Measurement Activities

This element should give anticipated start and completion dates for the project as well as anticipated dates of major milestones, such as the following:

- schedule of sampling events;
- schedule for analytical services by offsite laboratories;
- schedule for phases of sequential sampling (or testing), if applicable;
- schedule of test or trial runs; and
- schedule for peer review activities.

The use of bar charts showing time frames of various QAPP activities to identify both potential bottlenecks and the need for concurrent activities is recommended.

B1.3 Rationale for the Design

The objectives for an environmental study should be formulated in the planning stage of any investigation. The requirements and the rationale of the design for the collection of data are derived from the quantitative outputs of the DQO Process. The type of design used to collect data depends heavily on the key characteristic being investigated. For example, if the purpose of the study is to estimate overall average contamination at a site or location, the characteristic (or parameter) of interest would be the mean level of contamination. This information is identified in Step 5 of the DQO Process. The relationship of this parameter to any decision that has to be made from the data collected is obtained from Steps 2 and 3 of the DQO Process (see Figure 4).

The potential range of values for the parameter of interest should be considered during development of the data collection methodology and can be greatly influenced by knowledge of potential ranges in expected concentrations. For example, the number of composite samples needed per unit area is directly related to the variability in potential contaminant levels expected in that area.

The choice between a probability-based (statistical) data collection design or a nonrandom (judgmental) data collection methodology depends on the ultimate use of the data being collected. This information is specified in Steps 5 and 6 of the DQO Process. Adherence to the data collection design chosen in Step 7 of the DQO Process directly affects the magnitude of potential decision error rates (false positive rate and false negative rate) established in Step 6 of the DQO Process. Any procedures for coping with unanticipated data collection design changes also should be briefly discussed.

B1.4 Design Assumptions

The planning process usually recommends a specific data collection method (Step 7 of the DQO Process), but the effectiveness of this methodology rests firmly on assumptions made to establish the data collection design. Typical assumptions include the homogeneity of the medium to be sampled (for example, sludge, fine silt, or wastewater effluent), the independence in the collection of individual samples (for example, four separate samples rather than four aliquots derived from a single sample), and the stability of the conditions during sample collection (for example, the effects of a rainstorm during collection of wastewater from an industrial plant). The assumptions should have been considered during the DQO Process and should be summarized together with a contingency plan to account for exceptions to the proposed sampling plan. An important part of the contingency plan is documenting the procedures to be adopted in reporting deviations or anomalies observed after the data collection has been completed. Examples include an extreme lack of homogeneity within a physical sample or the presence of analytes that were not mentioned in the original sampling plan. Chapter 1 of EPA QA/G-9 provides an overview of sampling plans and the assumptions needed for their implementation. EPA QA/G-5S provides guidance on the construction of sampling plans to meet the requirements generated by the DQO Process.

B1.5 Procedures for Locating and Selecting Environmental Samples

The most appropriate plan for a particular sampling application will depend on: the practicality and feasibility (e.g., determining specific sampling locations) of the plan, the key characteristic (the parameter established in Step 5 of the DQO Process) to be estimated, and the implementation resource requirements (e.g., the costs of sample collection, transportation, and analysis).

This element of the QAPP should also describe the frequency of sampling and specific sample locations (e.g., sample port locations and traverses for emissions source testing, well installation designs for groundwater investigations) and sampling materials. When decisions on the number and location of samples will be made in the field, the QAPP should describe how these decisions will be driven whether by actual observations or by field screening data. When locational data are to be collected, stored, and transmitted, the methodology used must be described (or referenced) and include the following:

- procedures for finding prescribed sample locations,
- contingencies for cases where prescribed locations are inaccessible,
- location bias and its assessment, and
- procedures for reporting deviations from the sampling plan.

When appropriate, a map of the sample locations should be provided and locational map coordinates supplied. EPA QA/G-5S provides nonmandatory guidance on the practicality of constructing sampling plans and references to alternative sampling procedures.

B1.6 Classification of Measurements as Critical or Noncritical

All measurements should be classified as critical (i.e., required to achieve project objectives or limits on decision errors, Step 6 of the DQO Process) or noncritical (for informational purposes only or needed to provide background information). Critical measurements will undergo closer scrutiny during the data gathering and review processes and will have first claim on limited budget resources. It is also possible to include the expected number of samples to be tested by each procedure and the acceptance criteria for QC checks (as described in element B5, “Quality Control Requirements”).

B1.7 Validation of Any Nonstandard Methods

For nonstandard sampling methods, sample matrices, or other unusual situations, appropriate method validation study information may be needed to confirm the performance of the method for the particular matrix. The purpose of this validation information is to assess the potential impact on the representativeness of the data generated. For example, if qualitative data are needed from a modified method, rigorous validation may not be necessary. Such validation studies may include round-robin studies performed by EPA or by other organizations. If previous validation studies are not available, some level of single-user validation study or ruggedness study should be performed during the project and included as part of the project's final report. This element of the QAPP should clearly reference any available validation study information.

B2 SAMPLING METHODS REQUIREMENTS

Describe the procedures for collecting samples and identify the sampling methods and equipment. Include any implementation requirements, support facilities, sample preservation requirements, and materials needed. Describe the process for preparing and decontaminating sampling equipment, including disposing decontamination by-products; selecting and preparing sample containers, sample volumes, preservation methods, and maximum holding times for sampling and/or analysis.

Describe specific performance requirements for the method. Address what to do when a failure in the sampling occurs, who is responsible for corrective action, and how the effectiveness of the corrective action shall be determined and documented.

B2.1 Purpose/Background

Environmental samples should reflect the target population and parameters of interest. As with all other considerations involving environmental measurements, sampling methods should be chosen with respect to the intended application of the data. Just as methods of analysis vary in accordance with project needs, sampling methods can also vary according to these requirements. Different sampling methods have different operational characteristics, such as cost, difficulty, and necessary equipment. In addition, the sampling method can materially affect the representativeness, comparability, bias, and precision of the final analytical result.

In the area of environmental sampling, there exists a great variety of sample types. It is beyond the scope of this document to provide detailed advice for each sampling situation and sample type. Nevertheless, it is possible to define certain common elements that are pertinent to many sampling situations with discrete samples (see EPA QA/G-5S).

If a separate sampling and analysis plan is required or created for the project, it should be included as an appendix to the QAPP. The QAPP should simply refer to the appropriate portions of the sampling and analysis plan for the pertinent information and not reiterate information.

B2.2 Describe the Sample Collection, Preparation, and Decontamination Procedures

(1) *Select and describe appropriate sampling methods from the appropriate compendia of methods.* For each parameter within each sampling situation, identify appropriate sampling methods from applicable EPA regulations, compendia of methods, or other sources of methods that have been approved by EPA. When EPA-sanctioned procedures are available, they will usually be selected. When EPA-sanctioned procedures are not available, standard procedures from other organizations and disciplines may be used. A complete description of non-EPA methods should be provided in (or attached to) the QAPP. Procedures for sample homogenization of nonaqueous matrices may be described in part (2) as a technique for assuring sample representativeness. In addition, the QAPP should specify the type of sample to be collected (e.g., grab, composite, depth-integrated, flow- weighted) together with the method of sample preservation.

(2) *Discuss sampling methods' requirements.* Each medium or contaminant matrix has its own characteristics that define the method performance and the type of material to be sampled. Investigators should address the following:

- actual sampling locations,
- choice of sampling method/collection,
- delineation of a properly shaped sample,
- inclusion of all particles within the volume sampled, and
- subsampling to reduce the representative field sample into a representative laboratory aliquot.

Having identified appropriate and applicable methods, it is necessary to include the requirements for each method in the QAPP. If there is more than one acceptable sampling method applicable to a particular situation, it may be necessary to choose one from among them. DQOs should be considered in choosing these methods to ensure that: a) the sample accurately represents the portion of the environment to be characterized, b) the sample is of sufficient volume to support the planned chemical analysis, and c) the sample remains stable during shipping and handling.

(3) *Describe the decontamination procedures and materials.* Decontamination is primarily applicable in situations of sample acquisition from solid, semi-solid, or liquid media, but it should be addressed, if applicable, for continuous monitors as well. The investigator must

consider the appropriateness of the decontamination procedures for the project at hand. For example, if contaminants are present in the environmental matrix at the 1% level, it is probably unnecessary to clean sampling equipment to parts-per-billion (ppb) levels. Conversely, if ppb-level detection is required, rigorous decontamination or the use of disposable equipment is required. Decontamination by-products must be disposed of according to EPA policies and the applicable rules and regulations that would pertain to a particular situation, such as the regulations of OSHA, the Nuclear Regulatory Commission (NRC), and State and local governments.

B2.3 Identify Support Facilities for Sampling Methods

Support facilities vary widely in their analysis capabilities, from percentage-level accuracy to ppb-level accuracy. The investigator must ascertain that the capabilities of the support facilities are commensurate with the requirements of the sampling plan established in Step 7 of the DQO Process.

B2.4 Describe Sampling/Measurement System Failure Response and Corrective Action Process

This section should address issues of responsibility for the quality of the data, the methods for making changes and corrections, the criteria for deciding on a new sample location, and how these changes will be documented. This section should describe what will be done if there are serious flaws with the implementation of the sampling methodology and how these flaws will be corrected. For example, if part of the complete set of samples is found to be inadmissable, how replacement samples will be obtained and how these new samples will be integrated into the total set of data should be described.

B2.5 Describe Sampling Equipment, Preservation, and Holding Time Requirements

This section includes the requirements needed to prevent sample contamination (disposable samplers or samplers capable of appropriate decontamination), the physical volume of the material to be collected (the size of composite samples, core material, or the volume of water needed for analysis), the protection of physical specimens to prevent contamination from outside sources, the temperature preservation requirements, and the permissible holding times to ensure against degradation of sample integrity.

B2.6 References

Publications useful in assisting the development of sampling methods include:

Solid and Hazardous Waste Sampling

U.S. Environmental Protection Agency. 1986. *Test Methods for Evaluating Solid Waste (SW-846).* 3rd Ed., Chapter 9.

U.S. Environmental Protection Agency. 1985. *Characterization of Hazardous Waste Sites - A Methods Manual. Vol. I, Site Investigations.* EPA-600/4-84-075. Environmental Monitoring Systems Laboratory. Las Vegas, NV.

U.S. Environmental Protection Agency. 1984. *Characterization of Hazardous Waste Sites - A Methods Manual. Vol. II, Available Sampling Methods.* EPA-600/4-84-076. Environmental Monitoring Systems Laboratory. Las Vegas, NV.

U.S. Environmental Protection Agency. 1987. *A Compendium of Superfund Field Operations Methods.* NTIS PB88-181557. EPA/540/P-87/001. Washington, DC.

Ambient Air Sampling

U.S. Environmental Protection Agency. 1994. *Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. I, Principles*. EPA 600/9-76-005. Section 1.4.8 and Appendix M.5.6.

U.S. Environmental Protection Agency. 1994. *Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. II,* EPA 600/R-94-038b. Sections 2.0.1 and 2.0.2 and individual methods.

U.S. Environmental Protection Agency. 1984. *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air.* EPA/600-4-84-41. Environmental Monitoring Systems Laboratory. Research Triangle Park, NC. *Supplement:* EPA-600-4-87-006. September 1986.

Source Testing (Air)

U.S. Environmental Protection Agency. 1994. *Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. III,* EPA 600/R-94-038c. Section 3.0 and individual methods.

Water/ Ground Water

U.S. Environmental Protection Agency. *Handbook: Ground Water.* Cincinnati, OH. EPA/625/6-87/016. March 1987.

U.S. Environmental Protection Agency. *RCRA Ground Water Monitoring Technical Enforcement Guidance Document.* Washington, DC. 1986.

U.S. Environmental Protection Agency. *Standard Methods for the Examination of Water and Wastewater.* 16th ed. Washington, DC. 1985.

Acid Precipitation

U.S. Environmental Protection Agency. 1994. *Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. V*, EPA 600/94-038e.

Meteorological Measurements

U.S. Environmental Protection Agency. 1989. *Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. IV*, EPA 600/4-90-003.

Radioactive Materials and Mixed Waste

U.S. Department of Energy. 1989. *Radioactive-Hazardous Mixed Waste Sampling and Analysis: Addendum to SW-846.*

Soils and Sediments

U.S. Environmental Protection Agency. 1985. *Sediment Sampling Quality Assurance User's Guide.* NTIS PB85-233542. EPA/600/4-85/048. Environmental Monitoring Systems Laboratory. Las Vegas, NV.

U.S. Environmental Protection Agency. 1989. *Soil Sampling Quality Assurance User's Guide.* EPA/600/8-89/046. Environmental Monitoring Systems Laboratory. Las Vegas, NV.

Barth, D.S., and T.H. Starks. 1985. *Sediment Sampling Quality Assurance User's Guide.* EPA/600-4-85/048. Prepared for Environmental Monitoring and Support Laboratory. Las Vegas, NV.

Statistics, Geostatistics, and Sampling Theory

Myers, J.C. 1997. *Geostatistical Error Measurement.* New York: Van Nostrand Reinhold.

Pitard, F.F. 1989. *Pierre Gy's Sampling Theory and Sampling Practice. Vol I and II.* Boca Raton, FL: CRC Press.

Miscellaneous

American Chemical Society Joint Board/Council Committee on Environmental Improvement. 1990. *Practical Guide for Environmental Sampling and Analysis, Section II. Environmental Analysis.* Washington, DC.

ASTM Committee D-34. 1986. *Standard Practices for Sampling Wastes from Pipes and Other Point Discharges.* Document No. D34.01-001R7.

Keith, L. 1990. *EPA's Sampling and Analysis Methods Database Manual.* Austin, TX: Radian Corp.

Keith, L. 1991. *Environmental Sampling and Analysis: A Practical Guide.* Chelsea, MI: Lewis Publishers, Inc.

B3 SAMPLE HANDLING AND CUSTODY REQUIREMENTS

Describe the requirements and provisions for sample handling and custody in the field, laboratory, and transport, taking into account the nature of the samples, the maximum allowable sample holding times before extraction or analysis, and available shipping options and schedules.

Include examples of sample labels, custody forms, and sample custody logs.

B3.1 Purpose/Background

This element of the QAPP should describe all procedures that are necessary for ensuring that:

(1) samples are collected, transferred, stored, and analyzed by authorized personnel;

(2) sample integrity is maintained during all phases of sample handling and analyses; and

(3) an accurate written record is maintained of sample handling and treatment from the time of its collection through laboratory procedures to disposal.

Proper sample custody minimizes accidents by assigning responsibility for all stages of sample handling and ensures that problems will be detected and documented if they occur. A sample is in custody if it is in actual physical possession or it is in a secured area that is restricted to authorized personnel. The level of custody necessary is dependent upon the project's DQOs. While enforcement actions necessitate stringent custody procedures, custody in other types of situations (i.e., academic research) may be primarily concerned only with the tracking of sample collection, handling, and analysis.

Sample custody procedures are necessary to prove that the sample data correspond to the sample collected, if data are intended to be legally defensible in court as evidence. In a number of situations, a complete, detailed, unbroken chain of custody will allow the documentation and data to substitute for the physical evidence of the samples (which are often hazardous waste) in a civil courtroom. Some statutes or criminal violations may still necessitate that the physical evidence of sample containers be presented along with the custody and data documentation.

An outline of the scope of sample custody--starting from the planning of sample collection, field sampling, sample analysis to sample disposal--should also be included. This discussion should further stress the completion of sample custody procedures, which include the transfer of sample custody from field personnel to lab, sample custody within the analytical lab during sample preparation and analysis, and data storage.

B3.2 Sample Custody Procedure

The QAPP should discuss the sample custody procedure at a level commensurate with the intended use of the data. This discussion should include the following:

(1) List the names and responsibilities of all sample custodians in the field and laboratories.

(2) Give a description and example of the sample numbering system.

(3) Define acceptable conditions and plans for maintaining sample integrity in the field prior to and during shipment to the laboratory (e.g., proper temperature and preservatives).

(4) Give examples of forms and labels used to maintain sample custody and document sample handling in the field and during shipping. An example of a sample log sheet is given in Figure 5; an example sample label is given in Figure 6.

(5) Describe the method of sealing shipping containers with chain-of-custody seals. An example of a seal is given in Figure 7.

(6) Describe procedures that will be used to maintain the chain of custody and document sample handling during transfer from the field to the laboratory, within the laboratory, and among contractors. An example of a chain-of-custody record is given in Figure 8.

(7) Provide for the archiving of all shipping documents and associated paperwork.

(8) Discuss procedures that will ensure sample security at all times.

(9) Describe procedures for within-laboratory chain-of-custody together with verification of the printed name, signature, and initials of the personnel responsible for custody of samples, extracts, or digests during analysis at the laboratory. Finally, document disposal or consumption of samples should also be described. A chain-of-custody checklist is included in Appendix C to aid in managing this element.

Minor documentation of chain-of-custody procedures is generally applicable when:

- Samples are generated and immediately tested within a facility or site; and

- Continuous rather than discrete or integrated samples are subjected to real- or near real-time analysis (e.g., continuous monitoring).

The discussion should be as specific as possible about the details of sample storage, transportation, and delivery to the receiving analytical facility.

FOR________ SURVEY ________ SAMPLE LOG SHEET NO.________ DATE________

TYPE OF SAMPLE________ **SAMPLER:** *(Signature)*________

A N A L Y S E S R E Q U I R E D

STATION NUMBER	STATION DESCRIPTION	TIME SAMPLE TAKEN	TOTAL VOLUME	TYPE CONTAINER	PRESERVATIVE	NUTRIENTS	BOD	COD	TOC	TOTAL SOLIDS	SUSPENDED SOLIDS	ALKALINITY	DO	pH*	CONDUCTIVITY*	TEMPERATURE*	TOTAL COLIFORM	FECAL COLIFORM	TURBIDITY	OIL AND GREASE	METALS	BACTI	PESTICIDES	HERB	TRACE ORGANICS	PHENOL	CYANIDE

REMARKS

*Field Measurements

U.S. EPA, NEIC Director

Figure 5. An Example of a Sample Log Sheet

(Name of Sampling Organization)

Sample Description: ______________________________
____

Plant: ________________ Location: ________________
Date: ________________ ________________
Time: ________________ ________________
Media: ________________ Station: ________________
Sample Type: ____________ Preservative: ____________

Sampled By: ______________________________

Sample ID No.: ______________________________

Lab No. ______________________________

Remarks: ____

Figure 6. An Example of a Sample Label

CUSTODY SEAL
Date ________________
Signature ________________

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CUSTODY SEAL
____
Date
____
Signature

Figure 7. An Example of a Custody Seal

				SAMPLERS *(Signature)*							
STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE			SEQ NO.	NO. OF CONTAINERS	ANALYSIS REQUIRED		
				WATER		AIR					
				Comp	Grabx						

Relinquished by: *(Signature)*		Received by: *(Signature)*	DATE/TIME
Relinquished by: *(Signature)*		Received by: *(Signature)*	DATE/TIME
Relinquished by: *(Signature)*		Received by: *(Signature)*	DATE/TIME
Received by: *(Signature)*		Received by Mobile Laboratory for field analysis: *(Signature)*	DATE/TIME
Received by: *(Signature)*	DATE/TIME	Received for Laboratory by:	DATE/TIME
Method of Shipment:			

Distribution: Original - Accompany Shipment
1 Copy - Survey Coordinator Field Files

Figure 8. An Example of a Chain-of-Custody Record

B4 ANALYTICAL METHODS REQUIREMENTS

Identify the analytical methods and equipment required, including sub-sampling or extraction methods, laboratory decontamination procedures and materials (such as the case of hazardous or radioactive samples), waste disposal requirements (if any), and specific performance requirements for the method.

Identify analytical methods by number, date, and regulatory citation (as appropriate). If a method allows the user to select from various options, then the method citations should state exactly which options are being selected. For non-standard methods, such as unusual sample matrices and situations, appropriate method performance study information is needed to confirm the performance of the method for the particular matrix. If previous performance studies are not available, they must be developed during the project and included as part of the project results.

Address what to do when a failure in the analytical system occurs, who is responsible for corrective action, and how the effectiveness of the corrective action shall be determined and documented.

Specify the laboratory turnaround time needed, if important to the project schedule. Specify whether a field sampling and/or laboratory analysis case narrative is required to provide a complete description of any difficulties encountered during sampling or analysis.

B4.1 Purpose/Background

The choice of analytical methods will be influenced by the performance criteria, Data Quality Objectives, and possible regulatory criteria. If appropriate, a citation of analytical procedures may be sufficient if the analytical method is a complete SOP. For other methods, it may suffice to reference a procedure (i.e., from *Test Methods for Evaluating Solid Waste,* SW-846) and further supplement it with the particular options/variations being used by the lab, the detection limits actually achieved, the calibration standards and concentrations used, etc. If the procedure is unique or an adaption of a "standard" method, complete analytical and sample preparation procedures will need to be attached to the QAPP.

Specific monitoring methods and requirements to demonstrate compliance traditionally were specified in the applicable regulations and/or permits. However, this approach is being replaced by the Performance-Based Measurement System (PBMS). PBMS is a process in which data quality needs, mandates, or limitations of a program or project are specified and serve as a criterion for selecting appropriate methods. The regulated body selects the most cost-effective methods that meet the criteria specified in the PBMS. Under the PBMS framework, the performance of the method employed is emphasized rather than the specific technique or procedure used in the analysis. Equally stressed in this system is the requirement that the performance of the method be documented and certified by the laboratory that appropriate QA/QC procedures have been conducted to verify the performance. PBMS applies to physical, chemical, and biological techniques of analysis performed in the field as well as in the laboratory. PBMS does not apply to the method-defined parameters.

The QAPP should also address the issue of the quality of analytical data as indicated by the data's ability to meet the QC acceptance criteria. This section should describe what should be done if the calibration check samples exceed the control limits due to mechanical failure of the instrumentation, a drift in the calibration curve occurs, or if a reagent blank indicates contamination. This section should also indicate the authorities responsible for the quality of the data, the protocols for making changes and implementing corrective actions, and the methods for reporting the data and its limitations.

Laboratory contamination from the processing of hazardous materials such as toxic or radioactive samples for analysis and their ultimate disposal should be a considered during the planning stages for selection of analysis methods. Safe handling requirements for project samples in the laboratory with appropriate decontamination and waste disposal procedures should also be described.

B4.2 Subsampling

If subsampling is required, the procedures should be described in this QAPP element, and the full text of the subsampling operating procedures should be appended to the QAPP. Because subsampling may involve more than one stage, it is imperative that the procedures be documented fully so that the results of the analysis can be evaluated properly.

B4.3 Preparation of the Samples

Preparation procedures should be described and standard methods cited and used where possible. Step-by-step operating procedures for the preparation of the project samples should be listed in an appendix. The sampling containers, methods of preservation, holding times, holding conditions, number and types of all QA/QC samples to be collected, percent recovery, and names of the laboratories that will perform the analyses need to be specifically referenced.

B4.4 Analytical Methods

The citation of an analytical method may not always be sufficient to fully characterize a method because the analysis of a sample may require deviation from a standard method and selection from the range of options in the method. The SOP for each analytical method should be cited or attached to the QAPP, and all deviations or alternative selections should be detailed in the QAPP.

The matrix containing the subject analytes often dictates the sampling and analytical methods. Gaseous analytes often must be concentrated on a trap in order to collect a measurable quantity. If the matrix is a liquid or a solid, the analytes usually must be separated from it using various methods of extraction. Sometimes the analyte is firmly linked by chemical bonds to other elements and must be subjected to digestion methods to be freed for analysis.

Often the selected analytical methods may be presented conveniently in one or several tables describing the matrix, the analytes to be measured, the analysis methods, the type, the precision/accuracy data, the performance acceptance criteria, the calibration criteria, and etc. Appendix C contains a checklist of many important components to consider when selecting analytical methods.

B4.5 References

Greenberg, A.E., L.S. Clescer, and A. D. Eaton, eds. 1992. *Standard Methods for the Examination of Water and Wastewater. 18th ed.* American Public Health Association. Water Environment Federation.

U.S. Environmental Protection Agency. 1996. *Quality Control: Variability in Protocols.* EPA/600/9-91/034. Risk Reduction Engineering Laboratory. U.S. EPA. Cincinnati, OH.

U.S. Environmental Protection Agency. *Test Methods for Evaluating Solid Waste.* SW-846. Chapter 2, "Choosing the Correct Procedure."

B5 QUALITY CONTROL REQUIREMENTS

Identify required measurement QC checks for both the field and the laboratory. State the frequency of analysis for each type of QC check, and the spike compounds sources and levels. State or reference the required control limits for each QC check and corrective action required when control limits are exceeded and how the effectiveness of the corrective action shall be determined and documented.

Describe or reference the procedures to be used to calculate each of the QC statistics.

B5.1 Purpose/Background

QC is "the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer." QC is both corrective and proactive in establishing techniques to prevent the generation of unacceptable data, and so the policy for corrective action should be outlined. This element will rely on information developed in section A7, "Quality Objectives and Criteria for Measurement Data," which establishes measurement performance criteria.

B5.2 QC Procedures

This element documents any QC checks not defined in other QAPP elements and should reference other elements that contain this information where possible. Most of the QC acceptance limits of EPA methods are based on the results of interlaboratory studies. Because of improvements in measurement methodology and continual improvement efforts in individual laboratories, these acceptance limits may not be stringent enough for some projects. In some cases, acceptance limits are based on intralaboratory studies (which often result in narrower acceptance limits than those based on interlaboratory limits), and consultation with an expert may be necessary. Other elements of the QAPP that contain related sampling and analytical QC requirements include:

- **Sampling Process Design** (B1), which identifies the planned field QC samples as well as procedures for QC sample preparation and handling;
- **Sampling Methods Requirements** (B2), which includes requirements for determining if the collected samples accurately represent the population of interest;
- **Sample Handling and Custody Requirements** (B3), which discusses any QC devices employed to ensure samples are not tampered with (e.g., custody seals) or subjected to other unacceptable conditions during transport;
- **Analytical Methods Requirements** (B4), which includes information on the subsampling methods and information on the preparation of QC samples in the sample matrix (e.g., splits, spikes, and replicates); and

- **Instrument Calibration and Frequency** (B7), which defines prescribed criteria for triggering recalibration (e.g., failed calibration checks).

Table 1 lists QC checks often included in QAPPs. The need for the specific check depends on the project objectives.

Table 1. Project Quality Control Checks

QC Check	Information Provided
Blanks	
field blank	transport and field handling bias
reagent blank	contaminated reagent
rinsate blank	contaminated equipment
method blank	response of entire laboratory analytical system
Spikes	
matrix spike	analytical (preparation + analysis) bias
matrix spike replicate	analytical bias and precision
analysis matrix spike	instrumental bias
surrogate spike	analytical bias
Calibration Check Samples	
zero check	calibration drift and memory effects
span check	calibration drift and memory effects
mid-range check	calibration drift and memory effects
Replicates, splits, etc.	
collocated samples	sampling + measurement precision
field replicates	precision of all steps after acquisition
field splits	shipping + interlaboratory precision
laboratory splits	interlaboratory precision
laboratory replicates	analytical precision
analysis replicates	instrument precision

Many QC checks result in measurement data that are used to compute statistical indicators of data quality. For example, a series of dilute solutions may be measured repeatedly to produce an estimate of the instrument detection limit. The formulas for calculating such Data Quality Indicators (DQIs) should be provided or referenced in the text. This element should also prescribe any limits that define acceptable data quality for these indicators (see also Appendix D, "Data Quality Indicators"). A QC checklist should be used to discuss the relation of QC to the overall project objectives with respect to:

- the frequency and point in the measurement process in which the check sample is introduced,
- the traceability of the standards,
- the matrix of the check sample,
- the level or concentration of the analyte of interest,
- the actions to be taken if a QC check identifies a failed or changed measurement system,
- the formulas for estimating DQIs, and
- the procedures for documenting QC results, including control charts.

Finally, this element should describe how the QC check data will be used to determine that measurement performance is acceptable. This step can be accomplished by establishing QC "warning" and "control" limits for the statistical data generated by the QC checks (see standard QC textbooks or refer to EPA QA/G-5T for operational details).

Depending on the breadth of the potential audience for reviewing and implementing the QAPP, it may be advantageous to separate the field QC from the laboratory QC requirements.

B6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE REQUIREMENTS

Describe how inspections and acceptance testing of environmental sampling and measurement systems and their components will be performed and documented.

Identify and discuss the procedure by which final acceptance will be performed by independent personnel and/or by the EPA Project Officer.

Describe how deficiencies are to be resolved and when re-inspection will be performed.

Describe or reference how periodic preventive and corrective maintenance of measurement or test equipment shall be performed. Identify the equipment and/or systems requiring periodic maintenance. Discuss how the availability of critical spare parts, identified in the operating guidance and/or design specifications of the systems, will be assured and maintained.

B6.1 Purpose/Background

The purpose of this element of the QAPP is to discuss the procedures used to verify that all instruments and equipment are maintained in sound operating condition and are capable of operating at acceptable performance levels.

B6.2 Testing, Inspection, and Maintenance

The procedures described should (1) reflect consideration of the possible effect of equipment failure on overall data quality, including timely delivery of project results; (2) address any relevant site-specific effects (e.g., environmental conditions); and (3) include procedures for assessing the equipment status. This element should address the scheduling of routine calibration and maintenance activities, the steps that will be taken to minimize instrument downtime, and the prescribed corrective action procedures for addressing unacceptable inspection or assessment results. This element should also include periodic maintenance procedures and describe the availability of spare parts and how an inventory of these parts is monitored and maintained. The reader should be supplied with sufficient information to review the adequacy of the instrument/equipment management program. Appending SOPs containing this information to the QAPP and referencing the SOPs in the text are acceptable.

Inspection and testing procedures may employ reference materials, such as the National Institute of Standards and Technology's (NIST's) Standard Reference Materials (SRMs), as well as QC standards or an equipment certification program. The accuracy of calibration standards is important because all data will be measured in reference to the standard used. The types of standards or special programs should be noted in this element, including the inspection and acceptance testing criteria for all components. The acceptance limits for verifying the accuracy of all working standards against primary grade standards should also be provided.

B7 INSTRUMENT CALIBRATION AND FREQUENCY

Identify all tools, gauges, instruments, and other sampling, measuring, and test equipment used for data collection activities affecting quality that must be controlled and, at specified periods, calibrated to maintain performance within specified limits.

Identify the certified equipment and/or standards used for calibration. Describe or reference how calibration will be conducted using certified equipment and/or standards with known valid relationships to nationally recognized performance standards. If no such nationally recognized standards exist, document the basis for the calibration. Indicate how records of calibration shall be maintained and be traceable to the instrument.

B7.1 Purpose/Background

This element of the QAPP concerns the calibration procedures that will be used for instrumental analytical methods and other measurement methods that are used in environmental measurements. It is necessary to distinguish between defining calibration as the checking of physical measurements against accepted standards and as determining the relationship (function) of the response versus the concentration. The American Chemical Society (ACS) limits the definition of the term *calibration* to the checking of physical measurements against accepted standards, and uses the term *standardization* to describe the determination of the response function.

B7.2 Identify the Instrumentation Requiring Calibration

The QAPP should identify any equipment or instrumentation that requires calibration to maintain acceptable performance. While the primary focus of this element is on instruments of the measurement system (sampling and measurement equipment), all methods require standardization to determine the relationship between response and concentration.

B7.3 Document the Calibration Method that Will Be Used for Each Instrument

The QAPP must describe the calibration method for each instrument in enough detail for another researcher to duplicate the calibration method. It may reference external documents such as EPA-designated calibration procedures or SOPs providing that these documents can be easily obtained. Nonstandard calibration methods or modified standard calibration methods should be fully documented and justified.

Some instrumentation may be calibrated against other instrumentation or apparatus (e.g., NIST thermometer), while other instruments are calibrated using standard materials traceable to national reference standards. QAPP documentation for calibration apparatus and calibration standards are addressed in B7.4 and B7.5.

Calibrations normally involve challenging the measurement system or a component of the measurement system at a number of different levels over its operating range. The calibration may cover a narrower range if accuracy in that range is critical, given the end use of the data. Single-point calibrations are of limited use, and two-point calibrations do not provide information on nonlinearity. If single- or two-point calibrations are used for critical measurements, the potential shortcomings should be carefully considered and discussed in the QAPP. Most EPA-approved analytical methods require multipoint (three or more) calibrations that include zeros, or blanks, and higher levels so that unknowns fall within the calibration range and are bracketed by calibration points. The number of calibration points, the calibration range, and any replication (repeated measures at each level) should be given in the QAPP.

The QAPP should describe how calibration data will be analyzed. The use of statistical QC techniques to process data across multiple calibrations to detect gradual degradations in the measurement system should be described. The QAPP should describe any corrective action that will be taken if calibration (or calibration check) data fail to meet the acceptance criteria, including recalibration. References to appended SOPs containing the calibration procedures are an acceptable alternative to describing the calibration procedures within the text of the QAPP.

B7.4 Document the Calibration Apparatus

Some instruments are calibrated using calibration apparatus rather than calibration standards. For example, an ozone generator is part of a system used to calibrate continuous ozone monitors. Commercially available calibration apparatus should be listed together with the make (the manufacturer's name), the model number, and the specific variable control settings that will be used during the calibrations. A calibration apparatus that is not commercially available should be described in enough detail for another researcher to duplicate the apparatus and follow the calibration procedure.

B7.5 Document the Calibration Standards

Most measurement systems are calibrated by processing materials that are of known and stable composition. References describing these calibration standards should be included in the QAPP. Calibration standards are normally traceable to national reference standards, and the traceability protocol should be discussed. If the standards are not traceable, the QAPP must include a detailed description of how the standards will be prepared. Any method used to verify the certified value of the standard independently should be described.

B7.6 Document Calibration Frequency

The QAPP must describe how often each measurement method will be calibrated. It is desirable that the calibration frequency be related to any known temporal variability (i.e., drift) of the measurement system. The calibration procedure may involve less-frequent comprehensive calibrations and more-frequent simple drift checks. The location of the record of calibration frequency and maintenance should be referenced.

B7.7 References

American Chemical Society. 1980. "Calibration." *Analytical Chemistry*, Vol. 52, pps. 2,242-2,249.

Dieck, R.H. 1992. *Measurement Uncertainty Methods and Applications.* Research Triangle Park, NC: Instrument Society of America.

Dux, J.P. 1986. *Handbook of Quality Assurance for the Analytical Chemistry Laboratory.* New York: Van Nostrand Reinhold.

ILAC Task Force E. 1984. *Guidelines for the Determination of Recalibration Intervals of Testing Equipment Used in Testing Laboratories.* International Organization for Legal Metrology (OIML). International Document No. 10. 11 Rue Twigot, Paris 95009, France.

Ku, H.H., ed. 1969. *Precision Measurement and Calibration. Selected NBS Papers on Statistical Concepts and Procedures.* Special Publication 300. Vol. 1. Gaithersburg, MD: National Bureau of Standards.

Liggett, W. 1986. "Tests of the Recalibration Period of a Drifting Instrument." In *Oceans '86 Conference Record.* Vol. 3. Monitoring Strategies Symposium. The Institute of Electrical and Electronics Engineers, Inc., Service Center. Piscataway, NJ.

Pontius, P.E. 1974. *Notes on the Fundamentals of Measurement as a Production Process.* Publication No. NBSIR 74-545. Gaithersburg, MD: National Bureau of Standards.

Taylor, J.T. 1987. *Quality Assurance of Chemical Measurements.* Boca Raton, FL: Lewis Publishers, Inc.

B8 INSPECTION/ACCEPTANCE REQUIREMENTS FOR SUPPLIES AND CONSUMABLES

Describe how and by whom supplies and consumables shall be inspected and accepted for use in the project. State acceptance criteria for such supplies and consumables.

B8.1 Purpose

The purpose of this element is to establish and document a system for inspecting and accepting all supplies and consumables that may directly or indirectly affect the quality of the project or task. If these requirements have been included under another section, it is sufficient to provide a reference.

B8.2 Identification of Critical Supplies and Consumables

Clearly identify and document all supplies and consumables that may directly or indirectly affect the quality of the project or task. See Figures 9 and 10 for example documentation of inspection/acceptance testing requirements. Typical examples include sample bottles, calibration gases, reagents, hoses, materials for decontamination activities, deionized water, and potable water.

For each item identified, document the inspection or acceptance testing requirements or specifications (e.g., concentration, purity, cell viability, activity, or source of procurement) in addition to any requirements for certificates of purity or analysis.

B8.3 Establishing Acceptance Criteria

Acceptance criteria must be consistent with overall project technical and quality criteria (e.g., concentration must be within ± 2.5%, cell viability must be >90%). If special requirements are needed for particular supplies or consumables, a clear agreement should be established with the supplier, including the methods used for evaluation and the provisions for settling disparities.

B8.4 Inspection or Acceptance Testing Requirements and Procedures

Inspections or acceptance testing should be documented, including procedures to be followed, individuals responsible, and frequency of evaluation. In addition, handling and storage conditions for supplies and consumables should be documented.

B8.5 Tracking and Quality Verification of Supplies and Consumables

Procedures should be established to ensure that inspections or acceptance testing of supplies and consumables are adequately documented by permanent, dated, and signed records or logs that uniquely identify the critical supplies or consumables, the date received, the date tested, the date to be retested (if applicable), and the expiration date. These records should be kept by the responsible individual(s) (see Figure 11 for an example log). In order to track supplies and consumables, labels with the information on receipt and testing should be used.

These or similar procedures should be established to enable project personnel to (1) verify, prior to use, that critical supplies and consumables meet specified project or task quality objectives; and (2) ensure that supplies and consumables that have not been tested, have expired, or do not meet acceptance criteria are not used for the project or task.

Unique identification no. (if not clearly shown)______________________
Date received____
Date opened____
Date tested (if performed)____
Date to be retested (if applicable)_________________________________
Expiration date____

Figure 9. Example of a Record for Consumables

Critical Supplies and Consumables	Inspection/ Acceptance Testing Requirements	Acceptance Criteria	Testing Method	Frequency	Responsible Individual	Handling/Storage Conditions

Figure 10. Example of Inspection/Acceptance Testing Requirements

Critical Supplies and Consumable (Type, ID No.)	Date Received	Meets Inspection/ Acceptance Criteria (Y/N, Include Date)	Requires Retesting (Y/N, If Yes, Include Date)	Expiration Date	Comments	Initials/Date

Figure 11. Example of a Log for Tracking Supplies and Consumables

B9 DATA ACQUISITION REQUIREMENTS (NON-DIRECT MEASUREMENTS)

Identify any types of data needed for project implementation or decision making that are obtained from non-measurement sources such as computer databases, programs, literature files, and historical databases.

Define the acceptance criteria for the use of such data in the project and discuss any limitations on the use of the data resulting from uncertainty in its quality.

Document the rationale for the original collection of data and indicate its relevance to this project.

B9.1 Purpose/Background

This element of the QAPP should clearly identify the intended sources of previously collected data and other information that will be used in this project. Information that is non-representative and possibly biased and is used uncritically may lead to decision errors. The care and skepticism applied to the generation of new data are also appropriate to the use of previously compiled data (for example, data sources such as handbooks and computerized databases).

B9.2 Acquisition of Non-Direct Measurement Data

This element's criteria should be developed to support the objectives of element A7. Acceptance criteria for each collection of data being considered for use in this project should be explicitly stated, especially with respect to:

- **Representativeness.** Were the data collected from a population that is sufficiently similar to the population of interest and the population boundaries? How will potentially confounding effects (for example, season, time of day, and cell type) be addressed so that these effects do not unduly alter the summary information?

- **Bias.** Are there characteristics of the data set that would shift the conclusions. For example, has bias in analysis results been documented? Is there sufficient information to estimate and correct bias?

- **Precision.** How is the spread in the results estimated? Does the estimate of variability indicate that it is sufficiently small to meet the objectives of this project as stated in element A7? See also Appendix D.

- **Qualifiers.** Are the data evaluated in a manner that permits logical decisions on whether or not the data are applicable to the current project? Is the system of qualifying or flagging data adequately documented to allow the combination of data sets?

- **Summarization.** Is the data summarization process clear and sufficiently consistent with the goals of this project? (See element D2 for further discussion.) Ideally, observations and transformation equations are available so that their assumptions can be evaluated against the objectives of the current project.

This element should also include a discussion on limitations on the use of the data and the nature of the uncertainty of the data.

B10 DATA MANAGEMENT

Describe the project data management scheme, tracing the path of the data from their generation in the field or laboratory to their final use or storage. Describe or reference the standard record-keeping procedures, document control system, and the approach used for data storage and retrieval on electronic media.

Discuss the control mechanism for detecting and correcting errors and for preventing loss of data during data reduction, data reporting, and data entry to forms, reports, and databases. Provide examples of any forms or checklists to be used.

Identify and describe all data handling equipment and procedures to process, compile, and analyze the data, including any required computer hardware and software. Address any specific performance requirements and describe the procedures that will be followed to demonstrate acceptability of the hardware/software configuration required.

Describe the process for assuring that applicable Agency information resource management requirements and locational data requirements are satisfied. If other Agency data management requirements are applicable, discuss how these requirements are addressed.

B10.1 Purpose/Background

This element should present an overview of all mathematical operations and analyses performed on raw ("as-collected") data to change their form of expression, location, quantity, or dimensionality. These operations include data recording, validation, transformation, transmittal, reduction, analysis, management, storage, and retrieval. A diagram that illustrates the source(s) of the data, the processing steps, the intermediate and final data files, and the reports produced may be helpful, particularly when there are multiple data sources and data files. When appropriate, the data values should be subjected to the same chain-of-custody requirements as outlined in element B3. Appendix G has further details.

B10.2 Data Recording

Any internal checks (including verification and validation checks) that will be used to ensure data quality during data encoding in the data entry process should be identified together with the mechanism for detailing and correcting recording errors. Examples of data entry forms and checklists should be included.

B10.3 Data Validation

The details of the process of data validation and prespecified criteria should be documented in this element of the QAPP. This element should address how the method, instrument, or system performs the function it is intended to consistently, reliably, and accurately in generating the data. Part D of this document addresses the overall project data validation, which is performed after the project has been completed.

B10.4 Data Transformation

Data transformation is the conversion of individual data point values into related values or possibly symbols using conversion formulas (e.g., units conversion or logarithmic conversion) or a system for replacement. The transformations can be reversible (e.g., as in the conversion of data points using a formulas) or irreversible (e.g., when a symbol replaces actual values and the value is lost). The procedures for all data transformations should be described and recorded in this element. The procedure for converting calibration readings into an equation that will be applied to measurement readings should be documented in the QAPP. Transformation and aberration of data for statistical analysis should be outlined in element D3, "Reconciliation with Data Quality Objectives."

B10.5 Data Transmittal

Data transmittal occurs when data are transferred from one person or location to another or when data are copied from one form to another. Some examples of data transmittal are copying raw data from a notebook onto a data entry form for keying into a computer file and electronic transfer of data over a telephone or computer network. The QAPP should describe each data transfer step and the procedures that will be used to characterize data transmittal error rates and to minimize information loss in the transmittal.

B10.6 Data Reduction

Data reduction includes all processes that change the number of data items. This process is distinct from data transformation in that it entails an irreversible reduction in the size of the data set and an associated loss of detail. For manual calculations, the QAPP should include an example in which typical raw data are reduced. For automated data processing, the QAPP should clearly indicate how the raw data are to be reduced with a well-defined audit trail, and reference to the specific software documentation should be provided.

B10.7 Data Analysis

Data analysis sometimes involves comparing suitably reduced data with a conceptual model (e.g., a dispersion model or an infectivity model). It frequently includes computation of summary statistics, standard errors, confidence intervals, tests of hypotheses relative to model parameters, and goodness-of-fit tests. This element should briefly outline the proposed methodology for data analysis and a more detailed discussion should be included in the final report.

B10.8 Data Tracking

Data management includes tracking the status of data as they are collected, transmitted, and processed. The QAPP should describe the established procedures for tracking the flow of data through the data processing system.

B10.9 Data Storage and Retrieval

The QAPP should discuss data storage and retrieval including security and time of retention, and it should document the complete control system. The QAPP should also discuss the performance requirements of the data processing system, including provisions for the batch processing schedule and the data storage facilities.

C ASSESSMENT/OVERSIGHT

C1 ASSESSMENTS AND RESPONSE ACTIONS

Identify the number, frequency, and type of assessment activities needed for this project.

List and describe the assessments to be used in the project. Discuss the information expected and the success criteria for each assessment proposed. List the approximate schedule of activities, identify potential organizations and participants. Describe how and to whom the results of the assessments shall be reported.

Define the scope of authority of the assessors, including stop work orders. Define explicitly the unsatisfactory conditions under which the assessors are authorized to act and provide an approximate schedule for the assessments to be performed.

Discuss how response actions to non-conforming conditions shall be addressed and by whom. Identify who is responsible for implementing the response action and describe how response actions shall be verified and documented.

C1.1 Purpose/Background

During the planning process, many options for sampling design (see EPA QA/G-5S, *Guidance on Sampling Design to Support QAPPs*), sample handling, sample cleanup and analysis, and data reduction are evaluated and chosen for the project. In order to ensure that the data collection is conducted as planned, a process of evaluation and validation is necessary. This element of the QAPP describes the internal and external checks necessary to ensure that:

- all elements of the QAPP are correctly implemented as prescribed,
- the quality of the data generated by implementation of the QAPP is adequate, and
- corrective actions, when needed, are implemented in a timely manner and their effectiveness is confirmed.

Although any external assessments that are planned should be described in the QAPP, the most important part of this element is documenting all planned internal assessments. Generally, internal assessments are initiated or performed by the internal QA Officer so the activities described in this element should be related to the responsibilities of the QA Officer as discussed in Section A4.

C1.2 Assessment Activities and Project Planning

The following is a description of various types of assessment activities available to managers in evaluating the effectiveness of environmental program implementation.

C1.2.1 <u>Assessment of the Subsidiary Organizations</u>

A. *Management Systems Review (MSR).* A form of management assessment, this process is a qualitative assessment of a data collection operation or organization to establish whether the prevailing quality management structure, policies, practices, and procedures are adequate for ensuring that the type and quality of data needed are obtained. The

MSR is used to ensure that sufficient management controls are in place and carried out by the organization to adequately plan, implement, and assess the results of the project. See the *Guidance for the Management Systems Review Process* (EPA QA/G-3).

B. *Readiness reviews.* A readiness review is a technical check to determine if all components of the project are in place so that work can commence on a specific phase.

C1.2.2 Assessment of Project Activities

A. *Surveillance.* Surveillance is the continual or frequent monitoring of the status of a project and the analysis of records to ensure that specified requirements are being fulfilled.

B. *Technical Systems Audit (TSA).* A TSA is a thorough and systematic onsite qualitative audit, where facilities, equipment, personnel, training, procedures, and record keeping are examined for conformance to the QAPP. The TSA is a powerful audit tool with broad coverage that may reveal weaknesses in the management structure, policy, practices, or procedures. The TSA is ideally conducted after work has commenced, but before it has progressed very far, thus giving opportunity for corrective action.

C. *Performance Evaluation (PE).* A PE is a type of audit in which the quantitative data generated by the measurement system are obtained independently and compared with routinely obtained data to evaluate the proficiency of an analyst or laboratory. "Blind" PE samples are those whose identity is unknown to those operating the measurement system. Blind PEs often produce better performance assessments because they are handled routinely and are not given the special treatment that undisguised PEs sometimes receive. The QAPP should list the PEs that are planned, identifying:

- the constituents to be measured,
- the target concentration ranges,
- the timing/schedule for PE sample analysis, and
- the aspect of measurement quality to be assessed (e.g., bias, precision, and detection limit).

A number of EPA regulations and EPA-sanctioned methods require the successful accomplishment of PEs before the results of the test can be considered valid. PE materials are now available from commercial sources and a number of EPA Program Offices coordinate various interlaboratory studies and laboratory proficiency programs. Participation in these or in the National Voluntary Laboratory Accreditation Program (NVLAP, run by NIST) should be mentioned in the QAPP.

D. *Audit of Data Quality (ADQ).* An ADQ reveals how the data were handled, what judgments were made, and whether uncorrected mistakes were made. Performed prior to producing a project's final report, ADQs can often identify the means to correct systematic data reduction errors.

E. *Peer review.* Peer review is not a TSA, nor strictly an internal QA function, as it may encompass non-QA aspects of a project and is primarily designed for scientific review. Whether a planning team chooses ADQs or peer reviews depends upon the nature of the project, the intended use of the data, the policies established by the sponsor of the project, and overall the conformance to the Program Office or Region's peer-review policies and procedures. Reviewers are chosen who have technical expertise comparable to the project's performers but who are independent of the project. ADQs and peer reviews ensure that the project activities:

- were technically adequate,
- were competently performed,
- were properly documented,
- satisfied established technical requirements, and
- satisfied established QA requirements.

In addition, peer reviews assess the assumptions, calculations, extrapolations, alternative interpretations, methods, acceptance criteria, and conclusions documented in the project's report. Any plans for peer review should conform with the Agency's peer-review policy and guidance. The names, titles, and positions of the peer reviewers should be included in the final QAPP, as should their report findings, the QAPP authors' documented responses to their findings, and reference to where responses to peer-review comments may be located, if necessary.

F. *Data Quality Assessment (DQA).* DQA involves the application of statistical tools to determine whether the data meet the assumptions that the DQOs and data collection design were developed under and whether the total error in the data is tolerable. *Guidance for the Data Quality Assessment Process* (EPA QA/G-9) provides nonmandatory guidance for planning, implementing, and evaluating retrospective assessments of the quality of the results from environmental data operations.

C1.3 Documentation of Assessments

The following material describes what should be documented in a QAPP after consideration of the above issues and types of assessments.

C1.3.1 Number, Frequency, and Types of Assessments

Depending upon the nature of the project, there may be more than one assessment. A schedule of the number, frequencies, and types of assessments required should be given.

C1.3.2 Assessment Personnel

The QAPP should specify the individuals, or at least the specific organizational units, who will perform the assessments. Internal audits are usually performed by personnel who work for the organization performing the project work but who are organizationally independent of the management of the project. External audits are performed by personnel of organizations not connected with the project but who are technically qualified and who understand the QA requirements of the project.

C1.3.3 Schedule of Assessment Activities

A schedule of audit activities, together with relevant criteria for assessment, should be given to the extent that it is known in advance of project activities.

C1.3.4 Reporting and Resolution of Issues

Audits, peer reviews, and other assessments often reveal findings of practice or procedure that do not conform to the written QAPP. Because these issues must be addressed in a timely manner, the protocol for resolving them should be given here together with the proposed actions to ensure that the corrective actions were performed effectively. The person to whom the concerns should be addressed, the decision making hierarchy, the schedule and format for oral and written reports, and the responsibility for corrective action should all be discussed in this element. It also should explicitly define the unsatisfactory conditions upon which the assessors are authorized to act and list the project personnel who should receive assessment reports.

C2 REPORTS TO MANAGEMENT

Identify the frequency and distribution of reports issued to inform management of the status of the project; results of performance evaluations and systems audits; results of periodic data quality assessments; and significant quality assurance problems and recommended solutions.

Identify the preparer and the recipients of the reports, and the specific actions management is expected to take as a result of the reports.

C2.1 Purpose/Background

Effective communication between all personnel is an integral part of a quality system. Planned reports provide a structure for apprising management of the project schedule, the deviations from approved QA and test plans, the impact of these deviations on data quality, and the potential uncertainties in decisions based on the data. Verbal communication on deviations from QA plans should be noted in summary form in element D1 of the QAPP.

C2.2 Frequency, Content, and Distribution of Reports

The QAPP should indicate the frequency, content, and distribution of the reports so that management may anticipate events and move to ameliorate potentially adverse results. An important benefit of the status reports is the opportunity to alert the management of data quality problems, propose viable solutions, and procure additional resources. If program assessment (including the evaluation of the technical systems, the measurement of performance, and the assessment of data) is not conducted on a continual basis, the integrity of the data generated in the program may not meet the quality requirements. These audit reports, submitted in a timely manner, will provide an opportunity to implement corrective actions when most appropriate.

C2.3 Identify Responsible Organizations

It is important that the QAPP identify the personnel responsible for preparing the reports, evaluating their impact, and implementing follow-up actions. It is necessary to understand how any changes made in one area or procedure may affect another part of the project. Furthermore, the documentation for all changes should be maintained and included in the reports to management. At the end of a project, a report documenting the Data Quality Assessment findings to management should be prepared.

D DATA VALIDATION AND USABILITY

D1 DATA REVIEW, VALIDATION, AND VERIFICATION REQUIREMENTS

State the criteria used to review and validate data.

Provide examples of any forms or checklists to be used.

Identify any project-specific calculations required.

D1.1 Purpose/Background

The purpose of this element is to state the criteria for deciding the degree to which each data item has met its quality specifications as described in Group B. Investigators should estimate the potential effect that each deviation from a QAPP may have on the usability of the associated data item, its contribution to the quality of the reduced and analyzed data, and its effect on the decision.

The process of data verification requires confirmation by examination or provision of objective evidence that the requirements of these specified QC acceptance criteria are met. In design and development, verification concerns the process of examining the result of a given activity to determine conformance to the stated requirements for that activity. For example, have the data been collected according to a specified method and have the collected data been faithfully recorded and transmitted? Do the data fulfill specified data format and metadata requirements. The process of data verification effectively ensures the accuracy of data using validated methods and protocols and is often based on comparison with reference standards.

The process of data validation requires confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use have been fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs. For example, have the data and assessment methodology passed a peer review to evaluate the adequacy of their accuracy and precision in assessing progress towards meeting the specific commitment articulated in the objective or subobjective. The method validation process effectively develops the QC acceptance criteria or specific performance criteria.

Each of the following areas of discussion should be included in the QAPP elements. The discussion applies to situations in which a sample is separated from its native environment and transported to a laboratory for analysis and data generation. However, these principles can be adapted to other situations (for example, *in-situ* analysis or laboratory research).

D1.2 Sampling Design

How closely a measurement represents the actual environment at a given time and location is a complex issue that is considered during development of element B1. See *Guidance on Sampling Designs to Support QAPPs (*EPA QA/G-5S). Acceptable tolerances for each critical sample coordinate and the action to be taken if the tolerances are exceeded should be specified in element B1.

Each sample should be checked for conformity to the specifications, including type and location (spatial and temporal). By noting the deviations in sufficient detail, subsequent data users will be able to determine the data's usability under scenarios different from those included in project planning. The strength of conclusions that can be drawn from data (see *Guidance Document for Data Quality Assessment*, EPA QA/G-9) has a direct connection to the sampling design and deviations from that design. Where auxiliary variables are included in the overall data collection effort (for example, microbiological nutrient characteristics or process conditions), they should be included in this evaluation.

D1.3 Sample Collection Procedures

Details of how a sample is separated from its native time/space location are important for properly interpreting the measurement results. Element B2 provides these details, which include sampling and ancillary equipment and procedures (including equipment decontamination). Acceptable departures (for example, alternate equipment) from the QAPP, and the action to be taken if the requirements cannot be satisfied, should be specified for each critical aspect. Validation activities should note potentially unacceptable departures from the QAPP. Comments from field surveillance on deviations from written sampling plans also should be noted.

D1.4 Sample Handling

Details of how a sample is physically treated and handled during relocation from its original site to the actual measurement site are extremely important. Correct interpretation of the subsequent measurement results requires that deviations from element B3 of the QAPP and the actions taken to minimize or control the changes, be detailed. Data collection activities should indicate events that occur during sample handling that may affect the integrity of the samples.

At a minimum, investigators should evaluate the sample containers and the preservation methods used and ensure that they are appropriate to the nature of the sample and the type of data generated from the sample. Checks on the identity of the sample (e.g., proper labeling and chain-of-custody records) as well as proper physical/chemical storage conditions (e.g., chain-of-custody and storage records) should be made to ensure that the sample continues to be representative of its native environment as it moves through the analytical process.

D1.5 Analytical Procedures

Each sample should be verified to ensure that the procedures used to generate the data (as identified in element B4 of the QAPP) were implemented as specified. Acceptance criteria should be developed for important components of the procedures, along with suitable codes for characterizing each sample's deviation from the procedure. Data validation activities should determine how seriously a sample deviated beyond the acceptable limit so that the potential effects of the deviation can be evaluated during DQA.

D1.6 Quality Control

Element B5 of the QAPP specifies the QC checks that are to be performed during sample collection, handling, and analysis. These include analyses of check standards, blanks, spikes, and replicates, which provide indications of the quality of data being produced by specified components of the measurement process. For each specified QC check, the procedure, acceptance criteria, and corrective action (and changes) should be specified. Data validation should document the corrective actions that were taken, which samples were affected, and the potential effect of the actions on the validity of the data.

D1.7 Calibration

Element B7 addresses the calibration of instruments and equipment and the information that should be presented to ensure that the calibrations:

- were performed within an acceptable time prior to generation of measurement data;
- were performed in the proper sequence;
- included the proper number of calibration points;
- were performed using standards that "bracketed" the range of reported measurement results (otherwise, results falling outside the calibration range are flagged as such); and
- had acceptable linearity checks and other checks to ensure that the measurement system was stable when the calibration was performed.

When calibration problems are identified, any data produced between the suspect calibration event and any subsequent recalibration should be flagged to alert data users.

D1.8 Data Reduction and Processing

Checks on data integrity evaluate the accuracy of "raw" data and include the comparison of important events and the duplicate rekeying of data to identify data entry errors.

Data reduction is an irreversible process that involves a loss of detail in the data and may involve averaging across time (for example, hourly or daily averages) or space (for example, compositing results from samples thought to be physically equivalent). Since this summarizing process produces few values to represent a group of many data points, its validity should be well-documented in the QAPP. Potential data anomalies can be investigated by simple statistical analyses (see *Guidance for Data Quality Assessment*, EPA QA/G-9).

The information generation step involves the synthesis of the results of previous operations and the construction of tables and charts suitable for use in reports. How information generation is checked, the requirements for the outcome, and how deviations from the requirements will be treated, should be addressed in this element.

D2 VALIDATION AND VERIFICATION METHODS

Describe the process to be used for validating and verifying data, including the chain of custody for data throughout the life cycle of the project or task.

Discuss how issues shall be resolved and identify the authorities for resolving such issues.

Describe how the results are conveyed to the data users.

Precisely define and interpret how validation issues differ from verification issues for this project.

D2.1 Purpose/Background

The purpose of this element is to describe, in detail, the process for validating (determining if data satisfy QAPP-defined user requirements) and verifying (ensuring that conclusions can be correctly drawn) project data. The amount of data validated is directly related to the DQOs developed for the project. The percentage validated for the specific project together with its rationale should be outlined or referenced. The QAPP should have a clear definition of what is implied by "verification" and "validation."

D2.2 Describe the Process for Validating and Verifying Data

The individuals responsible for data validation together with the lines of authority should be shown on an organizational chart and may be indicated in the chart in element A7. The chart should indicate who is responsible for each activity of the overall validation and verification processes.

The data to be validated should be compared to "actual" events using the criteria documented in the QAPP. The data validation procedure for all environmental measurements should be documented in the SOPs for specific data validation. Verification and validation issues are discussed at length in *Guidance on Environmental Verification and Validation,* (EPA QA/G-8).

D3 RECONCILIATION WITH DATA QUALITY OBJECTIVES

Describe how the results obtained from the project or task will be reconciled with the requirements defined by the data user or decision maker.

Outline the proposed methods to analyze the data and determine possible anomalies or departures from assumptions established in the planning phase of data collection.

Describe how issues will be resolved and discuss how limitations on the use of the data will be reported to decision makers.

D3.1 Purpose/Background

The purpose of element D3 is to outline and specify, if possible, the acceptable methods for evaluating the results obtained from the project. This element includes scientific and statistical evaluations of data to determine if the data are of the right type, quantity, and quality to support their intended use.

D3.2 Reconciling Results with DQOs

The DQA process has been developed for cases where formal DQOs have been established. *Guidance for Data Quality Assessment* (EPA QA/G-9) focuses on evaluating data for fitness in decision making and also provides many graphical and statistical tools.

DQA is a key part of the assessment phase of the data life cycle, as shown in Figure 1. As the part of the assessment phase that follows data validation and verification, DQA determines how well the validated data can support their intended use. If an approach other than DQA has been selected, an outline of the proposed activities should be included.

CHAPTER IV

QAPP REVISIONS AND RELATED GUIDANCE

QAPP REVISIONS

During the course of environmental data collection, it is possible that changes will occur and revisions to the QAPP will have to be made. Any changes to the technical procedures should be evaluated by the EPA QA Officer and Project Officer to determine if they significantly affect the technical and quality objectives of the project. If so, the QAPP should be revised and reapproved, and a revised copy should be sent to all the persons on the distribution list.

COMPARISON WITH PREVIOUS GUIDANCE (QAMS-005/80)

EPA's previous guidance for preparing QAPPs, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans* (QAMS-005/80), was released in December 1980. The evolution of EPA programs, changing needs, and changes to quality management practices have mandated the preparation of a new guidance. The QAPPs that will be generated based on this guidance will be slightly different from those in the past because:

- New QAPP specifications are given in the R-5 requirements document.

- Additional guidance documents from the Agency including *Guidance for the Data Quality Objectives Process* (EPA QA/G-4), and *Guidance for Data Quality Assessment* (EPA QA/G-9), are available on important quality management practices. These guidance documents show how the DQO Process, the QAPP, and the DQA Process link together in a coherent way (see Appendix A for a crosswalk between the DQOs and the QAPP).

- The new guidance includes flexibility in the requirements and reporting format. However, if an element of the QAPP is not applicable to a particular project, the rationale for not addressing the element should be included.

- The elements of the QAPP are now organized in an order that corresponds to the customary planning, implementation, and assessment phases of a project. They have been categorized into four groups for ease of implementation:

    - Project Management,
    - Measurement/Data Acquisition,
    - Assessment/Oversight, and
    - Data Validation and Usability.

- There are more elements identified than in the previous QAMS-005/80 guidance and this encourages flexibility in construction of defensible QAPPs.

A comparison between the requirements of QAMS-005/80 and the R-5 document is presented in Appendix A, "Crosswalk Between EPA QA/R-5 and QAMS-005/80."

APPENDIX A

CROSSWALKS BETWEEN QUALITY ASSURANCE DOCUMENTS

This appendix consists of five sections. The first section describes the relationship between the systems requirements developed in ANSI/ASQC E4-1994 and the Environmental Protection Agency (EPA) Quality System requirements. The second section provides a crosswalk between the requirements document for Quality Assurance Project Plans (QAPPs), EPA QA/R-5, *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations*, and its predecessor document, QAMS 005/80, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*. The third section provides a crosswalk between QA/R-5 and the elements of International Organization for Standardization (ISO) 9000. The fourth section is a crosswalk between the requirements of the QAPP and the steps of the Data Quality Objectives (DQOs) Process. The final section describes the Agency's QA documents at the program and project levels.

AA1. RELATIONSHIP BETWEEN E4 AND EPA QUALITY SYSTEM

EPA Order 5360.1 establishes a mandatory Agency-wide Quality System that applies to all organizations, both internal and external, performing work for EPA. (The authority for the requirements defined by the Order are contained in the applicable regulations for extramural agreements.) These organizations must ensure that data collected for the characterization of environmental processes and conditions are of the appropriate type and quality for their intended use and that environmental technologies are designed, constructed, and operated according to defined expectations. All EPA Regional, Office, and Laboratory quality systems established in accordance with these requirements shall comply with ANSI/ASQC E4-1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs*, which conforms generally to ISO 9000. In addition, EPA has developed two documents **S** EPA QA/R-1, *EPA Quality Systems Requirements for Environmental Programs*, and EPA QA/R-2, *EPA Requirements for Quality Management Plans* **S** that specify the requirements for developing, documenting, implementing, and assessing a Quality System. This appendix describes these three Agency documents (Order 5360.1, EPA QA/R-1, and EPA QA/R-2) in order to define their relationships and roles in laying the foundation for EPA's Quality System.

ANSI/ASQC E4-1994 provides the basis for the preparation of a quality system for an organization's environmental programs. The document provides the requisite management and technical area elements necessary for developing and implementing a quality system. The document first describes the quality management elements that are generally common to environmental problems, regardless of their technical scope. The document then discusses the specifications and guidelines that apply to project-specific environmental activities involving the generation, collection, analysis, evaluation, and reporting of environmental data. Finally, the document contains the minimum specifications and guidelines that apply to the design, construction, and operation of environmental technology.

EPA QA/R-1 provides the details on EPA quality management requirements to organizations conducting environmental programs. This document states that "... all EPA organizations and all organizations performing work for EPA shall develop and establish Quality Systems, as appropriate, that conform to the American National Standard ANSI/ASQC E4-1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs*, and its additions and supplements from the American National Standards Institute (ANSI) and the American Society for Quality Control (ASQC)." R-1 applies to all EPA programs and organizations, unless explicitly exempted, that produce, acquire, or use environmental data depending on the purposes for which the data will be used. This document also applies to systems, facilities, processes, and methods for pollution control, waste treatment, waste remediation, and waste packaging and storage. Essentially, R-1 formally describes how EPA Order 5360.1 applies to extramural organizations.

EPA Requirements for Quality Management Plans, EPA QA/R-2, discusses the development, review, approval, and implementation of the Quality Management Plan (QMP). The QMP is a means of documenting how an organization will plan, implement, and assess the effectiveness of the management processes and structures (required under R-1) that relate to the Quality System. R-2 describes the program elements that should be part of a QMP. These requirements match the quality management elements described in ANSI/ASQC E4-1994 that are generally common to environmental projects. These elements include the following: (1) management and organization, (2) quality system and description, (3) personnel qualifications and training, (4) procurement of items and services, (5) documents and records, (6) computer hardware and software, (7) planning, (8) implementation of work processes, (9) assessment and response, and (10) quality improvement.

The procedures, roles, and responsibilities for QAPPs are addressed in the organization's QMP. In essence, the QMP establishes the nature of the requirements for QAPPs for work done by or for that organization.

AA2. CROSSWALK BETWEEN EPA QA/R-5 AND QAMS-005/80

QAMS-005/80 ELEMENTS		QA/R-5 ELEMENTS	
1.0	Title Page with Provision for Approval Signatures	A1	Title and Approval Sheet
2.0	Table of Contents	A2	Table of Contents
3.0	Project Description	A5	Problem Definition/Background
		A6	Project/Task Description
4.0	Project Organization and Responsibility	A4	Project/Task Organization
		A9	Documentation and Records
5.0	QA Objectives for Measurement Data (PARCC)	A7	Quality Objectives and Criteria for Measurement Data
6.0	Sampling Procedures	B1	Sampling Process Design
		B2	Sampling Methods Requirements
7.0	Sample Custody	A8	Special Training Requirements or Certification
		B3	Sample Handling and Custody Requirements
8.0	Calibration Procedures and Frequency	B7	Instrument Calibration and Frequency
9.0	Analytical Procedures	B4	Analytical Methods Requirements
10.0	Data Reduction, Validation, and Reporting	D1	Data Review, Validation, and Verification Requirements
		D2	Validation and Verification Methods
		B9	Data Acquisition Requirements
		B10	Data Quality Management
11.0	Internal Quality Control Checks and Frequency	B5	Quality Control Requirements
12.0	Performance and Systems	C1	Assessments and Response Actions
13.0	Preventive Maintenance	B6	Instrument/Equipment Testing, Procedures and Schedules Inspection, and Maintenance Requirements
		B8	Inspection/Acceptance Requirements for Supplies and Consumables
14.0	Specific Routine Procedures Measurement Parameters Involved	D3	Reconciliation with Data Used to Assess PARCC for Quality Objectives Measurement
15.0	Corrective Action	C1	Assessments and Response Actions
16.0	QA Reports to Management	A3	Distribution List
		C2	Reports to Management

AA3. CROSSWALK BETWEEN EPA QA/R-5 AND ISO 9000

EPA QA/R-5 Elements	ISO 9000 Elements
A1 Title and Approval Sheet	N/A
A2 Table of Contents	N/A
A3 Distribution List	N/A
A4 Project/Task Organization	4 Management Responsibility
A5 Problem Definition/Background	N/A
A6 Project/Task Description	N/A
A7 Quality Objectives and Criteria for Measurement Data	5 Quality System Principles 5.2 Structure of the Quality System
A8 Special Training Requirements/Certification	N/A
A9 Documentation and Records	N/A
B1 Sampling Process Design	8 Quality in Specification and Design
B2 Sampling Methods Requirements	10 Quality of Production
B3 Sample Handling and Custody Requirements	16 Handling and Post-Production Functions
B4 Analytical Methods Requirements	10 Quality of Production
B5 Quality Control Requirements	11 Control of Production
B6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements	13 Control of Measuring and Test Equipment
B7 Instrument Calibration and Frequency	N/A
B8 Inspection/Acceptance Requirements for Supplies and Consumables	9 Quality in Procurement 11.2 Material Control and Traceability
B9 Data Acquisition Requirements	N/A
B10 Data Quality Management	N/A
C1 Assessments and Response Actions	5.4 Auditing the Quality System 14 Nonconformity 15 Corrective Action
C2 Reports to Management	5.3 Documentation of the Quality System 6 Economics - Quality Related Costs
D1 Data Review, Validation, and Verification Requirements	11.7 Control of Verification Status
D2 Validation and Verification Methods	12 Verification Status
D3 Reconciliation with User Requirements	N/A
	7 Quality in Marketing

AA4. CROSSWALK BETWEEN THE DQO PROCESS AND THE QAPP

Elements		Requirements	DQO Overlap
PROJECT MANAGEMENT			
A1	Title and Approval Sheet	Title and approval sheet.	N/A
A2	Table of Contents	Document control format.	N/A
A3	Distribution List	Distribution list for the QAPP revisions and final guidance.	List the members of the scoping team. Step 1: State the Problem.
A4	Project/Task Organization	Identify individuals or organizations participating in the project and discuss their roles, responsibilities and organization.	Step 1: State the Problem requires definition of the DQO scoping or planning team, which includes the decision maker, technical staff, data users, etc. This step also requires the specification of each member's role and responsibilities.
A5	Problem Definition/Background	1) State the specific problem to be solved or the decision to be made. 2) Identify the decision maker and the principal customer for the results.	Step 1: State the Problem/Step 2: Identify the Decision requires a description of the problem. It also identifies the decision makers who could use the data.
A6	Project/Task Description	1) Hypothesis test, 2) expected measurements, 3) ARARs or other appropriate standards, 4) assessment tools (technical audits), 5) work schedule and required reports.	Step 1: State the Problem/Step 2: Identify the Decision requires a work schedule. Step 3: Identify the Inputs requires the ARARs or standards and expected measurements. Step 6: Specify Limits on Decision Errors.
A7	Data Quality Objectives for Measurement Data	Decision(s), population parameter of interest, action level, summary statistics and acceptable limits on decision errors. Also, scope of the project (domain or geographical locale).	Step 1: State the Problem, Step 2: Identify the Decision, Step 4: Define the Boundaries, Step 5: Develop a Decision Rule, Step 6: Specify Limits on Decision Errors.
A8	Special Training Requirements/ Certification	Identify special training that personnel will need.	Step 3: Identify the Inputs to the Decision.
A9	Documentation and Record	Itemize the information and records that must be included in a data report package, including report format and requirements for storage, etc.	Step 3: Identify the Inputs to the Decision, Step 7: Optimize the Design for Obtaining Data.
MEASUREMENT/DATA ACQUISITION			
B1	Sampling Process Designs (Experimental Design)	Outline the experimental design, including sampling design and rationale, sampling frequencies, matrices, and measurement parameter of interest.	Step 5: Develop a Decision Rule, Step 7: Optimize the Design for Obtaining Data.
B2	Sampling Methods Requirements	Sample collection method and approach.	Step 7: Optimize the Design for Obtaining Data.
B3	Sample Handling and Custody Requirements	Describe the provisions for sample labeling, shipment, chain-of-custody forms, procedures for transferring and maintaining custody of samples.	Step 3: Identify the Inputs to the Decision.
B4	Analytical Methods Requirements	Identify analytical method(s) and equipment for the study, including method performance requirements.	Step 3: Identify the Inputs to the Decision, Step 7: Optimize the Design for Obtaining Data.
B5	Quality Control Requirements	Describe routine (real-time) QC procedures that should be associated with each sampling and measurement technique. List required QC checks and corrective action procedures.	Step 3: Identify the Inputs to the Decision.

Elements		Requirements	DQO Overlap
B6	Instrument/Equipment Testing Inspection and Maintenance Requirements	Discuss how inspection and acceptance testing, including the use of QC samples, must be performed to ensure their intended use as specified by the design.	Step 3: Identify the Inputs to the Decision.
B7	Instrument Calibration and Frequency	Identify tools, gauges and instruments, and other sampling or measurement devices that need calibration. Describe how the calibration should be done.	Step 3: Identify the Inputs to the Decision.
B8	Inspection/Acceptance Requirements for Supplies and Consumables	Define how and by whom the sampling supplies and other consumables will be accepted for use in the project.	N/A
B9	Data Acquisition Requirements (Non-direct Measurements)	Define the criteria for the use of non-measurement data such as data that come from databases or literature.	Step 1: State the Problem, Step 7: Optimize the Design for Obtaining Data.
B10	Data Management	Outline the data management scheme including the path and storage of the data and the data record-keeping system. Identify all data handling equipment and procedures that will be used to process, compile, and analyze the data.	Step 3: Identify the Inputs to the Decision, Step 7: Optimize the Design for Obtaining Data.
		ASSESSMENT/OVERSIGHT	
C1	Assessments and Response Actions	Describe the assessment activities needed for this project. These may include DQA, PE, TSA, MSR/PR/RR	Step 5: Develop a Decision Rule, Step 6: Specify Limits on Decision Errors.
C2	Reports to Management	Identify the frequency, content, and distribution of reports issued to keep management informed.	N/A
		DATA VALIDATION AND USABILITY	
D1	Data Review, Validation, and Verification Requirements	State the criteria used to accept or reject the data based on quality.	Step 7: Optimize the Design for Obtaining Data.
D2	Validation and Verification Methods	Describe the process to be used for validating and verifying data, including the chain-of-custody for data throughout the lifetime of the project.	Step 3: Identify the Inputs to the Decision.
D3	Reconciliation With Data Quality Objectives	Describe how results will be evaluated to determine if DQOs have been satisfied.	Step 7: Optimize the Design for Obtaining Data.

AA5. EPA QUALITY ASSURANCE DOCUMENTS

The Quality Assurance Division issues QA documents for use both internally (National Programs, Centers, and Laboratories) and externally (state and local agencies, contractors, extramural agreement holders, and nonprofit groups). The scopes of the documents span all aspects of QA and can be obtained by writing QAD directly or by visiting the QAD Website:

http://es.epa.gov/ncerqa/qa/qa_docs.html

QAD documents fall into three categories: the EPA Quality Manual (for internal use); Requirements documents (for external use, labeled 'R-xx'); and Guidance documents (for internal and external use, labeled 'G-xx'). Requirements documents and the Quality Manual contain the Agency's QA policies and Guidance documents contain nonmandatory guidance on how to achieve these QA requirements.

Table A1 shows the general numbering system for EPA's Quality System documents, and Table A2 illustrates some specific documents available and under construction. The auxiliary letter on some of the documents denotes specialized audiences or areas of interest. Figure A1 shows the relationship among the documents at the Policy and Program levels. Figure A2 demonstrates the sequence and interrelationship of documents at the Program level.

Not all of the documents listed in Table A2 are available, as some are in various stages of development and will not be finalized until late 1998. Consult the Website or contact QAD directly for information on the current status and availability of all QAD documents.

Table AA1. Numbering System for EPA's Quality System Documents

1 = Quality System Policy and Quality Manual	6 = Standard Operating Procedures (SOPs)
2 = Quality Management Plans (QMPs)	7 = Technical Assessments (TAs)
3 = Management Systems Reviews (MSRs)	8 = Data Verification and Validation
4 = Data Quality Objectives (DQOs)	9 = Data Quality Assessment (DQA)
5 = Quality Assurance Project Plans (QAPPs)	10 = Training Issues

Table AA2. Quality System Documents

Overview	
QA/G-0	EPA Quality System Description
Program level	
QA/R-1	EPA Quality Systems Requirements for Environmental Programs
QA/G-1	Guidance for Developing Quality Systems for Environmental Data Operations
QA/R-2	EPA Requirements for Quality Management Plans
QA/G-2	Guidance for Preparing Quality Management Plans
QA/G-2C	Guide to Satisfying EPA Quality Assurance Requirements for Contracts
QA/G-2EA	Guide to Implementing Quality Assurance in Extramural Agreements
QA/G-2F	Guide to Satisfying EPA Quality Assurance Requirements for Financial Assistance Agreements
QA/G-3	Guidance for the Management Systems Review Process
QA/G-10	Guidance for Determining Quality Training Requirements for Environmental Data Operations
Project level	
QA/G-4	Guidance for the Data Quality Objectives Process
QA/G-4CS	The Data Quality Objectives Process: Case Studies
QA/G-4D	Data Quality Objectives Decision Errors Feasibility Trials (DEFT) Software
QA/G-4HW	Guidance for the Data Quality Objectives Process for Hazardous Waste Sites
QA/G-4R	Guidance for the Data Quality Objectives for Researchers
QA/R-5	EPA Requirements for Quality Assurance Project Plans
QA/G-5	EPA Guidance for Quality Assurance Project Plans
QA/G-5I	Guidance for Data Quality Indicators
QA/G-5S	Guidance on Sampling Designs to Support Quality Assurance Project Plans
QA/G-5T	Guidance on Specialized Topics in Quality Assurance
QA/G-6	Guidance for the Preparation of Standard Operating Procedures for Quality-Related Operations
QA/G-7	Guidance on Technical Assessments for Environmental Data Operations
QA/G-8	Guidance on Environmental Data Verification and Validation
QA/G-9	Guidance for Data Quality Assessment: Practical Methods for Data Analysis
QA/G-9D	Data Quality Evaluation Statistical Toolbox (DataQUEST).

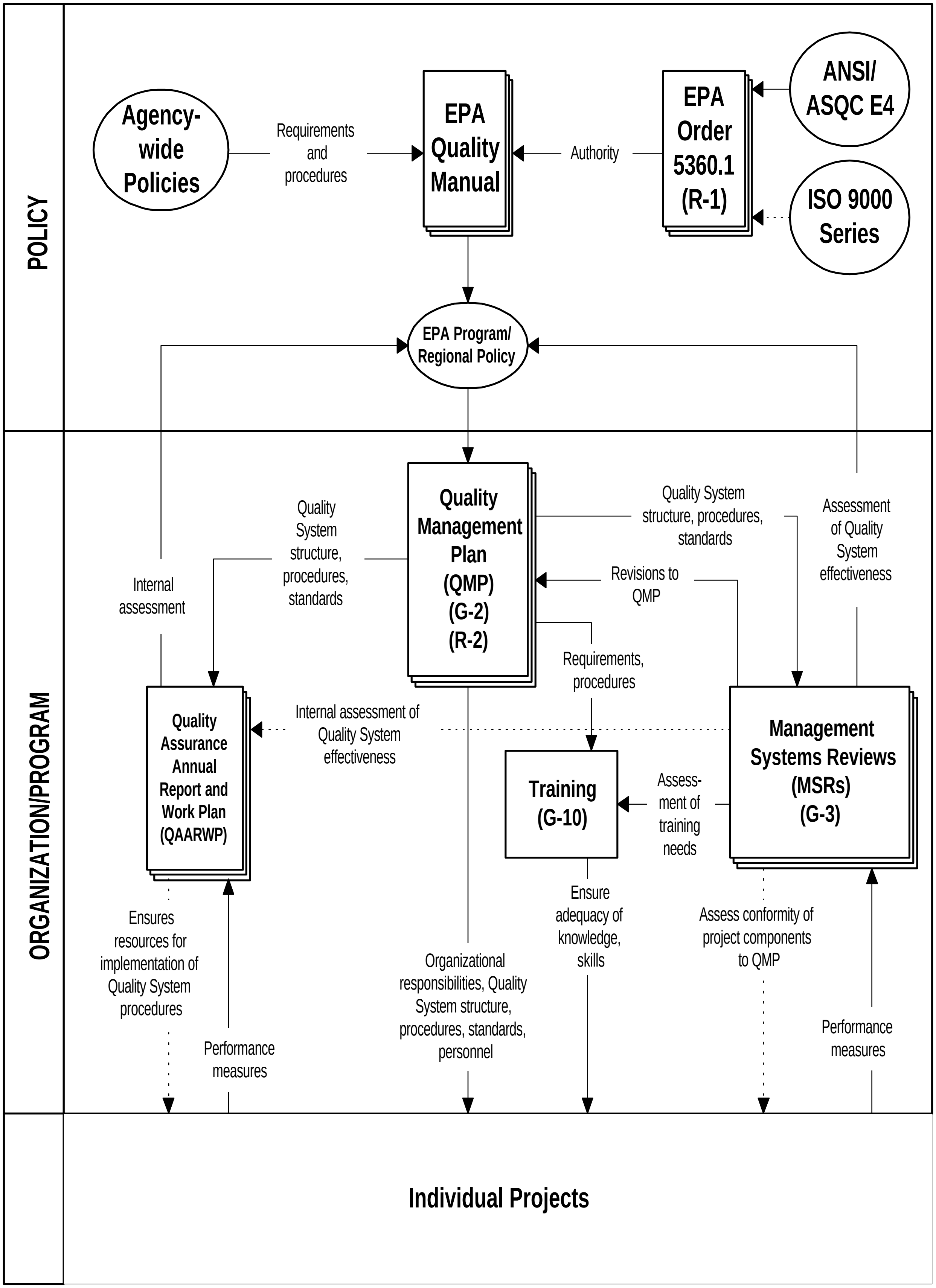

Figure AA1. Relationships Among EPA Quality System Documents at the Program Level

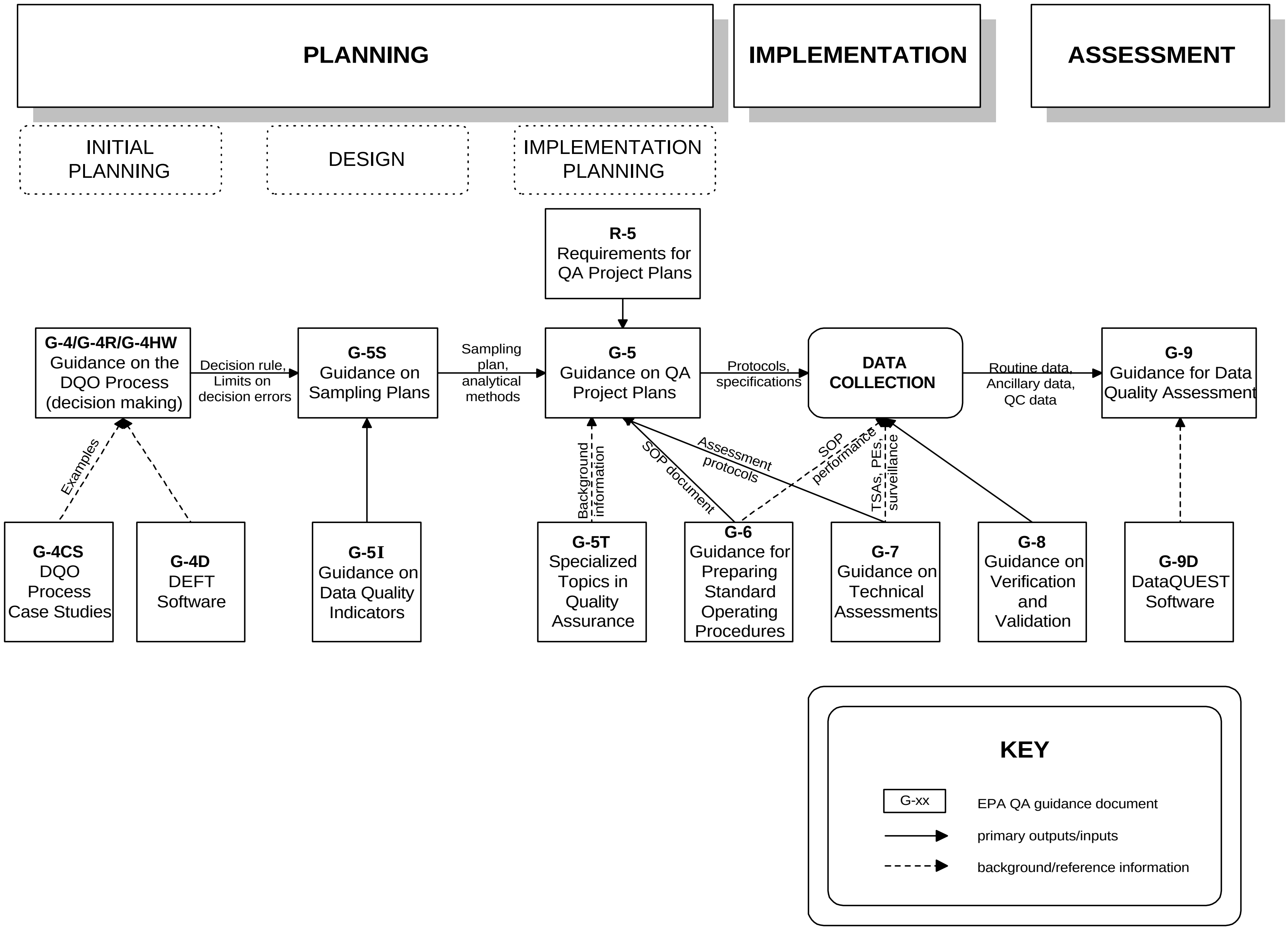

Figure AA2. Relationship Among EPA Quality System Documents at the Project Level

APPENDIX B

GLOSSARY OF QUALITY ASSURANCE AND RELATED TERMS

Acceptance criteria — Specified limits placed on characteristics of an item, process, or service defined in requirements documents. (ASQC Definitions)

Accuracy — A measure of the closeness of an individual measurement or the average of a number of measurements to the true value. Accuracy includes a combination of random error (precision) and systematic error (bias) components that are due to sampling and analytical operations; the EPA recommends using the terms *"precision"* and *"bias"*, rather than "accuracy," to convey the information usually associated with accuracy. Refer to *Appendix D, Data Quality Indicators* for a more detailed definition.

Activity — An all-inclusive term describing a specific set of operations of related tasks to be performed, either serially or in parallel (e.g., research and development, field sampling, analytical operations, equipment fabrication), that, in total, result in a product or service.

Assessment — The evaluation process used to measure the performance or effectiveness of a system and its elements. As used here, assessment is an all-inclusive term used to denote any of the following: audit, performance evaluation (PE), management systems review (MSR), peer review, inspection, or surveillance.

Audit (quality) — A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.

Audit of Data Quality (ADQ) — A qualitative and quantitative evaluation of the documentation and procedures associated with environmental measurements to verify that the resulting data are of acceptable quality.

Authenticate — The act of establishing an item as genuine, valid, or authoritative.

Bias — The systematic or persistent distortion of a measurement process, which causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value). Refer to *Appendix D, Data Quality Indicators,* for a more detailed definition.

Blank — A sample subjected to the usual analytical or measurement process to establish a zero baseline or background value. Sometimes used to adjust or correct routine analytical results. A sample that is intended to contain none of the analytes of interest. A blank is used to detect contamination during sample handling preparation and/or analysis.

Calibration — A comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to detect and quantify inaccuracies and to report or eliminate those inaccuracies by adjustments.

Calibration drift — The deviation in instrument response from a reference value over a period of time before recalibration.

Certification — The process of testing and evaluation against specifications designed to document, verify, and recognize the competence of a person, organization, or other entity to perform a function or service, usually for a specified time.

Chain of custody — An unbroken trail of accountability that ensures the physical security of samples, data, and records.

Characteristic — Any property or attribute of a datum, item, process, or service that is distinct, describable, and/or measurable.

Check standard — A standard prepared independently of the calibration standards and analyzed exactly like the samples. Check standard results are used to estimate analytical precision and to indicate the presence of bias due to the calibration of the analytical system.

Collocated samples — Two or more portions collected at the same point in time and space so as to be considered identical. These samples are also known as field replicates and should be identified as such.

Comparability — A measure of the confidence with which one data set or method can be compared to another.

Completeness — A measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct, normal conditions. Refer to *Appendix D, Data Quality Indicators*, for a more detailed definition.

Confidence Interval — The numerical interval constructed around a point estimate of a population parameter, combined with a probability statement (the confidence coefficient) linking it to the population's true parameter value. If the same confidence interval construction technique and assumptions are used to calculate future intervals, they will include the unknown population parameter with the same specified probability.

Confidentiality procedure — A procedure used to protect confidential business information (including proprietary data and personnel records) from unauthorized access.

Configuration — The functional, physical, and procedural characteristics of an item, experiment, or document.

Conformance — An affirmative indication or judgment that a product or service has met the requirements of the relevant specification, contract, or regulation; also, the state of meeting the requirements.

Consensus standard — A standard established by a group representing a cross section of a particular industry or trade, or a part thereof.

Contractor — Any organization or individual contracting to furnish services or items or to perform work.

Corrective action — Any measures taken to rectify conditions adverse to quality and, where possible, to preclude their recurrence.

Data Quality Assessment (DQA) — The scientific and statistical evaluation of data to determine if data obtained from environmental operations are of the right type, quality, and quantity to support their intended use. The five steps of the DQA Process include: 1) reviewing the DQOs and sampling design, 2) conducting a preliminary data review, 3) selecting the statistical test, 4) verifying the assumptions of the statistical test, and 5) drawing conclusions from the data.

Data Quality Indicators (DQIs) — The quantitative statistics and qualitative descriptors that are used to interpret the degree of acceptability or utility of data to the user. The principal data quality indicators are bias, precision, accuracy (bias is preferred), comparability, completeness, representativeness.

Data Quality Objectives (DQOs) — The qualitative and quantitative statements derived from the DQO Process that clarify study's technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

Data Quality Objectives (DQO) Process — A systematic strategic planning tool based on the scientific method that identifies and defines the type, quality, and quantity of data needed to satisfy a specified use. DQOs are the qualitative and quantitative outputs from the DQO Process.

Data reduction — The process of transforming the number of data items by arithmetic or statistical calculations, standard curves, and concentration factors, and collating them into a more useful form. Data reduction is irreversible and generally results in a reduced data set and an associated loss of detail.

Data usability — The process of ensuring or determining whether the quality of the data produced meets the intended use of the data.

Deficiency — An unauthorized deviation from acceptable procedures or practices, or a defect in an item.

Demonstrated capability — The capability to meet a procurement's technical and quality specifications through evidence presented by the supplier to substantiate its claims and in a manner defined by the customer.

Design — The specifications, drawings, design criteria, and performance requirements. Also, the result of deliberate planning, analysis, mathematical manipulations, and design processes.

Design change — Any revision or alteration of the technical requirements defined by approved and issued design output documents and approved and issued changes thereto.

Design review — A documented evaluation by a team, including personnel such as the responsible designers, the client for whom the work or product is being designed, and a quality assurance (QA) representative but excluding the original designers, to determine if a proposed design will meet the established design criteria and perform as expected when implemented.

Detection Limit (DL) — A measure of the capability of an analytical method to distinguish samples that do not contain a specific analyte from samples that contain low concentrations of the analyte; the lowest concentration or amount of the target analyte that can be determined to be different from zero by a single measurement at a stated level of probability. DLs are analyte- and matrix-specific and may be laboratory-dependent.

Distribution — 1) The appointment of an environmental contaminant at a point over time, over an area, or within a volume; 2) a probability function (density function, mass function, or distribution function) used to describe a set of observations (statistical sample) or a population from which the observations are generated.

Document control — The policies and procedures used by an organization to ensure that its documents and their revisions are proposed, reviewed, approved for release, inventoried, distributed, archived, stored, and retrieved in accordance with the organization's requirements.

Duplicate samples — Two samples taken from and representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variance of the total method, including sampling and analysis. See also *collocated sample*.

Environmental conditions — The description of a physical medium (e.g., air, water, soil, sediment) or a biological system expressed in terms of its physical, chemical, radiological, or biological characteristics.

Environmental data — Any parameters or pieces of information collected or produced from measurements, analyses, or models of environmental processes, conditions, and effects of pollutants on human health and the ecology, including results from laboratory analyses or from experimental systems representing such processes and conditions.

Environmental data operations — Any work performed to obtain, use, or report information pertaining to environmental processes and conditions.

Environmental monitoring — The process of measuring or collecting environmental data.

Environmental processes — Any manufactured or natural processes that produce discharges to, or that impact, the ambient environment.

Environmental programs — An all-inclusive term pertaining to any work or activities involving the environment, including but not limited to: characterization of environmental processes and conditions; environmental monitoring; environmental research and development; the design, construction, and operation of environmental technologies; and laboratory operations on environmental samples.

Environmental technology — An all-inclusive term used to describe pollution control devices and systems, waste treatment processes and storage facilities, and site remediation technologies and their components that may be utilized to remove pollutants or contaminants from, or to prevent them from entering, the environment. Examples include wet scrubbers (air), soil washing (soil), granulated activated carbon unit (water), and filtration (air, water). Usually, this term applies to hardware-based systems; however, it can also apply to methods or techniques used for pollution prevention, pollutant reduction, or containment of contamination to prevent further movement of the contaminants, such as capping, solidification or vitrification, and biological treatment.

Estimate — A characteristic from the sample from which inferences on parameters can be made.

Evidentiary records — Any records identified as part of litigation and subject to restricted access, custody, use, and disposal.

Expedited change — An abbreviated method of revising a document at the work location where the document is used when the normal change process would cause unnecessary or intolerable delay in the work.

Field blank — A blank used to provide information about contaminants that may be introduced during sample collection, storage, and transport. A clean sample, carried to the sampling site, exposed to sampling conditions, returned to the laboratory, and treated as an environmental sample.

Field (matrix) spike — A sample prepared at the sampling point (i.e., in the field) by adding a known mass of the target analyte to a specified amount of the sample. Field matrix spikes are used, for example, to determine the effect of the sample preservation, shipment, storage, and preparation on analyte recovery efficiency (the analytical bias).

Field split samples — Two or more representative portions taken from the same sample and submitted for analysis to different laboratories to estimate interlaboratory precision.

Financial assistance — The process by which funds are provided by one organization (usually governmental) to another organization for the purpose of performing work or furnishing services or items. Financial assistance mechanisms include grants, cooperative agreements, and governmental interagency agreements.

Finding — An assessment conclusion that identifies a condition having a significant effect on an item or activity. An assessment finding may be positive or negative, and is normally accompanied by specific examples of the observed condition.

Goodness-of-fit test — The application of the chi square distribution in comparing the frequency distribution of a statistic observed in a sample with the expected frequency distribution based on some theoretical model.

Grade — The category or rank given to entities having the same functional use but different requirements for quality.

Graded approach — The process of basing the level of application of managerial controls applied to an item or work according to the intended use of the results and the degree of confidence needed in the quality of the results. (See also *Data Quality Objectives (DQO) Process.*)

Guidance — A suggested practice that is not mandatory, intended as an aid or example in complying with a standard or requirement.

Guideline — A suggested practice that is not mandatory in programs intended to comply with a standard.

Hazardous waste — Any waste material that satisfies the definition of hazardous waste given in 40 CFR 261, "Identification and Listing of Hazardous Waste."

Holding time — The period of time a sample may be stored prior to its required analysis. While exceeding the holding time does not necessarily negate the veracity of analytical results, it causes the qualifying or "flagging" of any data not meeting all of the specified acceptance criteria.

Identification error — The misidentification of an analyte. In this error type, the contaminant of concern is unidentified and the measured concentration is incorrectly assigned to another contaminant.

Independent assessment — An assessment performed by a qualified individual, group, or organization that is not a part of the organization directly performing and accountable for the work being assessed.

Inspection — The examination or measurement of an item or activity to verify conformance to specific requirements.

Internal standard — A standard added to a test portion of a sample in a known amount and carried through the entire determination procedure as a reference for calibrating and controlling the precision and bias of the applied analytical method.

Laboratory split samples — Two or more representative portions taken from the same sample and analyzed by different laboratories to estimate the interlaboratory precision or variability and the data comparability.

Limit of quantitation — The minimum concentration of an analyte or category of analytes in a specific matrix that can be identified and quantified above the method detection limit and within specified limits of precision and bias during routine analytical operating conditions.

Management — Those individuals directly responsible and accountable for planning, implementing, and assessing work.

Management system — A structured, nontechnical system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for conducting work and producing items and services.

Management Systems Review (MSR) — The qualitative assessment of a data collection operation and/or organization(s) to establish whether the prevailing quality management structure, policies, practices, and procedures are adequate for ensuring that the type and quality of data needed are obtained.

Matrix spike — A sample prepared by adding a known mass of a target analyte to a specified amount of matrix sample for which an independent estimate of the target analyte concentration is available. Spiked samples are used, for example, to determine the effect of the matrix on a method's recovery efficiency.

Mean (arithmetic) — The sum of all the values of a set of measurements divided by the number of values in the set; a measure of central tendency.

Mean squared error — A statistical term for variance added to the square of the bias.

Measurement and Testing Equipment (M&TE) — Tools, gauges, instruments, sampling devices, or systems used to calibrate, measure, test, or inspect in order to control or acquire data to verify conformance to specified requirements.

Memory effects error — The effect that a relatively high concentration sample has on the measurement of a lower concentration sample of the same analyte when the higher concentration sample precedes the lower concentration sample in the same analytical instrument.

Method — A body of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, quantification), systematically presented in the order in which they are to be executed.

Method blank — A blank prepared to represent the sample matrix as closely as possible and analyzed exactly like the calibration standards, samples, and quality control (QC) samples. Results of method blanks provide an estimate of the within-batch variability of the blank response and an indication of bias introduced by the analytical procedure.

Mid-range check — A standard used to establish whether the middle of a measurement method's calibrated range is still within specifications.

Mixed waste — A hazardous waste material as defined by 40 CFR 261 Resource Conservation and Recovery Act (RCRA) and mixed with radioactive waste subject to the requirements of the Atomic Energy Act.

Must — When used in a sentence, a term denoting a requirement that has to be met.

Nonconformance — A deficiency in a characteristic, documentation, or procedure that renders the quality of an item or activity unacceptable or indeterminate; nonfulfillment of a specified requirement.

Objective evidence — Any documented statement of fact, other information, or record, either quantitative or qualitative, pertaining to the quality of an item or activity, based on observations, measurements, or tests that can be verified.

Observation — An assessment conclusion that identifies a condition (either positive or negative) that does not represent a significant impact on an item or activity. An observation may identify a condition that has not yet caused a degradation of quality.

Organization — A company, corporation, firm, enterprise, or institution, or part thereof, whether incorporated or not, public or private, that has its own functions and administration.

Organization structure — The responsibilities, authorities, and relationships, arranged in a pattern, through which an organization performs its functions.

Outlier — An extreme observation that is shown to have a low probability of belonging to a specified data population.

Parameter — A quantity, usually unknown, such as a mean or a standard deviation characterizing a population. Commonly misused for "variable," "characteristic," or "property."

Peer review — A documented critical review of work generally beyond the state of the art or characterized by the existence of potential uncertainty. Conducted by qualified individuals (or an organization) who are independent of those who performed the work but collectively equivalent in technical expertise (i.e., peers) to those who performed the original work. Peer reviews are conducted to ensure that activities are technically adequate, competently performed, properly documented, and satisfy established technical and quality requirements. An in-depth assessment of the assumptions, calculations, extrapolations, alternate interpretations, methodology, acceptance criteria, and conclusions pertaining to specific work and of the documentation that supports them. Peer reviews provide an evaluation of a subject where quantitative methods of analysis or measures of success are unavailable or undefined, such as in research and development.

Performance Evaluation (PE) — A type of audit in which the quantitative data generated in a measurement system are obtained independently and compared with routinely obtained data to evaluate the proficiency of an analyst or laboratory.

Pollution prevention — An organized, comprehensive effort to systematically reduce or eliminate pollutants or contaminants prior to their generation or their release or discharge into the environment.

Precision — A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions expressed generally in terms of the standard deviation. Refer to *Appendix D, Data Quality Indicators*, for a more detailed definition.

Procedure — A specified way to perform an activity.

Process — A set of interrelated resources and activities that transforms inputs into outputs. Examples of processes include analysis, design, data collection, operation, fabrication, and calculation.

Project — An organized set of activities within a program.

Qualified data — Any data that have been modified or adjusted as part of statistical or mathematical evaluation, data validation, or data verification operations.

Qualified services — An indication that suppliers providing services have been evaluated and determined to meet the technical and quality requirements of the client as provided by approved procurement documents and demonstrated by the supplier to the client's satisfaction.

Quality — The totality of features and characteristics of a product or service that bears on its ability to meet the stated or implied needs and expectations of the user.

Quality Assurance (QA) — An integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client.

Quality Assurance Program Description/Plan — See *quality management plan*.

Quality Assurance Project Plan (QAPP) — A formal document describing in comprehensive detail the necessary quality assurance (QA), quality control (QC), and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. The QAPP components are divided into four classes: 1) Project Management, 2) Measurement/Data Acquisition, 3) Assessment/Oversight, and 4) Data Validation and Usability. Requirements for preparing QAPPs can be found in EPA QA/R-5.

Quality Control (QC) — The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality. The system of activities and checks used to ensure that measurement systems are maintained within prescribed limits, providing protection against "out of control" conditions and ensuring the results are of acceptable quality.

Quality control (QC) sample — An uncontaminated sample matrix spiked with known amounts of analytes from a source independent of the calibration standards. Generally used to establish intralaboratory or analyst-specific precision and bias or to assess the performance of all or a portion of the measurement system.

Quality improvement — A management program for improving the quality of operations. Such management programs generally entail a formal mechanism for encouraging worker recommendations with timely management evaluation and feedback or implementation.

Quality management — That aspect of the overall management system of the organization that determines and implements the quality policy. Quality management includes strategic planning, allocation of resources, and other systematic activities (e.g., planning, implementation, and assessment) pertaining to the quality system.

Quality Management Plan (QMP) — A formal document that describes the quality system in terms of the organization's structure, the functional responsibilities of management and staff, the lines of authority, and the required interfaces for those planning, implementing, and assessing all activities conducted.

Quality system — A structured and documented management system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for ensuring quality in its work processes, products (items), and services. The quality system provides the framework for planning, implementing, and assessing work performed by the organization and for carrying out required quality assurance (QA) and quality control (QC).

Radioactive waste — Waste material containing, or contaminated by, radionuclides, subject to the requirements of the Atomic Energy Act.

Readiness review — A systematic, documented review of the readiness for the start-up or continued use of a facility, process, or activity. Readiness reviews are typically conducted before proceeding beyond project milestones and prior to initiation of a major phase of work.

Record (quality) — A document that furnishes objective evidence of the quality of items or activities and that has been verified and authenticated as technically complete and correct. Records may include photographs, drawings, magnetic tape, and other data recording media.

Recovery — The act of determining whether or not the methodology measures all of the analyte contained in a sample. Refer to *Appendix D, Data Quality Indicators,* for a more detailed definition.

Remediation — The process of reducing the concentration of a contaminant (or contaminants) in air, water, or soil media to a level that poses an acceptable risk to human health.

Repeatability — The degree of agreement between independent test results produced by the same analyst, using the same test method and equipment on random aliquots of the same sample within a short time period.

Reporting limit — The lowest concentration or amount of the target analyte required to be reported from a data collection project. Reporting limits are generally greater than detection limits and are usually not associated with a probability level.

Representativeness — A measure of the degree to which data accurately and precisely represent a characteristic of a population, a parameter variation at a sampling point, a process condition, or an environmental condition. See also *Appendix D, Data Quality Indicators.*

Reproducibility — The precision, usually expressed as variance, that measures the variability among the results of measurements of the same sample at different laboratories.

Requirement — A formal statement of a need and the expected manner in which it is to be met.

Research (applied) — A process, the objective of which is to gain the knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.

Research (basic) — A process, the objective of which is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind.

Research development/demonstration — The systematic use of the knowledge and understanding gained from research and directed toward the production of useful materials, devices, systems, or methods, including prototypes and processes.

Round-robin study — A method validation study involving a predetermined number of laboratories or analysts, all analyzing the same sample(s) by the same method. In a round-robin study, all results are compared and used to develop summary statistics such as interlaboratory precision and method bias or recovery efficiency.

Ruggedness study — The carefully ordered testing of an analytical method while making slight variations in test conditions (as might be expected in routine use) to determine how such variations affect test results. If a variation affects the results significantly, the method restrictions are tightened to minimize this variability.

Scientific method — The principles and processes regarded as necessary for scientific investigation, including rules for concept or hypothesis formulation, conduct of experiments, and validation of hypotheses by analysis of observations.

Self-assessment — The assessments of work conducted by individuals, groups, or organizations directly responsible for overseeing and/or performing the work.

Sensitivity — the capability of a method or instrument to discriminate between measurement responses representing different levels of a variable of interest. Refer to *Appendix D, Data Quality Indicators*, for a more detailed definition.

Service — The result generated by activities at the interface between the supplier and the customer, and the supplier internal activities to meet customer needs. Such activities in environmental programs include design, inspection, laboratory and/or field analysis, repair, and installation.

Shall — A term denoting a requirement that is mandatory whenever the criterion for conformance with the specification permits no deviation. This term does not prohibit the use of alternative approaches or methods for implementing the specification so long as the requirement is fulfilled.

Significant condition — Any state, status, incident, or situation of an environmental process or condition, or environmental technology in which the work being performed will be adversely affected sufficiently to require corrective action to satisfy quality objectives or specifications and safety requirements.

Software life cycle — The period of time that starts when a software product is conceived and ends when the software product is no longer available for routine use. The software life cycle typically includes a requirement phase, a design phase, an implementation phase, a test phase, an installation and check-out phase, an operation and maintenance phase, and sometimes a retirement phase.

Source reduction — Any practice that reduces the quantity of hazardous substances, contaminants, or pollutants.

Span check — A standard used to establish that a measurement method is not deviating from its calibrated range.

Specification — A document stating requirements and referring to or including drawings or other relevant documents. Specifications should indicate the means and criteria for determining conformance.

Spike — A substance that is added to an environmental sample to increase the concentration of target analytes by known amounts; used to assess measurement accuracy (spike recovery). Spike duplicates are used to assess measurement precision.

Split samples — Two or more representative portions taken from one sample in the field or in the laboratory and analyzed by different analysts or laboratories. Split samples are quality control (QC) samples that are used to assess analytical variability and comparability.

Standard deviation — A measure of the dispersion or imprecision of a sample or population distribution expressed as the positive square root of the variance and has the same unit of measurement as the mean.

Standard Operating Procedure (SOP) — A written document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps and that is officially approved as the method for performing certain routine or repetitive tasks.

Supplier — Any individual or organization furnishing items or services or performing work according to a procurement document or a financial assistance agreement. An all-inclusive term used in place of any of the following: vendor, seller, contractor, subcontractor, fabricator, or consultant.

Surrogate spike or analyte — A pure substance with properties that mimic the analyte of interest. It is unlikely to be found in environmental samples and is added to them to establish that the analytical meyhod has been performed properly.

Surveillance (quality) — Continual or frequent monitoring and verification of the status of an entity and the analysis of records to ensure that specified requirements are being fulfilled.

Technical review — A documented critical review of work that has been performed within the state of the art. The review is accomplished by one or more qualified reviewers who are independent of those who performed the work but are collectively equivalent in technical expertise to those who performed the original work. The review is an in-depth analysis and evaluation of documents, activities, material, data, or items that require technical verification or validation for applicability, correctness, adequacy, completeness, and assurance that established requirements have been satisfied.

Technical Systems Audit (TSA) — A thorough, systematic, on-site qualitative audit of facilities, equipment, personnel, training, procedures, record keeping, data validation, data management, and reporting aspects of a system.

Traceability — The ability to trace the history, application, or location of an entity by means of recorded identifications. In a calibration sense, traceability relates measuring equipment to national or international standards, primary standards, basic physical constants or properties, or reference materials. In a data collection sense, it relates calculations and data generated throughout the project back to the requirements for the quality of the project.

Trip blank — A clean sample of a matrix that is taken to the sampling site and transported to the laboratory for analysis without having been exposed to sampling procedures.

Validation — Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use have been fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs. See also *Appendix G, Data Management.*

Variance (statistical) — A measure or dispersion of a sample or population distribution.

Verification — Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of a given activity to determine conformance to the stated requirements for that activity.

APPENDIX C

CHECKLISTS USEFUL IN QUALITY ASSURANCE REVIEW

This appendix contains three checklists:

AC.1 Sample Handling, Preparation, and Analysis Checklist
AC.2 QAPP Review Checklist
AC.3 Chain-of-Custody Checklist

These three checklists were developed as tools for quality assurance (QA) managers to screen for completeness of documentation. This appendix was not intended to be used or adapted for auditing purposes. The items listed on the checklists are not ranked or identified to indicate which items are trivial and which are of major importance. When using these checklists, it is extremely important to ensure that a mechanism be established for assessing and addressing important comments or violations during the data assessment (e.g., Data Quality Assessment [DQA]) stage.

AC1. SAMPLE HANDLING, PREPARATION, AND ANALYSIS CHECKLIST

This checklist covers most of the appropriate elements performed during the analysis of environmental samples. Functions not appropriate for a specific analysis should be annotated.

Information on the collection and handling of samples should be completely documented to allow the details of sample collection and handling to be re-created. All information should be entered in ink at the time the information was generated in a permanently bound logbook. Errors should not be erased or crossed-out but corrected by putting a line through the erroneous information and by entering, initialing, and dating the correct information. Blank spaces should have an obliterating line drawn through to prevent addition of information. Each set of information should have an identifying printed name, signature, and initials.

Sample Handling

• Field Logs	Documentation of events occurring during field sampling to identify individual field samples.
• Sample Labels	Links individual samples with the field log and the chain-of-custody record.
• Chain-of-Custody Records	Documentation of exchange and transportation of samples from the field to final analysis.
• Sample Receipt Log	Documentation of receipt of the laboratory or organization of the entire set of individual samples for analysis.

Sample Preparation and Analysis

• Sample Preparation Log	Documents the preparation of samples for a specific method.
• Sample Analysis Log	Records information on the analysis of analytical results.
• Instrument Run Log	Records analyses of calibration standards, field samples, and quality control (QC) samples.

Chemical Standards

• Chemical Standard Receipt Log	Records receipt of analytical standards and chemicals.
• Standards/Reagent Preparation Log	Records of the preparation of internal standards, reagents, spiking solutions, surrogate solutions, and reference materials.

AC.1 SAMPLE HANDLING, REPORTING, AND ANALYSIS CHECKLIST

Field Logs

ELEMENT	COMMENT
Project name/ID and location	
Sampling personnel	
Geological observations including map	
Atmospheric conditions	
Field measurements	
Sample dates, times, and locations	
Sample identifications present	
Sample matrix identified	
Sample descriptions (e.g., odors and colors)	
Number of samples taken per location	
Sampling method/equipment	
Description of any QC samples	
Any deviations from the sampling plan	
Difficulties in sampling or unusual circumstances	

Sample Labels

ELEMENT	COMMENT
Sample ID	
Date and time of collection	
Sampler's signature	
Characteristic or parameter investigated	
Preservative used	

Chain of Custody Records

ELEMENT	COMMENT
Project name/ID and location	
Sample custodian signatures verified and on file	
Date and time of each transfer	
Carrier ID number	
Integrity of shipping container and seals verified	
Standard Operating Procedures (SOPs) for receipt on file	
Samples stored in same area	
Holding time protocol verified	
SOPs for sample preservation on file	
Identification of proposed analytical method verified	
Proposed analytical method documentation verified	
QA Plan for proposed analytical method on file	

AC.1 SAMPLE HANDLING, REPORTING, AND ANALYSIS CHECKLIST (CONTINUED)

Sample Receipt Log

ELEMENT	COMMENT
Date and time of receipt	
Sample collection date	
Client sample ID	
Number of samples	
Sample matrices	
Requested analysis, including method number(s)	
Signature of the sample custodian or designee	
Sampling kit code (if applicable)	
Sampling condition	
Chain-of-custody violations and identities	

SAMPLE PREPARATION AND ANALYSIS

Sample Preparation Logs

ELEMENT	COMMENT
Parameter/analyte of investigation	
Method number	
Date and time of preparation	
Analyst's initials or signature	
Initial sample volume or weight	
Final sample volume	
Concentration and amount of spiking solutions used	
QC samples included with the sample batch	
ID for reagents, standards, and spiking solutions used	

Sample Analysis Logs

ELEMENT	COMMENT
Parameter analyte of investigation	
Method number/reference	
Date and time of analysis	
Analyst's initials or signature	
Laboratory sample ID	
Sample aliquot	
Dilution factors and final sample volumes (if applicable)	
Absorbance values, peak heights, or initial concentrations reading	
Final analyte concentration	
Calibration data (if applicable)	
Correlation coefficient (including parameters)	
Calculations of key quantities available	
Comments on interferences or unusual observations	
QC information, including percent recovery	

AC.1 SAMPLE HANDLING, REPORTING, AND ANALYSIS CHECKLIST (CONTINUED)

Instrument Run Logs

ELEMENT	COMMENT
Name/type of instrument	
Instrument manufacturer and model number	
Serial number	
Date received and date placed in service	
Instrument ID assigned by the laboratory (if used)	
Service contract information, including service representative details	
Description of each maintenance or repair activity performed	
Date and time when of each maintenance or repair activity	
Initials of maintenance or repair technicians	

CHEMICAL STANDARDS

Chemical/Standard Receipt Logs

ELEMENT	COMMENT
Laboratory control number	
Date of receipt	
Initials or signature of person receiving chemical	
Chemical name and catalog number	
Vendor name and log number	
Concentration or purity of standard	
Expiration date	

Standards/Reagent Preparation Log

ELEMENT	COMMENT
Date of preparation	
Initials of analyst preparing the standard solution or reagent	
Concentration or purity of standard or reagent	
Volume or weight of the stock solution or neat materials	
Final volume of the solution being prepared	
Laboratory ID/control number assigned to the new solution	
Name of standard reagent	
Standardization of reagents, titrants, etc. (if applicable)	
Expiration date	

References

Roserance, A. and L. Kibler. 1994. "Generating Defensible Data," *Environmental Testing and Analysis.* May/June.

Roserance, A. and L. Kibler. 1996. "Documentation and Record Keeping Guidelines." In *Proceedings of the 12th Annual Waste Testing and Quality Assurance Symposium*. July.

AC.2 QAPP REVIEW CHECKLIST

ELEMENT	COMMENTS
A1. Title and Approval Sheet	
Title	
Organization's name	
Dated signature of project manager	
Dated signature of quality assurance officer	
Other signatures, as needed	
A2. Table of Contents	
A3. Distribution List	
A4. Project/Task Organization	
Identifies key individuals, with their responsibilities (data users, decision-makers, project QA manager, subcontractors, etc.)	
Organization chart shows lines of authority and reporting responsibilities	
A5. Problem Definition/Background	
Clearly states problem or decision to be resolved	
Provides historical and background information	
A6. Project/Task Description	
Lists measurements to be made	
Cites applicable technical, regulatory, or program-specific quality standards, criteria, or objectives	
Notes special personnel or equipment requirements	
Provides work schedule	
Notes required project and QA records/reports	
A7. Quality Objectives and Criteria for Measurement Data	
States project objectives and limits, both qualitatively and quantitatively	
States and characterizes measurement quality objectives as to applicable action levels or criteria	
A8. Special Training Requirements/Certification Listed	
States how provided, documented, and assured	
A9. Documentation and Records	
Lists information and records to be included in data report (e.g., raw data, field logs, results of QC checks, problems encountered)	
States requested lab turnaround time	
Gives retention time and location for records and reports	
B1. Sampling Process Design (Experimental Design) States the following:	
Type and number of samples required	
Sampling design and rationale	
Sampling locations and frequency	
Sample matrices	

AC.2 QAPP REVIEW CHECKLIST (CONTINUED)

ELEMENT	COMMENTS
Classification of each measurement parameter as either critical or needed for information only	
Appropriate validation study information, for nonstandard situations	
B2. Sampling Methods Requirements	
Identifies sample collection procedures and methods	
Lists equipment needs	
Identifies support facilities	
Identifies individuals responsible for corrective action	
Describes process for preparation and decontamination of sampling equipment	
Describes selection and preparation of sample containers and sample volumes	
Describes preservation methods and maximum holding times	
B3. Sample Handling and Custody Requirements	
Notes sample handling requirements	
Notes chain-of-custody procedures, if required	
B4. Analytical Methods Requirements	
Identifies analytical methods to be followed (with all options) and required equipment	
Provides validation information for nonstandard methods	
Identifies individuals responsible for corrective action	
Specifies needed laboratory turnaround time	
B5. Quality Control Requirements	
Identifies QC procedures and frequency for each sampling, analysis, or measurement technique, as well as associated acceptance criteria and corrective action	
References procedures used to calculate QC statistics including precision and bias/accuracy	
B6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements	
Identifies acceptance testing of sampling and measurement systems	
Describes equipment preventive and corrective maintenance	
Notes availability and location of spare parts	
B7. Instrument Calibration and Frequency	
Identifies equipment needing calibration and frequency for such calibration	
Notes required calibration standards and/or equipment	
Cites calibration records and manner traceable to equipment	
B8. Inspection/Acceptance Requirements for Supplies and Consumables	
States acceptance criteria for supplies and consumables	
Notes responsible individuals	
B9. Data Acquisition Requirements for Nondirect Measurements	

AC.2 QAPP REVIEW CHECKLIST (CONTINUED)

ELEMENT	COMMENTS
Identifies type of data needed from nonmeasurement sources (e.g., computer databases and literature files), along with acceptance criteria for their use	
Describes any limitations of such data	
Documents rationale for original collection of data and its relevance to this project	
B10. Data Management	
Describes standard record-keeping and data storage and retrieval requirements	
Checklists or standard forms attached to QAPP	
Describes data handling equipment and procedures used to process, compile, and analyze data (e.g., required computer hardware and software)	
Describes process for assuring that applicable Office of Information Resource Management requirements are satisfied	
C1. Assessments and Response Actions	
Lists required number, frequency and type of assessments, with approximate dates and names of responsible personnel (assessments include but are not limited to peer reviews, management systems reviews, technical systems audits, performance evaluations, and audits of data quality)	
Identifies individuals responsible for corrective actions	
C2. Reports to Management Identifies frequency and distribution of reports for:	
Project status	
Results of performance evaluations and audits	
Results of periodic data quality assessments	
Any significant QA problems	
Preparers and recipients of reports	
D1. Data Review, Validation, and Verification	
States criteria for accepting, rejecting, or qualifying data	
Includes project-specific calculations or algorithms	
D2. Validation and Verification Methods	
Describes process for data validation and verification	
Identifies issue resolution procedure and responsible individuals	
Identifies method for conveying these results to data users	
D3. Reconciliation with User Requirements	
Describes process for reconciling project results with DQOs and reporting limitations on use of data	

References

Personal Communication, Margo Hunt, EPA Region II, February, 1996.
Personal Communication, Robert Dona, EPA Region VII, November, 1997.

AC.3 CHAIN-OF-CUSTODY CHECKLIST

Item	Y	N	Comment
1. Is a sample custodian designated? If yes, name of sample custodian.			
2. Are the sample custodian's procedures and responsibilities documented? If yes, where are these documented?			
3. Are written Standard Operating Procedures (SOPs) developed for receipt of samples? If yes, where are the SOPs documented (laboratory manual, written instructions, etc.)?			
4. Is the receipt of chain-of-custody record(s) with samples being documented? If yes, where is this documented?			
5. Is the nonreceipt of chain-of-custody record(s) with samples being documented? If yes, where is this documented?			
6. Is the integrity of the shipping container(s) being documented (custody seal(s) intact, container locked, or sealed properly, etc.)? If yes, where is security documented?			
7. Is the lack of integrity of the shipping container(s) being documented (i.e., evidence of tampering, custody seals broken or damaged, locks unlocked or missing, etc.)? If yes, where is nonsecurity documented?			
8. Is agreement between chain-of-custody records and sample tags being verified and documented? If yes, state source of verification and location of documentation.			
9. Are sample tag numbers recorded by the sample custodian? If yes, where are they recorded?			
10. Are written SOPs developed for sample storage? If yes, where are the SOPs documented (laboratory manual, written instructions, etc.)?			
11. Are samples stored in a secure area? If yes, where and how are they stored?			
12. Is sample identification maintained? If yes, how?			
13. Is sample extract (or inorganics concentrate) identification maintained? If yes, how?			
14. Are samples that require preservation stored in such a way as to maintain their preservation? If yes, how are the samples stored?			

AC.3 CHAIN-OF-CUSTODY CHECKLIST (CONTINUED)

Item	Y	N	Comment
15. Based upon sample records examined to determine holding times, are sample holding time limitations being satisfied? Sample records used to determine holding times:			
16. Are written SOPs developed for sampling handling and tracking? If yes, where are the SOPs documented (laboratory manual, written instructions, etc.)?			
17. Do laboratory records indicate personnel receiving and transferring samples in the laboratory? If yes, what laboratory records document this?			
18. Does each instrument used for sample analysis (GC, GC/MS, AA, etc.) have an instrument log? If no, which instruments do not?			
19. Are analytical methods documented and available to the analysts? If yes, where are these documented?			
20. Are QA procedures documented and available to the analysts? If yes, where are these documented?			
21. Are written SOPs developed for compiling and maintaining sample document files? If yes, where are the SOPs documented (laboratory manual, written instructions, etc.)?			
22. Are sample documents filed by case number? If no, how are documents filed?			
23. Are sample document files inventoried?			
24. Are documents in the case files consecutively numbered according to the file inventories?			
25. Are documents in the case files stored in a secure area? If yes, where and how are they stored?			
26. Has the laboratory received any confidential documents?			
27. Are confidential documents segregated from other laboratory documents? If no, how are they filed?			
28. Are confidential documents stored in a secure manner? If yes, where and how are they stored?			
29. Was a debriefing held with laboratory personnel after the audit was completed?			
30. Were any recommendations made to laboratory personnel during the debriefing?			

APPENDIX D

DATA QUALITY INDICATORS

INTRODUCTION

Data Quality Indicators (DQIs) are qualitative and quantitative descriptors used in interpreting the degree of acceptability or utility of data. The principal DQIs are precision, bias, representativeness, comparability, and completeness. Secondary DQIs include sensitivity, recovery, memory effects, limit of quantitation, repeatability, and reproducibility. Establishing acceptance criteria for the DQIs sets quantitative goals for the quality of data generated in the analytical measurement process. DQIs may be expressed for entire measurement systems, but it is customary to allow DQIs to be applied only to laboratory measurement processes. The issues of design and sampling errors, the most influential components of variability, are discussed separately in EPA QA/G-5S, *Guidance on Sampling Designs to Support QAPPs.*

Of the five principal DQIs, precision and bias are the quantitative measures, representativeness and comparability are qualitative, and completeness is a combination of both quantitative and qualitative measures.

The five principal DQIs are also referred to by the acronym PARCC, with the "A" in PARCC referring to accuracy instead of bias. This inconsistency results because some analysts believe accuracy and bias are synonymous, and PARCC is a more convenient acronym than PBRCC. Accuracy comprises both random error (precision) and systematic error (bias), and these indicators are discussed separately in this appendix. DQIs are discussed at length in EPA QA/G-5I, *Guidance on Data Quality Indicators*.

AD1. PRINCIPAL DQIs: PARCC

AD1.1 PARCC: Precision

Precision is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions. This agreement is calculated as either the range (R) or as the standard deviation (s). It may also be expressed as a percentage of the mean of the measurements, such as relative range (RR) (for duplicates) or relative standard deviation (RSD).

For analytical procedures, precision may be specified as either **intra**laboratory (within a laboratory) or **inter**laboratory (between laboratories) precision. Intralaboratory precision estimates represent the agreement expected when a single laboratory uses the same method to make repeated measurements of the same sample. Interlaboratory precision refers to the agreement expected when two or more laboratories analyze the same or identical samples with the same method. Intralaboratory precision is more commonly reported; however, where available, both intralaboratory and interlaboratory precision are listed in the data compilation.

When possible, a sample subdivided in the field and preserved separately is used to assess the variability of sample handling, preservation, and storage along with the variability of the analysis process.

When collocated samples are collected, processed, and analyzed by the same organization, intralaboratory precision information on sample acquisition, handling, shipping, storage, preparation. and analysis is obtained. Both samples can be carried through the steps in the measurement process together to provide an estimate of short-term precision. Likewise, the two samples, if separated and processed at different times or by different people and/or analyzed using different instruments, provide an estimate of long-term precision.

AD1.2 PARCC: Bias

Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. Bias assessments for environmental measurements are made using personnel, equipment, and spiking materials or reference materials as independent as possible from those used in the calibration of the measurement system. When possible, bias assessments should be based on analysis of spiked samples rather than reference materials so that the effect of the matrix on recovery is incorporated into the assessment. A documented spiking protocol and consistency in following that protocol are important to obtaining meaningful data quality estimates. Spikes should be added at different concentration levels to cover the range of expected sample concentrations. For some measurement systems (e.g., continuous analyzers used to measure pollutants in ambient air), spiking samples may not be practical, so assessments should be made using appropriate blind reference materials.

For certain multianalyte methods, bias assessments may be complicated by interferences among multiple analytes, which prevents all of the analytes from being spiked into a single sample. For such methods, lower spiking frequencies can be employed for analytes that are seldom or never found. The use of spiked surrogate compounds for multianalyte gas chromatography/ mass spectrometry (GC/MS) procedures, while not ideal, may be the best available procedure for assessment of bias.

AD1.3 PARCC: Accuracy

Accuracy is a measure of the closeness of an individual measurement or the average of a number of measurements to the true value. Accuracy includes a combination of random error (precision) and systematic error (bias) components that result from sampling and analytical operations.

Accuracy is determined by analyzing a reference material of known pollutant concentration or by reanalyzing a sample to which a material of known concentration or amount of pollutant has been added. Accuracy is usually expressed either as a percent recovery (P) or as a percent bias (P - 100). Determination of accuracy always includes the effects of variability (precision); therefore, accuracy is used as a combination of bias and precision. The combination is known statistically as mean square error.

Mean square error (MSE) is the quantitative term for overall quality of individual measurements or estimators. To be accurate, data must be both precise and unbiased. Using the analogy of archery, to be accurate, one must have one’s arrows land close together and, on average, at the spot where they are aimed. That is, the arrows must all land near the bull’s-eye (see Figure AD.1).

Mean square error is the sum of the variance plus the square of the bias. (The bias is squared to eliminate concern over whether the bias is positive or negative.) Frequently, it is impossible to quantify all of the components of the mean square error--especially the biases--but it is important to attempt to quantify the magnitude of such potential biases, often by comparison with auxiliary data.

AD1.4 PARCC: Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental

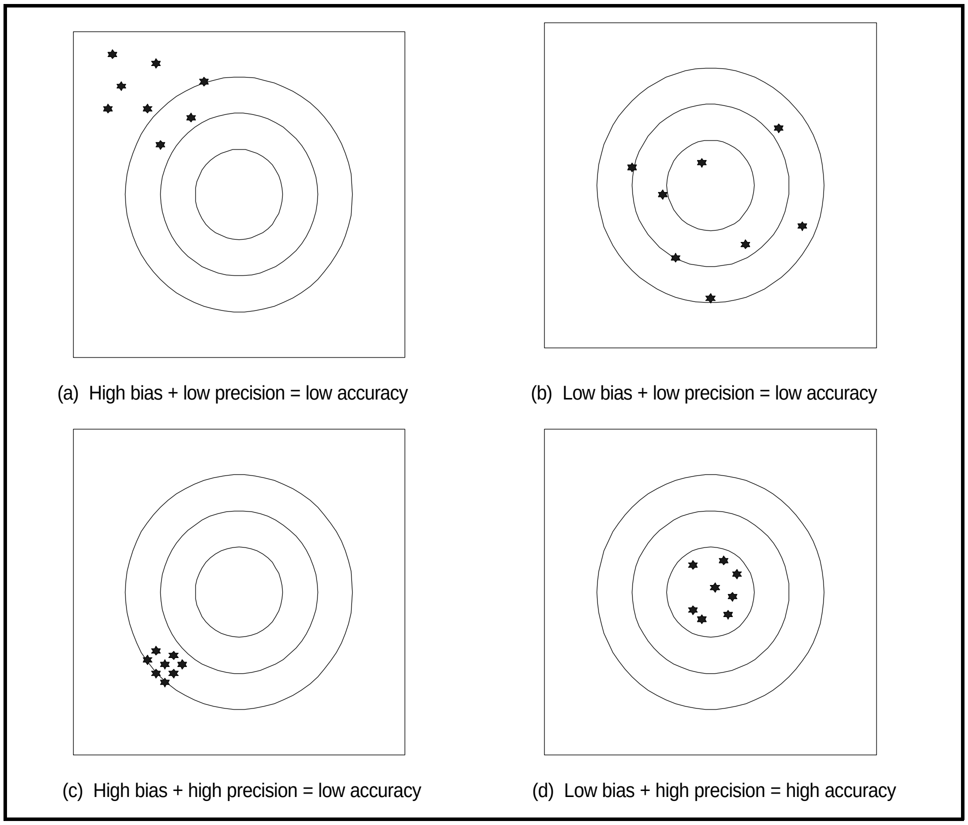

Figure AD1. Measurement Bias and Random Measurement Uncertainties: Shots at a Target

condition. Representativeness is a qualitative term that should be evaluated to determine whether in situ and other measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and phenomenon measured or studied.

AD1.5 PARCC: Comparability

Comparability is the qualitative term that expresses the confidence that two data sets can contribute to a common analysis and interpolation. Comparability must be carefully evaluated to establish whether two data sets can be considered equivalent in regard to the measurement of a specific variable or groups of variables. In a laboratory analysis, the term comparability focuses on method type comparison, holding times, stability issues, and aspects of overall analytical quantitation.

There are a number of issues that can make two data sets comparable, and the presence of each of the following items enhances their comparability:

- two data sets should contain the same set of variables of interest;
- units in which these variables were measured should be convertible to a common metric;
- similar analytic procedures and quality assurance should be used to collect data for both data sets;
- time of measurements of certain characteristics (variables) should be similar for both data sets;

- measuring devices used for both data sets should have approximately similar detection levels;
- rules for excluding certain types of observations from both samples should be similar;
- samples within data sets should be selected in a similar manner;
- sampling frames from which the samples were selected should be similar; and
- number of observations in both data sets should be of the same order or magnitude.

These characteristics vary in importance depending on the final use of the data. The closer two data sets are with regard to these characteristics, the more appropriate it will be to compare them. Large differences between characteristics may be of only minor importance, depending on the decision that is to be made from the data.

Comparability is very important when conducting meta-analysis, which combines the results of numerous studies to identify commonalities that are then hypothesized to hold over a range of experimental conditions. Meta-analysis can be very misleading if the studies being evaluated are not truly comparable. Without proper consideration of comparability, the findings of the meta-analysis may be due to an artifact of methodological differences among the studies rather than due to differences in experimentally controlled conditions. The use of expert opinion to classify the importance of differences in characteristics among data sets is invaluable.

AD1.6 PARCC: Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that should have been collected (i.e., measurements that were planned to be collected).

Completeness is not intended to be a measure of representativeness; that is, it does not describe how closely the measured results reflect the actual concentration or distribution of the pollutant in the media sampled. A project could produce 100% data completeness (i.e., all samples planned were actually collected and found to be valid), but the results may not be representative of the pollutant concentration actually present.

Alternatively, there could be only 70% data completeness (30% lost or found invalid), but, due to the nature of the sample design, the results could still be representative of the target population and yield valid estimates. Lack of completeness is a vital concern with stratified sampling. Substantial incomplete sampling of one or more strata can seriously compromise the validity of conclusions from the study. In other situations (for example, simple random sampling of a relatively homogeneous medium), lack of completeness results only in a loss of statistical power. The degree to which lack of completeness affects the outcome of the study is a function of many variables ranging from deficiencies in the number of field samples acquired to failure to analyze as many replications as deemed necessary by the QAPP and DQOs. The intensity of effect due to incompleteness of data is sometimes best expressed as a qualitative measure and not just as a quantitative percentage.

Completeness can have an effect on the DQO parameters. Lack of completeness may require reconsideration of the limits for the false negative and positive error rates because insufficient completeness will decrease the power of the statistical test.

The following four situations demonstrate the importance of considering the planned use of the data when determining the completeness of a study. The purpose of the study is to determine whether the average concentration of dioxin in surface soil is no more than 1.0 ppb. The DQOs specified that the sample average should estimate the true average concentration to within ±0.30 ppb with 95 % confidence. The resulting sampling design called for 30 samples to be drawn according to a simple random sampling scheme. The results were as follows:

	Study result	Completeness	Outcome
1.	1.5 ppb ± 0.28 ppb	97%	satisfies DQOs and study purpose
2.	500 ppb ± 0.28 ppb	87%	satisfies DQOs and study purpose
3.	1.5 ppb ± 0.60 ppb	93%	doesn't satisfy either
4.	500 ppb ± 0.60 ppb	67%	fails DQOs but meets study purpose

For all but the third situation, the data that were collected completely achieved their purpose, meeting data quality requirements originally set out, or providing a conclusive answer to the study question. The degree of incompleteness did not affect some situations (situations 2 and 4) but may have been a prime cause for situation 3 to fail the DQO requirements. Expert opinion would then be required to ascertain if further samples for situation 3 would be necessary in order to meet the established DQOs.

Several factors may result in lack of completeness: (1) the DQOs may have been based on poor assumptions, (2) the survey design may have been poorly implemented, or (3) the design may have proven impossible to carry out given resource limitations. Lack of completeness should always be investigated, and the lessons learned from conducting the study should be incorporated into the planning of future studies.

AD2. OTHER DATA QUALITY INDICATORS

AD2.1 Sensitivity

Sensitivity is the capability of a method or instrument to discriminate between measurement responses representing different levels of a variable of interest. Sensitivity is determined from the value of the standard deviation at the concentration level of interest. It represents the minimum difference in concentration that can be distinguished between two samples with a high degree of confidence.

AD2.2 Recovery

Recovery is an indicator of bias in a measurement. This is best evaluated by the measurement of reference materials or other samples of known composition. In the absence of reference materials, spikes or surrogates may be added to the sample matrix. The recovery is often stated as the percentage measured with respect to what was added. Complete recovery (100%) is the ultimate goal. At a minimum, recoveries should be constant and should not differ significantly from an acceptable value. This means that control charts or some other means should be used for verification. Significantly low recoveries should be pointed out, and any corrections made for recovery should be stated explicitly.

AD2.3 Memory Effects

A memory effect occurs when a relatively high-concentration sample influences the measurement of a lower concentration sample of the same analyte when the higher concentration sample precedes the lower concentration sample in the same analytical instrument. This represents a fault in an analytical measurement system that reduces accuracy.

AD2.4 Limit of Quantitation

The limit of quantitation is the minimum concentration of an analyte or category of analytes in a specific matrix that can be identified and quantified above the method detection limit and within specified limits of precision and bias during routine analytical operating conditions.

AD2.5 Repeatability

Repeatability is the degree of agreement between independent test results produced by the same analyst using the same test method and equipment on random aliquots of the same sample within a short time period.

AD2.6 Reproducibility

Reproducibility is the precision that measures the variability among the results of measurements of the same sample at different laboratories. It is usually expressed as a variance and low values of variance indicate a high degree of reproducibility.

AD2.7 DQIs and the QAPP

At a minimum, the following DQIs should be addressed in the QAPP: accuracy and/or bias, precision, completeness, comparability, and representativeness. Accuracy (or bias), precision, completeness, and comparability should be addressed in Section A7.3, Specifying Measurement Performance Criteria. Refer to that section of the G-5 text for a discussion of the information to present and a suggested format. Representativeness should be discussed in Sections B4.2 (Subsampling) and B1 (Sampling Design).

Table AD1. Principal Types of Error

Types of Error	Sources of Error
Random Error (precision; "P" in PARCC)	Natural variability in the population from which the sample is taken. Measurement system variability, introduced at each step of sample handling and measurement processes.
Systematic Error (accuracy/bias; "A" in PARCC)	Interferences that are present in sample matrix. Loss (or addition) of contaminants during sample collection and handling. Loss (or addition) of contaminants during sample preparation and analysis. Calibration error or drift in the response function estimated by the calibration curve.

Lack of representativeness ("R" in PARCC)	Sample is not representative of the population, which often occurs in judgmental sampling because not all the units of the population have equal or known selection probabilities. Sample collection method does not extract the material from its natural setting in a way that accurately captures the desired qualities to be measured. Subsample (taken from a sample for chemical analysis) is not representative of the sample, which occurs because the sample is not homogeneous and the subsample is taken from the most readily available portion of the sample. Consequently, other parts of the sample had less chance of being selected for analysis.
Lack of comparability ("C" in PARCC)	Failure to use similar data collection methods, analytical procedures, and QA protocols. Failure to measure the same parameters over different data sets.
Lack of completeness ("C" in PARCC)	Lack of completeness sometimes caused by loss of a sample, loss of data, or inability to collect the planned number of samples. Incompleteness also occurs when data are discarded because they are of unknown or unacceptable quality.

AD2.8 References

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APPENDIX E

QUALITY CONTROL TERMS

AE1. QUALITY CONTROL OPERATIONS

Quality control (QC) plays an increasingly important role in environmental studies, especially when those studies are conducted to decide how to address an environmental problem. To minimize the chance of making an incorrect decision, data of adequate quality must be collected. The purpose of QC is to ensure that measurement and other data-producing systems operate within defined performance limits as specified in planning. QC programs can both lower the chances of making an incorrect decision and help the data user understand the level of uncertainty that surrounds the decision. QC operations help identify where error is occurring, what the magnitude of that error is, and how that error might impact the decision-making process. This appendix provides a brief overview of this complex topic. It surveys the different types of QC samples that can be applied to environmental studies and evaluates how they are currently deployed as specified by EPA methods and regulations.

AE1.1 General Objectives

The most important QC questions a project manager should consider are:

- What are the QC requirements for the methods to be used in the project?
- What types of problems in environmental measurement systems do these requirements enable the Agency to detect?

Addressing these questions should provide the manager with the background needed for defining a uniform, minimum set of QC requirements for any environmental data collection activity. Understanding existing QC requirements for environmental data generation activities provides a framework for considering what set of QC requirements should be considered "core" requirements irrespective of the end use of the data.

While it is difficult to define a standard of data quality regardless of its intended use, core QC requirements can be established that will enable one to provide data of known quality in accordance with the Agency's QA program. This program requires that all environmental data collection efforts gather information on bias, variability, and sample contamination. These error types are incurred throughout the data generation process, including all sampling and analytical activities (i.e., sample collection, handling, transport, and preparation; sample analysis; and subsampling). The principal issue centers on what level of detail in the error structure should QC operations be capable of revealing, given that it is impractical to explore every known potential source of error.

AE1.2 Background

Many of the essential elements of a Quality Assurance Project Plan (QAPP) apply directly to sampling and analytical activities and include: Quality assurance (QA) objectives for measurement data specified in terms of Data Quality Indicators (precision, accuracy, bias, representativeness and comparability); sampling procedures; sample custody; calibration procedures and frequency; analytical procedures; internal QC checks and frequency; performance and system audits and frequency; and specific routine procedures that should be used to assess both data precision and the completeness of the specific measurement parameters involved.

AE1.3 Definitions and Terminology

In order to ensure that managers have a uniform perspective of QC requirements, it is necessary to discuss some basic terminology and definitions. QC and QA, total study error and its components, types of QC operations, and Good Laboratory Practices (GLPs) will be discussed here. Specific definitions of these terms and others are provided in Appendix B, *Glossary of Quality Assurance and Monitoring Terms,* while Table E.1 summarizes the results of a study on how these terms are defined and used in EPA and non-EPA literature. Five commonly available sources are discussed in Table E.1: Appendix B in EPA QA/G-5; American Society for Quality Control (1996); van Ee, Blume, and Starks (1989); Taylor (1987); and Keith (1988).

AE1.1.3 <u>Quality Control vs. Quality Assurance</u>

All of the cited literature provides somewhat similar definitions for both QA and QC. QC activities are designed to control the quality of a product so that it meets the user's needs. QA includes QC as one of the activities needed to ensure that the product meets defined standards of quality.

These two terms have been defined in slightly different ways by other authors, but all are in agreement that QC is a component of QA. Many authors define QC as "those laboratory operations whose objective is to ensure that the data generated by the laboratory are of known accuracy to some stated, quantitative degree of probability" (Dux 1986). The objective of QC is not to eliminate or minimize errors but to measure or estimate what they are in the system as it exists. The same authors then define QA as the ability to prove that the quality of the data is as reported. QA relies heavily on documentation, including documentation of implemented QC procedures, accountability, traceability, and precautions to protect raw data.

AE1.3.2 <u>QC Samples</u>

Table E.1 offers a broad survey of commonly used QC terms, including the definitions of QC sample types that span the measurement process. The authors cited in Table E.1 define different sample types in varied ways; however, the definitions are not contradictory.

AE1.3.3 <u>Good Laboratory Practices</u>

The Food and Drug Administration (FDA) promulgated the first version of the Good Laboratory Practices (GLPs) in 1978. The EPA enacted similar guidance requirements in 1983 for Resource Conservation Recovery Act (RCRA) and Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) compliance. The FIFRA GLPs were revised in 1988. Though much of the content relates to laboratory animal science, many requirements are relevant to the analytical chemist. The GLP standards for FIFRA (40 *Code of Federal Regulations* [CFR] Part 160) and the Toxic Substances Control Act (TSCA) (40 CFR 792) are similar (Dux 1986). Selected topics of FIFRA subparts A through K appear below.

Subpart A	General Provisions.
Subpart B	Organization and Personnel. Includes QA unit.
Subpart C	Facilities. Includes: facilities for handling test, control, and reference substances; laboratory operations areas; and specimen and data storage facilities.
Subpart D	Equipment. Includes: maintenance and calibration of equipment.
Subpart E	Testing Facilities Operation. Includes: standard operation procedures (SOPs); reagents and solutions.

Subpart F	Test, Control, and Reference Substances. Includes: characterization and handling; mixtures of substances with carriers.
Subpart G	Protocol for and Conduct of a Study.
Subpart H	Reserved.
Subpart I	Reserved.
Subpart J	Records and Reports. Includes: reporting of study results; storage and retrieval of records and data; and retention of records.

GLPs are defined similarly by the Agency and by Taylor (1987) as an acceptable way to perform some basic laboratory operation or activity that is known or believed to influence the quality of its outputs.

AE2. QUALITY CONTROL REQUIREMENTS IN EXISTING PROGRAMS

To identify QC requirements for this section, standard EPA method references, such as SW-846, and the CFR were reviewed together with information on non-EPA methods identified through a computerized literature search. Within the EPA literature, some of the major programs were reviewed, including the Drinking Water, Air and the Contract Laboratory Program (CLP). Different types of methods, such as gas chromatography (GC), atomic absorption (AA), and inductively coupled plasma (ICP), and different media were included in this process, but it was not intended to be exhaustive.

AE2.1 Summary of QC Requirements by Program and Method

Table AE.2 presents the frequency of QC requirements for different selected programs and Table AE.3 presents information for methods. In cases where different programs use dissimilar terms for similar QC samples, the table uses the term from the program or method.

AE2.2 Comparing Various QC Requirements

AE2.2.1 QC Requirements for Program Offices

Table AE.2 shows that QC requirements vary considerably and are established by the Program Office responsible for the data collection activity. Ambient air monitoring methods (Office of Air Quality Planning and Standards [OAQPS]) require periodic analysis of standards for assessment of accuracy (combination of imprecision and bias) for manual methods, and analysis of collocated samples for the assessment of imprecision. Prevention of Significant Deterioration (PSD) and State and Local Air Monitoring Stations (SLAMS) make a unique distinction in defining two terms: precision checks and accuracy checks. These checks entail essentially the same QC requirements, but they are performed by different parties; the accuracy check is essentially an external audit, while the precision check is an internal QC operation. It should be noted that some water methods require additional QC operations for GC/MS than for other methods (e.g., tuning, isotopic dilution).

In general, the wet chemistry analytical methods (the toxicity characteristic leaching procedure [TCLP] being a preparation method) require periodic analysis of blanks and calibration standards. Most require analysis of matrix spikes and replicate samples, the exceptions being the 200 Series (no spikes or replicates) and the 600 series (GC/MS require no replicates).

While the QC operations for the PSD and SLAMS methods appear minimal, these monitoring programs require active QA programs that include procedures for zero/span checks. (The zero check may be considered a blank sample, while the span check may be considered a calibration check sample.)

The Program Office Quality Assurance Officer (QAO) or representative should have details on specific QC requirements.

AE2.2.2 Organized by Type of Potential Problem

Table AE.3 lists the QC requirements of various EPA measurement methods and presents the required frequencies for different kinds of QC operations. The table is divided into four sections, one for each general type of QC problem:

- *Contamination*: This occurs when the analyte of interest or an interferant is introduced through any of a number of sources, including contaminated sample equipment, containers, and reagents. The contaminant can be the analyte of interest or another chemical that interferes with the measurement of the analyte or causes loss or generation of the analyte.

- *Calibration Drift*: This is a nonrandom change in the measurement system over time, such as a (systematic) change in instrument response over time. It is often detectable by periodic remeasurement of a standard.

- *Bias*: This can be regarded as a systematic error caused by contamination and calibration drift and also by numerous other causes, such as extraction efficiency by the solvent, matrix effect, and losses during shipping and handling.

- *Imprecision*: This is a random error, observed as different results from repeated measurements of the same or identical samples.

For internal consistency, the names of QC operations used in Table AE.3 are those given in the specific reference methods.

AE2.3 Using QC Data

The relationships between monitoring design specifications and the final use of the data described above incorporate two significant assumptions: (1) laboratory measurements, through the use of internal standards or other adjustments that are integral to the analytical protocol, are unbiased; and (2) the variance structure of these measurements does not change over time. Bias enters as a consequence of under-recovery of the contaminant of interest during the sample preparation stage of the analytical protocol and as undetected drift in calibration parameters. The variance of measurements also may change over time due to unintentional changes in the way samples are prepared and/or to degradation of the electromechanical instrumentation used to analyze the samples. QC samples are intended to detect bias and variability changes and should be specified in the QAPP.

QC samples that address bias are calibration check standards (CCSs) and spiked samples (performance check samples [PCSs]). CCSs typically consist of reagent water samples spiked with the concentrations used to develop the calibration curve. Measurements obtained by analyzing these samples, which reflect the existing calibration relationship, are compared to the actual concentrations that were added to the samples. If the difference exceeds a prespecified calibration test limit, the measurement system is considered "out of control" and the calibration function is re-estimated.

Detecting a change in calibration parameters is a statistical decision problem in detecting a material change in the calibration function. In many QC programs, CCSs typically are analyzed at the beginning and end of each shift and after any other QC sample has detected a failure. By definition, significant change in the calibration parameters leads to biased measurements of field samples. This can be detected through use of statistical tests.

A spiked sample typically has the same matrix characteristics found in field samples, but it has been spiked (as soon after the sample is taken as is practical) with a known concentration of the target contaminant. Because spiked samples are intended to detect recovery changes, they are processed through the same preparation steps as field samples, and the spiked sample measurement is used to form an estimate of recovery. Significant changes lead to the conclusion that measurements of field samples are biased.

The second of the two monitoring program assumptions identified at the beginning of this section is a constant variance structure for monitoring data over time. Measurements from split (or duplicate) field samples provide a check on this variance assumption. Changes in measurement variability, for example a uniform increase in the standard deviation or changes in the way variability depends on concentration, have a direct impact on subsequent investigations.

AE2.4 Classifying QC Samples: Control versus Assessment

QC programs are designed foremost to detect a measurement process entering an "out of control" state so that corrective measures can be initiated. QC samples used in this way are performing a control function. Each of the three types of QC samples previously discussed, CCSs, spiked samples, and split (or duplicate) samples, may be used for control. In addition, spiked samples and split samples also may be used to estimate measurement bias and variability. QC samples that also can be used to estimate measurement parameters are sometimes referred to as quality assessment samples. These should not be confused with the much larger Data Quality Assessment Process; see also EPA QA/G-9, *Guidance for Data Quality Assessment*.

QC samples that are used for control must be analyzed and reported soon after they are obtained if their intervention potential is to be realized. Among the three types of QC samples discussed above, CCSs are the most likely to be effective for control purposes. Spiked samples and split samples generally are not effective for control purposes, in part because they are analyzed "blind" and therefore the results cannot be reviewed immediately. Spiked samples and split samples, however, may be used for control if consecutive batches of similar field samples are being analyzed.

Spiked samples and split samples can be effective quality assessment samples. For example, spiked samples may be used to indicate the presence of bias. The estimate is applied as a bias correcting adjustment to individual measurements or to batches of measurements before the measurements are used in compliance tests. The adjustment improves the test by eliminating bias. However, the variance of the adjusted estimate used in the test is greater than the variance of the unadjusted estimate.

Split (or duplicate) samples also can be used as quality assessment samples, but their application in the monitoring program is not as constructive as the application of spiked samples. Split samples lead to an estimate of the measurement replication component of variability. (The variance of a measurement has, at a minimum, a sampling component and a measurement replication component, which is sometimes referred to as measurement error. If the sampling design involves stratification, the variance will include additional components.) If the estimate based on split samples suggests a measurement replication standard deviation larger than the value assumed in establishing the original sampling design, a loss in efficiency will result.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Blank sample	A clean sample or a sample of matrix processed so as to measure artifacts in the measurement (sampling and analysis) process.	Blanks provide a measure of various cross-contamination sources, background levels in reagents, decontamination efficiency, and other potential error that can be introduced from sources other than the sample. A rinsate blank (decontamination sample) measures any chemical that may have been on the sampling and sample preparation tools after the decontamination process is completed.	The measured value obtained when a specified component of a sample is not present during measurement. Measured value/signal for the component is believed to be due to artifacts; it should be deducted from a measured value to give a net value due to the component contained in a sample. The blank measurement must be made to make the correction process valid.	Samples expected to have negligible or unmeasurable amounts of the substance of interest. They are necessary for determining some of the uncertainty due to random errors. Three kinds required for proper quality assurance: equipment blanks, field blanks. and sampling blanks.
Blind sample	A subsample submitted for analysis with a composition and identity known to the submitter but unknown to the analyst. Used to test analyst or laboratory proficiency in execution of the measurement process.	Single-Blind Samples: Field Rinsate Blanks, Preparation Rinsate Blank, Trip Blank	A sample submitted for analysis whose composition is known to the submitter but unknown to the analyst. One way to test the proficiency of a measurement process.	
Calibration standard	A substance or reference material used to calibrate an instrument. (calibration check standard, reference standard, quality control check sample)		In physical calibration, an artifact measured periodically, the results of which typically are plotted on a control chart to evaluate the measurement process.	Or quality control calibration standard (CCS). In most laboratory procedures, a solution containing the analyte of interest at a low but measurable concentration. Standard deviation of the CCSs is a measure of instrument precision unless the CCS is analyzed as a sample, in which case it is a measure of method precision.
Checks sample		Example: ICP Interference Check Sample - Part A contains potential interfering analytes. Part B contains both the analytes of interest and the target analytes. Part A and B are analyzed separately to determine the potential for interferences.		
Check standard	A substance or reference material obtained from a source independent from the source of the calibration standard; used to prepare check samples. (control standard)			Laboratory control standards are certified standards, generally supplied by an outside source. They are used to ensure that the accuracy of the analysis is in control.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Double blind samples		Samples that can not be distinguished from routine samples by analytical laboratory. Examples: Field Evaluation Samples, Low Level Field Evaluation Samples, External Laboratory Evaluation Samples, Low Level External Laboratory Evaluation Samples, Field Matrix Spike, Field Duplicate, Field Split	A sample known by the submitter but submitted to an analyst so that neither its composition nor its identification as a check sample are known to the analyst.	
Duplicate measurement			A second measurement made on the same (or identical) sample of material to assist in the evaluation of measurement variance.	
Duplicate sample	Two samples taken from and representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Used to assess variance of the total method including sampling and analysis.	Field duplicate - an additional sample taken near the routine field sample to determine total within-batch measurement variability. Analytical laboratory duplicate - a subsample of a routine sample analyzed by the same method. Used to determine method precision. It is non-blind so it can only be used by the analyst in internal control, not an unbiased estimate of analytical precision.	A second sample randomly selected from a population of interest to assist in the evaluation of sample variance.	
Error	The difference between a computed, observed, or measured value or condition and the true, specified, or theoretical value or condition.		Difference between the true or expected value and the measured value of a quantity or parameter.	
Field blank				Used to estimate incidental or accidental contamination of a sample during the collection procedure. One should be allowed per sampling team per day per collection apparatus. Examples include matched-matrix blank, sampling media or trip blank, equipment blank.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Good Laboratory Practices (GLPs)	Either general guidelines or formal regulations for performing basic laboratory operations or activities that are known or believed to influence the quality and integrity of the results.		An acceptable way to perform some basic operation or activity in a laboratory that is known or believed to influence the quality of its outputs. GLPs ordinarily are essentially independent of the measurement techniques used.	
Instrument blank				Also called system blank. Used to establish baseline response of an analytical system in the absence of a sample. Not a simulated sample but a measure of instrument or system background response.
Method blank				One of the most important in any process. DDI water processed through analytical procedure as a normal sample. After use to determine the lower limit of detection, a reagent blank is analyzed for each 20 samples and whenever a new batch of reagents is used.
Non-blind sample		QC samples with a concentration and origin known to the analytical laboratory. Examples: Laboratory Control Sample, Pre-digest Spike, Post-digest Spike, Analytical Laboratory Duplicate, Initial Calibration Verification and Continuing Calibration Verification Solutions, Initial Calibration Blank and Continuing Calibration Blank Solution, CRDL Standard for ICP and AA, Linear Range Verification Check Standard, ICP Interference Check Sample.		
Performance Evaluation (PE)	A type of audit in which the quantitative data generated in a measurement system are obtained independently and compared with routinely obtained data to evaluate the proficiency of an analyst or laboratory. (Defined in EPA QA/G-5, App. B)			

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Quality assessment	Assessment is the evaluation of environmental data to determine if they meet the quality criteria required for a specific application.	The overall system of activities that provides an objective measure of the quality of data produced.	The overall system of activities whose purpose is to provide assurance that the quality control activities are done effectively. It involves a continuing evaluation of performance of the production system and the quality of the products produced.	
Quality assessment sample (QAS)		Those samples that allow statements to be made concerning the quality of the measurement system. Allow assessment and control of data quality to assure that it meets original objectives. Three categories: double-blind, single-blind, and non-blind.		
Quality assurance (QA)	An integrated system of activities involving planning, quality control, quality assessment, reporting and quality improvement to ensure that a product or service meets defined standards of quality with a stated level of confidence.	A system of activities whose purpose is to provide to the producer or user of a product or service the assurance that it meets defined standards of quality. It consists of two separate, but related activities, quality control and quality assessment.	Same as van Ee.	
Quality control (QC)	The overall system of technical activities whose purpose is to measure and control the quality of a product or service so that it meets the needs of users. The aim is to provide quality that is satisfactory, adequate, dependable, and economical.	The overall system of activities whose purpose is to control the quality of the measurement data so that they meet the needs of the user.	The overall system of activities whose purpose is to control the quality of a product or service so that it meets the needs of users. The aim is to provide quality that is satisfactory, adequate dependable, and economic.	
Quality control sample	An uncontaminated sample matrix spiked with known amounts of analytes from a source independent from the calibration standards. Generally used to establish intralaboratory or analyst specific precision and bias or to assess performance of all or part of the measurement system. (Laboratory control sample) (Defined in EPA QA/G-5, App. B)	A sample of well-characterized soil, whose analyte concentrations are known to the laboratory. Used for internal laboratory control. Also called QC audit sample.	A material of known composition that is analyzed concurrently with test samples to evaluate a measurement process.	Used in quality control procedures to determine whether or not the analytical procedures are in control.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Reagent blank	A sample consisting of reagent(s), without the target analyte or sample matrix, introduced into analytical procedure at the appropriate point and carried through all subsequent steps to determine the contribution of the reagents in the absence of matrix and the involved analytical steps to error in the observed value (analytical blank, laboratory blank). (Defined in EPA QA/G-5, App. B)			Also called method blank. Used to detect and quantitate contamination introduced during sample preparation and analysis. Contains all reagents used in sample preparation and analysis and is carried through the complete analytical procedure.
Reference material			A material or substance, one or more properties of which are sufficiently well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for the assignment of values to materials.	
Sample preparation blank				Required when methods like stirring, mixing, blending, or subsampling are used to prepare a sample prior to analysis. One should be prepared per 20 samples processed.
Sampling equipment blank				Used to determine types of contaminants introduced through contact with sampling equipment; also to verify the effectiveness of cleaning procedures. Prepared by collecting water or solvents used to rinse sampling equipment.
Solvent blank				Used to detect and quantitate solvent impurities; the calibration standard corresponds to zero analyte concentration. Consists only of solvent used to dilute the sample.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Spiked sample	A sample prepared by adding a known mass of target analyte to a specified amount of matrix sample for which an independent estimate of target analyte concentration is available. Spiked samples are used, for example, to determine the effect of the matrix on a method's recovery efficiency (matrix spike).	A sample prepared by adding a known amount of reference chemical to one of a pair of split samples. Comparing the results of the analysis of a spiked member to that of the non-spiked member of the split measures spike recovery and provides a measure of the analytical bias. Field matrix spike - a routine sample spiked with the contaminant of interest in the field.		Matrix control or field spike -for sample matrices where a complex mixture (e.g. sediments, sludges) may interfere with analysis, a field spike may be required to estimate the magnitude of those interferences. Losses from transport, storage treatment, and analysis can be assessed by adding a known amount of the analyte of interest to the sample in the field.
Split sample	Two or more representative portions taken from a sample or subsample and analyzed by different analysts or laboratories. Split samples are used to replicate the measurement of the variable(s) of interest.	Samples can provide: a measure of within-sample variability; spiking materials to test recovery; and a measure of analytical and extraction errors. Where the sample is split determines the components of variance that are measured. Field split - a sample is homogenized and spilt into two samples of theoretically equal concentration at the sampling site. Indicate within-batch measurement error. Also called replicates.	A replicate portion or subsample of a total sample obtained in such a manner that is not believed to differ significantly from other portions of the same sample.	
Total measurement error	The sum of all the errors that occur from the taking of the sample through the reporting of results; the difference between the reported result and the true value of the population that was to have been sampled.			
Transport blank				Used to estimate sample contamination from the container and preservative during transport and storage of the sample. One should be allowed per day per type of sample.

Table AE1. Comparison of QC Terms

Terms	ASQC, *Definitions of Environmental Quality Assurance Terms* or EPA QA/G-5 Appendix B	van Ee, Blume, and Starks *A Rationale for the Assessment of Errors in the Sampling of Soils*	John Keenan Taylor *Quality Assurance of Chemical Measurements*	Lawrence H. Keith, ed. *Principles of Environmental Sampling*
Trip blank	A clean sample of matrix that is carried to the sampling site and transported to the laboratory for analysis without having been exposed to sampling procedures. (Defined in EPA QA/G-5, App. B)	Used when volatile organics are sampled. Consists of actual sample containers filled with ASTM Type II water, kept with routine samples throughout sampling event, packaged for shipment with routine samples and sent with each shipping container to the laboratory. Used to determine the presence or absence of contamination during shipment.		A type of field blank also called sampling media blank. To detect contamination associated with the sampling media such as filters, traps, and sample bottles. Consists of sampling media used for sample collection.

Table AE2. QC Requirements for Programs

Potential Problems:	Contamination		Calibration Drift	Bias		Imprecision		
QC Samples to Identify Potential Problems:	Blanks		Calibration Check Samples	Spike	Standard	Replicate	Collocated	Other
CLP Organics: 1991 Statement of Work, Exhibit E	Volatiles	A method blank once every 12 hours.	Continuing calibration standard every 12 hours. BFB analysis once every 12 hours.	Matrix spike with every case, batch, 20 samples, or 14 days.	3 system monitoring compounds added to every sample.	Matrix spike duplicate with every case, batch, 20 samples, or 14 days.		
	Semi-volatiles	A method blank with every batch.	DFTPP analysis once every 12 hours. Continuing calibration standard every 12 hours.	Matrix spike with every case, batch, 20 samples, or 14 days.	8 surrogates spiked into each sample.	Matrix spike duplicate with every case, batch, 20 samples, or 14 days.		
	Pesticides/ Aroclor	Instrument blank at start of analyses and every 12 hours. Method blank with each case, 14 days, or batch. Sulfur blanks are sometimes required.	Performance evaluation mixture to bracket 12-hour periods.	Matrix spike with every 20 samples.	2 surrogates added to each sample.	Matrix spike duplicate with every 20 samples.		

Table AE2. QC Requirements for Programs							
Potential Problems:	**Contamination**	**Calibration Drift**	**Bias**		**Imprecision**		
QC Samples to Identify Potential Problems:	**Blanks**	**Calibration Check Samples**	**Spike**	**Standard**	**Replicate**	**Collocated**	**Other**
CLP Inorganics: 1991 Statement of Work, Exhibit E	Initial calibration blank; then continuing calibration blank 10% or every 2 hours. Preparation blank with every batch.	Initial calibration verification standard; then continuing calibration verification 10% or every 2 hours.	1 spike for every batch. Method of standard additions for AA if spikes indicate problem.	Interference check sample for ICP 2 x /8 hours. Laboratory control sample with each batch.	1 duplicate/ batch. For AA, duplicate injections.		
PSD 40 CFR Part 58 Appendix B				For SO_2, NO_2, O_3, and CO, response check 1/ sampling quarter. For TSP and lead, sample flow check 1/sampling quarter. For lead, check with audit strips 1/quarter.		For TSP and lead, collocated sample 1/week or every 3rd day for continuous sampling.	For SO_2, NO_2, O_3, and CO, precision check once every 2 weeks.

Table AE2. QC Requirements for Programs							
Potential Problems:	**Contamination**	**Calibration Drift**	**Bias**		**Imprecision**		
QC Samples to Identify Potential Problems:	**Blanks**	**Calibration Check Samples**	**Spike**	**Standard**	**Replicate**	**Collocated**	**Other**
SLAMS 40 CFR Part 58 Appendix A				For automated SO_2, NO_2, O_3, and CO response check for at least 1 analyzer (25% of all) each quarter. For manual SO_2 and NO_2, analyze audit standard solution each day samples are analyzed (at least 2x/quarter). For TSP, PM_{10}, and lead, sample flow rate check at least 1 analyzer/quarter (25% of all analyzers). For lead, check with audit strips 1/quarter.		For manual methods, including lead, collocated sample 1/week.	For automated SO_2, NO_2, O_3, and CO, precision check once every 2 weeks.
A Rationale for the Assessment of Errors in the Sampling of Soils, by van Ee, Blume, and Starks	Preparation rinsate blanks and field rinsate blanks discussed, but no frequency given.			At least 21 pairs of field evaluation samples. At least 20 pairs of external laboratory evaluation samples if estimating components of variance is important.	At least 20 pairs or 10 triples of field duplicates. At least 20 pairs of preparation splits if estimating variance is important.		

Table AE3. QC Requirements for Methods

Potential Problems:	Contamination	Calibration Drift	Bias		Imprecision		
QC Samples to Identify Potential Problems:	Blanks	Calibration Check Samples	Spike	Standard	Replicate	Collocated	Other
SW-846 Method 7000 (Proposed Update I) Atomic Absorption	Reagent blank as part of daily calibration.	Mid-range standard analyzed every 10 samples.	1 spiked matrix sample analyzed every 20 samples or analytical batch. Method of standard additions required for difficult matrices.		1 replicate sample every 20 samples or analytical batch; 1 spiked replicate sample for each matrix type.		
SW-846 Method 8000 (Proposed Update I) Gas Chromatography	Reagent blank before sample analysis and for each batch of up to 20 samples.	A daily calibration sample analyzed.	1 matrix spike for each batch of up to 20 samples.	QC check sample required, but frequency not specified.	1 replicate or matrix spike replicate for each analytical batch of up to 20 samples.		
503.1 Volatile Aromatic and Unsaturated Organic Compounds in Water by Purge and Trap GC (from PB89-220461)	Laboratory reagent blank with each batch. Field reagent blank with each set of field samples.	Calibration verified daily with 1 or more calibration standards.	Laboratory-fortified blank with each batch or 20 samples.	QC sample analyzed at least quarterly.	Samples collected in duplicate. Laboratory- fortified blanks analyzed in duplicate at least quarterly.		
200 Atomic Absorption Methods (from EPA-600-4-79-020)	Reagent blank at least daily.	Daily checks at least with reagent blank and 1 standard. Verification with an additional standard every 20 samples.		Analysis of an unknown performance sample at least once per year.			
624-Purgeables 40 CFR Part 136, Appendix A	Reagent water blank daily.	Analyze BFB every day analyses are performed.	Spike a minimum of 5% of samples.	Surrogate standards used with all samples. Analyze QC check samples as 5% of analyses.			

Table AE3. QC Requirements for Methods

Potential Problems:	Contamination	Calibration Drift	Bias		Imprecision		
QC Samples to Identify Potential Problems:	Blanks	Calibration Check Samples	Spike	Standard	Replicate	Collocated	Other
1624-Volatile Organic Compounds by Isotope Dilution GC/MS 40 CFR Part 136, Appendix A	Blanks analyzed initially and with each sample lot.	Aqueous standard with BFB, internal standards, and pollutants is analyzed daily. A standard used to compare syringe injection with purge and trap.	All samples spiked with labeled compounds.		8 aliquots of the aqueous performance standard analyzed initially.		
TCLP-Fed. Reg., Vol 55, No. 126 Friday, June 29, 1990	1 blank for every 20 extractions.		1 matrix spike for each waste type and for each batch.				
SW-846 Method 6010 (Proposed Update I) Inductively Coupled Plasma Atomic Emission Spectroscopy	At least 1 reagent blank with every sample batch.	Verify calibration every 10 samples and at the end of the analytical run with a blank and standard.	Spiked replicate samples analyzed at a frequency of 20%.	An interference check sample analyzed at the beginning and end of each run or 8-hour shift.	1 replicate with every batch or 20 samples. Also spiked replicates analyzed, as discussed under "Spikes."		

AE2.4 References

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APPENDIX F

SOFTWARE FOR THE DEVELOPMENT AND PREPARATION OF A QUALITY ASSURANCE PROJECT PLAN

This appendix contains three sections:

AF1. an overview of the potential need for software in QAPP preparation,
AF2. information on existing software, and
AF3. information on software availability and sources.

The information presented in this appendix on various types of software that may be useful in constructing a QAPP is only a subset of what is available to the QA Manager. Mention of certain products or software does not constitute endorsement, only that some potentially useful material can be obtained from those products.

AF1. OVERVIEW OF POTENTIAL NEED FOR SOFTWARE IN QAPP PREPARATION

The general structure of a QAPP can be adapted easily for an organization's needs by automating some of the components of the QAPP. Several commercial and governmental organizations have produced software to facilitate this automation. The software needs are categorized under the four classes of QAPP elements. Within each category is an explanation of the general functions of the software that could prove useful in preparing, reviewing, or implementing a QAPP. In addition, the QAPP elements to which the software applies are listed.

AF1.1 Class A: Project Management

This type of software can be used to produce planning documentation and preparation of the QAPP document. In addition, this type of software can be used to produce other project documentation such as Standard Operating Procedures (SOPs), Quality Management Plans (QMPs), and Data Quality Objectives (DQOs) reports.

GENERAL SOFTWARE FUNCTIONS	QAPP ELEMENTS
Provides the user guidance on what to address in each QAPP element and serves as a template for the production of the QAPP document.	All elements
Generates flowcharts to assist in preparing project organization charts and in illustrating processes that occur in the project, such as sample collection and analysis or data management.	A4, B10
Identifies training or certification required for personnel in given program areas.	A8
Provides applicable regulatory standards (e.g., action or clean-up levels) for the various program areas (e.g., air, water, and solid waste).	A6
Provides guidance on implementing the DQO Process.	A5, A6, A7

AF1.2 Class B: Measurement and Data Acquisition

This type of software can be used to assist in the design of a sampling plan. In addition, this software can provide information on analytical methods and sample collection and handling.

GENERAL SOFTWARE FUNCTIONS	QAPP ELEMENTS
Assists in the development of sampling designs that will meet specified DQOs. The software should handle a variety of general design types with and without compositing, such as simple random sampling, grid sampling, and stratified sampling.	B1
Provides information on analytical procedures and sampling methods for various contaminants and media. This software provides QC data for the analytical method (method detection limit [MDL], precision, and bias), references to standard methods, and SOPs (where calibration and maintenance information could be found).	B2, B4, B5, B6, B7
Assists in tracking samples and assisting with documenting sample handling and custody.	B3
Integrates QC design and sampling design to meet DQOs and facilitate Data Quality Assessment (DQA).	B1, B5, B10

AF1.3 Class C: Assessment and Oversight

This software can assist in assessment and oversight activities.

GENERAL SOFTWARE FUNCTIONS	QAPP ELEMENTS
Produces checklists, checklist templates, or logic diagrams (such as problem diagnostics) for Technical Systems Audits (TSAs), Management Systems Reviews (MSRs), and Audits of Data Quality (ADQs).	C1
Perform DQA and facilitates corrective actions during the implementation phase as preliminary or field screening data become available.	C1, C2

AF1.4 Class D: Data Validation and Usability

This software assists in validating data and assessing its usability.

GENERAL SOFTWARE FUNCTIONS	QAPP ELEMENTS
Assists in performing data validation and usability.	D2
Assists in performing data quality assessment.	D3

AF2. EXISTING SOFTWARE

This information is summarized as a list of identified software; a more detailed description of each item is found in Section AF3. A variety of commercial software packages are available to assist in statistical analysis, laboratory QC, and related activities, but this appendix focuses on software used specifically by those preparing, implementing, and reviewing QAPPs. See Table AF.1 for a summary of the software described below.

AF2.1 Template Software

Several applications have been implemented in word-processing software that provide guidance on how to complete each QAPP element and a template for the discussion portion. Four examples of these applications are:

- Quality Integrated Work Plan Template (QIWP) (Section AF3, No. 2)
- QAPP Template (Section AF3, No. 3)
- Region 5 QAPP Template (Section AF3, No. 4)

A more sophisticated application, Quality Assurance Sampling Plan for Environmental Response (QASPER), was identified that combines a template with links to a variety of lists that provide the user response options (Section AF3, No. 1).

AF2.2 Flowcharting Software

Various flowcharting software is commercially available. One example found in QA/QC literature is allCLEAR III (Section AF3, No. 5). Other more sophisticated packages link the flowchart diagrams to active databases or simulation modeling capabilities.

AF2.3 Regulatory Standards Software

This software provides regulatory limits under the various statutes for a wide variety of contaminants:

- Environmental Monitoring Methods Index (EMMI) (Section AF3, No. 6)
- Clean-Up Criteria for Contaminated Soil and Groundwater (an example of a commercially available product) (Section AF3, No. 8)

AF2.4 Sampling Design Software

A variety of software has been developed to assist in the creation of sampling designs:

- Decision Error Feasibility Trials (DEFT) (Section AF3, No. 9)
- GeoEAS (Section AF3, No. 10)
- ELIPGRID-PC (Section AF3, No. 11)
- DQOPro (Section AF3, No. 12)

In addition, there are many statistical packages that support sampling design.

AF2.5 Analytical Methods Software

This software provides information on method detection limits (MDLs) and method summaries for a wide variety of analytical methods:

- EMMI (Section AF3, No. 6)
- EPA's Sampling and Analysis Methods Database (Section AF3, No. 7)

AF2.6 Data Validation Software

The Research Data Management and Quality Control System (RDMQ) (Section AF3, No. 13) is a data management system that allows for the verification, flagging, and interpretation of data.

AF2.7 Data Quality Assessment Software

Several software packages have been developed to perform data quality assessment tasks. Examples of this software include:

- DataQUEST (Section AF3, No. 14)
- ASSESS (Section AF3, No. 15)
- RRELSTAT (Section AF3, No.16)

Note that most commercially available statistical packages (not listed above) perform a variety of DQA tasks.

AF2.8 QAPP Review

QATRACK (Section AF3, No. 17) is used to track QAPPs undergoing the review process.

Table AF1. Software Available to Meet QAPP Development Needs

SOFTWARE NEED	QAPP ELEMENTS	EXISTING SOFTWARE
PROJECT MANAGEMENT		
Template guidance	All elements	QASPER, QWIP, QAPP Template
Flowcharting	A4, B10	allCLEAR III
Regulatory standards	A6	EMMI, Clean-Up Criteria for Contaminated Soil and Groundwater
MEASUREMENT AND DATA ACQUISITION		
Sample design	B1	DEFT, GeoEAS, ELIPGRID-PC, DRUMs, DQOPro, miscellaneous statistical packages
Analytical and sampling procedures	B2, B4, B5, B6, B7	EMMI, EPA's Sampling and Analysis Database
Integrating QC design and sampling design to meet DQOs and facilitate DQA.	B1, B5, B10	DQOPro

SOFTWARE NEED	QAPP ELEMENTS	EXISTING SOFTWARE
ASSESSMENT AND OVERSIGHT		
Data Quality Assessment	C1, C2	DataQUEST, ASSESS, RRELSTAT
DATA VALIDATION AND USABILITY		
Data validation	D2	RDMQ
Data Quality Assessment	D3	DataQUEST, ASSESS, RRELSTAT, miscellaneous statistical packages

AF3. SOFTWARE AVAILABILITY AND SOURCES

The wide variety of existing software has potential to meet the needs identified for preparing QAPPs. As illustrated in Table AF.1, at least one example of a software tool was identified that could potentially be applied to aspects of QAPP preparation or implementation for all but three of the need areas. The capabilities of the existing software should match the QAPP needs, as most of the software was developed for use with a QAPP or for environmental data collection or analysis. Software not designed for these uses could be modified or used to form the basis of an application that is more tailored to QAPP preparation or implementation.

AF3.1 Quality Assurance Sampling Plan for Environmental Response (QASPER), Version 4.0

QASPER allows the creation and editing of a Quality Assurance sampling plan for environmental response. The plan template consists of 11 sections: (1) title page, (2) site background, (3) data use objectives, (4) sampling design, (5) sampling and analysis, (6) SOPs, (7) QA requirements, (8) data validation, (9) deliverables, (10) project organization and responsibilities, and (11) attachments. While preparing the plan, the user may enter the required information or select from the options provided in a variety of "picklists." The picklists cover topics such as holding times, methods, preservatives, and sampling approaches. The user may add or delete options from the picklists. QASPER also provides various utility functions such as backing up, restoring, exporting, and importing a plan. Output may be directed to a file or a printer. Contact: EPA, (732) 906-6921, *Quality Assurance Sampling Plan for Environmental Response (QASPER Version 4.0 User's Guide;* latest version is *QASPER Version 4.1,* January 1995.

AF3.2 Quality Integrated Work Plan (QIWP) Template for R&D and Monitoring Projects

The QIWP template is a tool designed to assist with planning, managing, and implementing a specific monitoring or R&D project. The QIWP template is formatted with comment boxes that provide guidance on the information to provide in each section. When activated, the text in the comment boxes will appear on screen; however, they will not appear in a printout. An asterisk indicates where the user should begin entering the discussion for each section. The QIWP document control format is already set up in the template header. When a particular element is considered not applicable, the rationale for that decision must be stated in response to that element. Once the user is satisfied with the information entered under all elements of the template, the resulting printout is the combined project work plan and QA plan. In addition, a printout of the QIWP template, prior to entering project related information, can be used as a checklist for planning and review purposes. Other software packages available are the QWIP Template for Model Development Projects and the QWIP Template for Model Application Projects. Contact: EPA, (919) 541-3779 and North American Research Strategy for Tropospheric Ozone (NARSTO) homepage.

AF3.3 Region 2 QAPP Template

This package contains an annotated template containing instructions for completing each section of the QAPP. The users are also instructed where to insert their discussions within the template. After completing the QAPP, the italicized instructions are not printed, leaving only the preparer's discussion. In addition, a table of contents is automatically generated. The template describes the information that should be provided under the main topics of project management, measurement/data acquisition, data, assessment/oversight, and references. The project management section covers the introduction, goals of the project, organization of the project participants and of QA, and DQOs. The measurement/data acquisition section discusses the topics to address to describe the statistical research design and sampling. This section also covers the elements related to sample analysis: description of the instrument, calibration, QC, consumables, and preventative maintenance. The data section provides for a discussion of the data management procedures. The assessment/oversight section covers audits and QA reports. The next section is a list of references. Finally, six tables are provided as examples for displaying information on the following topics: (1) measurement quality criteria; (2) sample collection, handling, and preservation; (3) instrument data and interferences; (4) instrument calibration, (5) QC checks; and (6) preventive maintenance. Contact: EPA, (401) 782-3163, or (503) 754-4670.

AF3.4 Region 5 QAPP Template

This software consists of two model documents (one for Superfund sites and one for RCRA sites) that describe the preparation of a QAPP in a series of elements. Each element contains two types of information: (1) content requirements that are presented as smaller text and (2) structural guidance that is presented as larger text and headed by the appropriate section number. This information is intended to show to the QAPP preparer the requirements that must be described in each element and the level of detail that is typically needed to gain Region 5 approval. Example text is provided that should be deleted and replaced with the specific site information.

A TSCA Model Plan template is also available that attempts to be a comprehensive guide to all the data gathering activities for Fiscal Year 94 Title IV grantees. In this template, headers are provided in "background" format, and text that may apply to specific situations is in an italic font. Open spaces indicate where the preparer's input is required. Contact: EPA, (312) 886-6234.

AF3.5 allCLEAR III

This software enables the creation of simple process diagrams, organizational charts, or decision trees. It also creates diagrams from text outlines, spreadsheets, and database information. Contact: American Society for Quality Control Quality Press, Publications Catalogue, (800) 248-1946.

AF3.6 Environmental Monitoring Methods Index (EMMI)

This software consists of an analytical methods database containing more than 4,200 analytes, 3,400 analytical and biological methods, and 47 regulatory and nonregulatory lists. EMMI cross-references analytes, methods, and lists and has information about related laws, organizations, and other chemical databases. This information does not include measurement method performance such as precision and bias. Contact: DynCorp Environmental Technical Support, (703) 519-1222.

AF3.7 EPA's Sampling and Analysis Methods Database, 2nd Edition

This software has a menu-driven program allowing the user to search a database of 178 EPA-approved analytical methods with more than 1,300 method and analyte summaries. The database covers industrial chemicals, pesticides, herbicides, dioxins, and PCBs and focuses on water, soil matrices, and quality parameters. The software generates reports that are stand-alone documents that can be browsed, printed, or copied to files. Each report contains information for initial method selection such as applicable matrices, analytical interferences and elimination recommendations, sampling and preservation requirements, MDLs, and precision, accuracy, and applicable concentration ranges. Contact: Radian Corporation, (512) 454-4797.

AF3.8 Clean-Up Criteria for Contaminated Soil and Groundwater, 2nd edition

This software consists of a one-volume document and diskette summarizing cleanup criteria developed by EPA, all 50 State regulatory agencies, and select countries outside the United States. Contact: ASTM Publications Catalogue, (610) 832-9585, http://www.astm.org.

AF3.9 Decision Error Feasibility Trials (DEFT)

This package allows quick generation of cost information about several simple sampling designs based on the DQO constraints. The DQO constraints can be evaluated to determine their appropriateness and feasibility before the sampling and analysis design is finalized.

This software supports the *Guidance for the Data Quality Objectives Process*, EPA QA/G-4, that provides general guidance to organizations on developing data quality criteria and performance specifications for decision-making. The *Data Quality Objectives Decision Error Feasibility Trials (DEFT) User's Guide*, contains detailed instructions on how to use DEFT software and provides background information on the sampling designs that the software uses. Contact: EPA, (202) 564-6830.

AF3.10 GeoEAS

Geostatistical Environmental Assessment Software (GeoEAS) is a collection of interactive software tools for performing two-dimensional geostatistical analyses of spatially distributed data. Programs are provided for data file management, data transformations, univariate statistics, variogram analysis, cross-validation, kriging, contour mapping, post plots, and line/scatter plots. Users may alter parameters and re-calculate results or reproduce graphs, providing a "what if" analysis capability.

This software and a user's guide can be downloaded through the Office of Research and Development (ORD) World Wide Web site at http://www.epa.gov/ORD or http://www.epa.gov/ORD/nerl.htm. Contact: *GEO-EAS 1.2.1 User's Guide*, EPA/600/8-91/008, April, 1991, EPA, (702) 798-2248.

AF3.11 ELIPGRID-PC

ELIPGRID-PC calculates the probabilities related to hitting a single hot spot. The user has the following options: (1) calculating the probability of detecting a hot spot of given size and shape when using a specified grid, (2) calculating the grid size required to find a hot spot of given size and shape with specified confidence, (3) calculating the size of the smallest hot spot likely to be hit with a specified sampling grid, (4) calculating a grid size based on fixed sampling cost, and (5) displaying a graph of the probability of hitting a hot spot versus sampling costs. Contact: *ELIPGRID-PC: UPGRADED VERSION*, Oak Ridge National Laboratory/TM-13103, (970) 248-6259.

AF3.12 DQOPro

This software consists of a series of three computer programs that calculate the number of samples needed to meet specific DQOs. DQOPro provides answers for three objectives: (1) determining the rate at which an event occurs, (2) determining an estimate of an average within a tolerable error, and (3) determining the sampling grid necessary to detect "hot-spots." Contact: Radian International, (512) 454-4797.

AF3.13 Research Data Management and Quality Control System (RDMQ)

This software is a data management system that allows for the verification, flagging, and interpretation of data. RDMQ is a menu-driven application with facilities for loading data, applying QC checks, viewing and changing data, producing tabular and graphical reports, and exporting data in ASCII files. RDMQ provides a shell environment that allows the user to perform these tasks in a structured manner. Contact: Environment Canada, (416) 639-5722, or EPA, (919) 541-2408.

AF3.14 DataQUEST

This tool is designed to provide a quick and easy way for managers and analysts to perform baseline Data Quality Assessment. The goal of the system is to allow those not familiar with standard statistical packages to review data and verify assumptions that are important in implementing the DQA Process. This software supports the *Guidance for Data Quality Assessment*, EPA QA/G-9, that demonstrates the use of the DQA Process in evaluating environmental data sets. Contact: EPA, (202) 564-6830.

AF3.15 ASSESS 1.01a

This software tool was designed to calculate variances for quality assessment samples in a measurement process. The software performs the following functions: (1) transforming the entire data set, (2) producing scatter plots of the data, (3) displaying error bar graphs that demonstrate the variance, and (4) generating reports of the results and header information. Contact: EPA, (702) 798-2367.

AF3.16 QATRACK

This Microsoft Access software provides a database that tracks QAPPs requiring approval. Data are entered into QATRACK during the assistance agreement start-up stage, as soon as the QA manager reviews and signs the agreement. Users can edit the data, query the database to perform data reviews, and archive files once the QAPP is approved. Contact: EPA, (919) 541-2408.

APPENDIX G

ISSUES IN DATA MANAGEMENT

AG1. INTRODUCTION

EPA QA/G-5 provides guidance on many different operations that involve generating, collecting, manipulating, and interpreting environmental data. These activities include field sampling, sample handling and storage, laboratory analysis, modeling, data storage and retrieval, and Data Quality Assessment. All these activities generate data or require data to be manipulated in some way, usually with the aid of a computerized data management tool such as a database, spreadsheet, computer model, or statistical program.

This appendix expands the guidance currently provided in EPA QA/G-5, Section B10, Data Management. Guidance is provided on Quality Assurance (QA) considerations and planning for the development, implementation, and testing of computer-based tools that perform the data management aspects of the overall environmental project described in the Quality Assurance Project Plan (QAPP). These data management aspects include data storage, data acquisition, data transformations, data reduction, modeling, and other data management tasks associated with environmental data collection projects. This guidance can be used for applications developed in-house or for those developed using commercial software. It can be used for systems of different sizes, from individual spreadsheet applications to large integrated systems. The amount of planning and documentation involved are tailored according to the use of the data and the size and complexity of the application.

This appendix incorporates into EPA QA/G-5 the QA elements of guidance from the EPA Office of Information Resources Management (OIRM) and applicable industry standards, such as those of the Institute of Electronic and Electrical Engineers, relating to development of information and data management systems. Because data and information system development projects differ widely in many different respects, this appendix does not attempt to address the low-level details of planning, implementation and assessment nor does it provide step-by-step procedures to follow when developing a data management system. These details are left to other EPA guidance documents (See Section AG2.4), national consensus standards, and the best judgement of the personnel on each project.

AG2. REGULATORY AND POLICY FRAMEWORK

This section provides a brief overview of the legislation, policies, standards and guidelines most applicable to the development of EPA data management and information systems. Sections AG2.1 and AG2.2 of this overview are intended to provide the QAPP preparer (specifically the preparer of the data management section) with a general understanding of the relevant agency-level policies, Sections AG2.3 and AG2.4 provide a reference for the major guidance documents containing more specific and detailed information on development of data management systems.

AG2.1 Legislation

The following is a summary of the major legislative policies that pertain to information technology and the development of data management systems. The two most relevant pieces of legislation are:

(1) the Paperwork Reduction Act (PRA) of 1980 (P.L. 96-511) as amended in 1986 (P.L. 99-500) and 1995 (P.L. 104-13), and

(2) the Clinger-Cohen Act of 1996 (P.L.-104-208). (Note that the Clinger-Cohen Act is the amended title for the Information Technology Management Reform Act and the Federal Acquisition Reform Act of 1996 (P.L. 104-106)).

The overall purpose of the PRA is to reduce paperwork and enhance the economy and efficiency of the government and private sector by improving Federal information policy development and implementation. The PRA establishes a broad mandate for executive agencies to perform their information activities in an efficient, effective, and economical manner. The 1995 amendments established several broad objectives for improving the management of Federal information resources. These objectives include maximizing the utility of information, improving the quality and use of information to strengthen decision making, and establishing uniform resource management policies.

The Clinger-Cohen Act (CCA) sets forth requirements for the Office of Management and Budget (OMB) and the individual executive agencies. OMB responsibilities include promoting and improving the acquisition, use, and disposal of information technology by the Federal Government to improve the productivity, efficiency, and effectiveness of Federal programs. In addition, the CCA requires each agency to design and implement a process for maximizing the value and assessing and managing the risks of information technology acquisitions. The CCA also requires each agency to utilize the same performance- and results-based management practices as encouraged by OMB.

AG2.2 Policy Circulars and Executive Orders

Circular A-130 implements OMB authority under the PRA and sets forth the policy that applies to the information activities of all the executive agencies. The policies include requirements for information management planning as well as information systems and information technology management. Part of the information management policy is that agencies, when creating or collecting data, need to plan from the outset how to perform the following data management functions: (1) data processing and transmission, (2) data end use and integrity protection, (3) data access, (4) data dissemination, (5) data storage and retrieval, and (6) data disposal. In addition, these planning activities need to be documented. The information systems and information technology management policies describe an information system life cycle that is defined as the phases through which an information system passes. These phases are typically characterized as initiation, development, operation, and termination. However, no specific number of phases is set, and the life cycle management techniques that agencies use may vary depending on the complexity and risk inherent in the project. In addition, the division between the phases of the system life cycle may not be distinct.

Current implementation of the CCA comes through Executive Order 13011, which outlines the executive agencies. The agencies are to strengthen the quality of decisions about the use of information resources to meet mission needs and establish mission-based performance measures for information systems. In addition, to establish agency-wide and project-level management structures and processes responsible and accountable for managing, selecting, controlling, and evaluating investments in information systems.

G2.3 Federal Information Processing Standards

The National Institute of Standards and Technology (NIST) develops standards for Federal computer systems. NIST issues these standards and guidelines as Federal Information Processing Standards (FIPS) for government-wide use. NIST develops FIPS when there are compelling Federal government requirements (such as for security and interoperability) and there are no acceptable industry standards or solutions. FIPS publications include standards, guidelines, and program information documents in the following seven subject areas: (1) general publications, (2) hardware standards and guidelines, (3) software standards and guidelines, (4) data standards and guidelines, (5) computer security standards and guidelines, (6) operations standards and guidelines, and (7) telecommunications standards. Additional information about FIPS, including ordering information and a list and description of the individual documents, is available online using the World Wide Web (WWW) at the following Uniform Resource Locator (URL) address: http//www.nist.gov/itl/div879/pubs/.

AG2.4 EPA Guidance

EPA's Office of Information Resources Management (OIRM), which has the primary functional responsibility for Information Resources Management (IRM) policy development and overall management of EPA's IRM program, has published several IRM guidance documents. The *Information Resources Management Policy Manual 2100* establishes a policy framework for managing information resources in the Agency. The document is intended to provide a structure for the implementation of legislation concerning the management of Federal information resources such as the PRA. Also, the manual establishes the authorities and responsibilities under which the OIRM will function. The Policy Manual consists of twenty chapters that cover subjects such as software management, information security, system life cycle management, and information and data management. The Policy Manual can be obtained online using the WWW at the following URL address: http://www.epa.gov/irmpoli8/.

The *System Design and Development Guidance* document provides a framework that Agency managers can use to document a problem and justify the need for an information-system-based solution. The document also provides guidance for identifying solutions to specified problems and for information system development. The guidance consists of three volumes (A, B, and C). Volume A provides a method for documenting the need for an information system and developing an initial system concept that describes the inputs, outputs, and processes of the proposed system. Volume B provides guidance for developing design options that satisfy the initial system concept developed in Volume A. Volume B also gives guidance for selecting the most cost-effective solution. Volume C describes the system-design and development process (and the required associated documentation) and outlines a software management plan that is used to ensure the quality of EPA software design, development, implementation, and maintenance efforts. This document can be obtained online using the WWW at the following URL address: http://www.epa.gov/irmpoli8/.

Additional EPA guidance documents pertaining to information system development, operations, and maintenance are listed in Section G4, References. Up-to-date OIRM documents can be obtained online using the WWW at the following URL address: http://www.epa.gov/irmpoli8/.

Another source of guidance is EPA Quality Assurance Division's (QAD) Development Management System Template. The template includes a description of the roles of management in planning for the development of data management systems. The responsible project officer or contracting officer representative outlines a management scheme based upon the planning and documentation activities that satisfy OIRM policy or an organization's Quality Management Plan. The project manager works with the quality assurance manager to identify the tasks, work products, and management procedures for the project.

AG3. QA PLANNING FOR INFORMATION SYSTEMS

Data generated or managed by an information system must be defensible and appropriate to their final use or the conclusions to be drawn from the data. To help ensure that data will be defensible, project teams should include adequate QA planning in the development of data management or other information systems. There are three elements to QA planning for data management:

- *Needs Analysis*—identifying applicable qualitative and quantitative requirements and establishing corresponding quality goals.
- *Planning and Implementing*—implementing an appropriate planning and management framework for achieving these goals.
- *Verification*—testing and auditing to determine that the established goals are being met.

AG3.1 Quality Assurance Needs Analysis

The type and magnitude of the QA effort needed in developing a new information system depends on the qualitative and quantitative criteria that the data must meet and on the complexity and magnitude of the project. Other specific concerns such as security and system performance also help define the QA program requirements. Only by establishing the ultimate needs and objectives for data quality in the early planning stages can appropriate decisions be made to guide the system development process to a successful conclusion.

AG3.1.1 Quantitative and Qualitative Criteria

Considerations similar to those in the Data Quality Objectives (DQO) framework can be used to identify and define the general criteria that computer-processed data must meet. For example, very high standards must be set for information systems that generate or manage data supporting Congressional testimony, for developing new laws and regulations, for litigation, or for real-time health and safety protection. More modest levels of defensibility and rigor are required for data used for technology assessment or "proof of principle," where no litigation or regulatory actions are expected. Still lower levels of defensibility apply to basic exploratory research requiring extremely fast turn-around, or high flexibility and adaptability. In this case, the work may have to be replicated under tighter controls or the results carefully reviewed prior to publication. By analyzing the end-use needs, appropriate criteria can be established to guide the information system development process.

More detailed criteria can also be developed to address the specific ways in which computer-generated or computer-processed results can be in error. The following are some specific questions to be asked when quantitative or qualitative objectives are being defined:

- What is the required level of accuracy/uncertainty for numerical approximations?
- Are the correct data elements being used in calculations (e.g., the correct "cell" in a spreadsheet)?
- Have the appropriate statistical models, mathematical formulas, etc. been chosen?
- What "chain-of-custody" requirements pertain to the data and results?

AG3.1.2 Project Scope, Magnitude, and Complexity Criteria

Software and systems development projects vary widely in scope and magnitude. Application of effective management controls (including the QA program) are critical for successful performance on large projects. Risks associated with large, complex projects commonly include overruns and schedule delays. The integrity of results can also be compromised by rushing to complete an overdue project. Table G1 summarizes risks as a function of project size or scope.

Table AG1. Project Scope and Risks

PROJECT SCOPE	POTENTIAL RISKS
Large Project (information system development is a major component)	• Major budget overruns • Schedule slippage • Unusable system or data • Public relations problems
Medium Size Project (including projects in which an information system is not the major component)	• Budget overrun • Schedule slippage • Uncertain data quality
Small Projects (including projects in which computer-related development is a minor component)	• Lack of confidence in data • Lack of data traceability • Schedule slippage
Projects with ad hoc software development and data management practices (no QA program)	• Lack of confidence in data • Inefficient use of time and resources

EPA OIRM's Chapter 17, System Life Cycle Management, in *Information Resources Management Policy Manual*, provides a similar rationale for categorizing information systems. Four system types are defined based on the significance of the risk assessment for the Information System. Major factors included in this risk assessment are the importance of the data, the cost of the system, and the organizational scope of the system. For the purposes of a management review, OIRM defines Information Systems using the following classes:

- A Major Agency System is a system that is mission critical for multiple AAships or Regions or Agency Core Financial System or has a life cycle cost greater than $25 million or $5 million annually.
- A Major AAship or Regional System is a system that is mission critical for one AAship or Regional Office or has a life cycle cost greater than $10 million or $1 million annually.
- A Significant Program Office System is a system that is mission critical in one Program Office or has a life cycle cost greater than $2 million or $100,000 annually.
- A Local Office or Individual Use System is a system for local office or individual user or costs less than $100,000 annually for one project.

AG3.1.3 Other Quality Issues

While the issues discussed in the preceding two sections are of key importance in determining the necessary level of the QA effort, there are many individual quality issues that should not be overlooked in defining the requirements for a particular project. These issues should be addressed in project planning, implementation, and testing. Some commonly encountered issues are discussed in the following text.

AG3.1.3.1 *Security Issues*. There are many different types of threats to data security and communications. Common concerns include viruses, hackers, and interception of e-mail. If these concerns apply for a particular system, the following issues should be addressed during system planning. Tests and audits may be planned to assess system vulnerability. Some of the management and QA techniques that can be employed in this assessment include:

- reviewing the project requirements documentation to ensure that security issues are included among project requirements;
- reviewing the testing documents to ensure that security features are adequately and thoroughly tested; and
- planning audits to be conducted by security personnel outside the immediate project team.

AG3.1.3.2 *Communication Issues.* Most business computers are extensively interconnected through the Internet, agency networks, or local networks. Computer communications is a rapidly changing area of technology. Consequently, communications software and hardware are frequently the source of problems to developers and users. Some communication issues that might be addressed in system planning, design, and testing include the following:

- adequately defining the communication interfaces;
- thoroughly testing the communications hardware and software, including "stress testing" under high load and adverse conditions; and
- conducting a beta test that encompasses users with a variety of different hardware and communications connections.

AG3.1.3.3 *Software Installation Issues.* Many software packages are being developed and distributed by the Agency to run on the individual user's personal computer. Many of these use auto-installation routines that copy files into various directories and modify system initialization and registry files. Planning the necessary systems requirements should address the following considerations:

- testing on as many different platforms as possible including various combinations of processors, memory sizes, video controllers, and printers (Beta Testing can be extremely helpful for this);
- including an "uninstall" program that not only deletes files, but also properly removes entries in the initialization and registry files; and
- ensuring that both the “setup” and “uninstall” routines are thoroughly tested and debugged before release.

AG3.1.3.4 *Response Time Issues.* A frequently overlooked aspect of computerized systems is the impact of of system load and the resulting effect on response time. Response time is important not only for real-time data acquisition and control systems, but also for interactive user interfaces. It is a good idea to establish quantitative objectives for response time performance for all interactive and real-time systems. These goals must be explicit and testable. A typical specification might be that the user should not wait longer than *x* seconds for a response after submitting a request to the program.

AG3.1.3.5 *Compliance with EPA and other Federal Policies and Regulations*. Since individual managers and scientists may not track information systems regulations and policy, requirements should be determined at project inception. Some of the more important policies have been summarized in Section AG2 of this appendix. Many of the policies and guidances are aimed at ensuring individual project success, while others are intended to foster Agency-wide goals, including consistency of hardware and software platforms, purchasing economies, and security. For example, EPA’s Acquisition Regulation requires Agency contractors to collect and review OIRM’s most recent policies by downloading the most current documents available online at OIRM’s WWW Site.

AG3.2 System Development Planning

Proper planning, execution, and QA protocols are vital to the success of projects involving information systems development, software development, or computer data processing. The project management team should work closely with the responsible QA staff to implement a program that best suits the needs of the individual project. A few of the issues to be addressed include the level of documentation required, schedule, personnel assignments, and change control. The following section describes a commonly used planning framework and associated documentation that is based on the widely recognized software- or system-development life cycle.

AG3.2.1 <u>System Development Life Cycle</u>

Software and information system development projects tend to evolve in distinct phases. Recognition of this fact can be helpful in planning and managing a new project. Table G2 outlines eight commonly recognized stages in the system development life cycle, along with typical activities and documentation for each stage. This approach can be modified to meet the needs of individual projects.

Table AG2. Software Development Life Cycle

LIFE CYCLE STAGE	TYPICAL ACTIVITIES	DOCUMENTATION
Needs Assessment and High- Level Requirements Definition	Assessment of needs and requirements through literature search, interviews with users and other experts.	• Needs Assessment Documentation (e.g., QA Project Plan) • Requirements Document
Detailed Requirements Analysis	Listing of all inputs, outputs, actions, computations, etc. that the system is to perform. Listing of ancillary needs such as security, user interface requirements. Design team meetings.	• Detailed Requirements Document, including Performance, Security, User Interface Requirements etc. • System Development Standards
System Design	Translation of requirements into a design to be implemented.	• Design Document(s) including Technical Design (algorithms, etc.), Software/Systems Design
Implementation Controls	Coding and configuration control. Design/implementation team meetings.	• In-line comments • Change control documentation
Testing, Verification, and Validation	Verification that the system meets requirements. Verification that the design has been correctly implemented. Beta Testing (users outside team). Acceptance Testing (for final acceptance of a contracted product). Implement necessary corrective actions.	• Test Plan • Test Result Documentation • Corrective Action Documentation • Beta Test Comments • Acceptance Test Results

LIFE CYCLE STAGE	TYPICAL ACTIVITIES	DOCUMENTATION
Installation and Training	Installing data management system and training users.	• Installation Documentation • User's Guide
Operations, Maintenance, and User Support	Use of the system or data requires usage instructions and maintenance resources.	• User's Guide • Maintenance Manual or Programmer's Manual
System Retirement and Archival	Information on how data or software can be retrieved if needed.	• Project files • Final Report

AG3.2.2 Planning Documentation

Individual project and QA managers should tailor documentation to meet the specific needs of their project. References in Section AG4 such as *EPA System Design and Development Guidance* and Chapter 17, System Life Cycle Management, in *Information Resources Management Policy Manual* describe in more detail the various types of documentation related to the system life cycle planning phases. The following list describes in more detail some of the planning documentation listed in Table AG2:

- Requirements Documentation—The high-level requirements document gives an overview of the functions an information system must perform. Detailed requirements documents define all critical functions that the completed information system must support. Performance goals derived from analysis of the project's DQOs should be included among the requirements. In addition, frequently overlooked issues such as those described in Section AG3.1.3 should be addressed. Requirements documentation should be reviewed by the end-user, if possible, to ensure that critical functions and other requirements have not been overlooked.

- Design Documentation—Design documents are used to plan and describe the structure of the computer program. These are particularly important in multi-programmer projects in which modules written by different individuals must interact. Even in small or single-programmer projects, a formal design document can be useful for communication and for later reference.

- Coding Standards or SOPs—These may apply to a single project, an entire organizational Branch, or other functional group. Uniform standards for code formats, subroutine calling conventions, and in-line documentation can significantly improve the maintainability of software.

- Testing Plans—Testing, which is discussed in Section AG3.3, must be planned in advance and must address all original requirements and performance goals. Specific procedures for the corrective action and retesting process should be described in QA planning documents and implemented in the Testing Plan.

- Data Dictionary—A data dictionary can be useful to developers, users, and maintenance programmers who may need to modify the system later. The data dictionary is often developed before code is written as part of the design process. The dictionary should be updated as necessary when new elements are added to the data structure. A data dictionary need not be a separately written document. For example, the record definition files required for many database systems can serve this purpose, provided that they are available in a form that is readily accessible to the user or maintenance programmer.

- User’s Manual—The user's manual can often borrow heavily from the requirements document because all of the software's functions should be specified there. The scope of the user’s manual should take into account such issues as the level and sophistication of the intended user and the complexity of the interface. Online help can also be used to serve this function.

- Maintenance Manual—The maintenance manual’s purpose is to explain a program's logic and organization for the maintenance programmer. This manual should also contain crucial references documenting algorithms, numerical methods, and assumptions. Instructions on how to rebuild the system from source code must be included. The maintenance manual will often borrow heavily from the design manual.

- Source Code—It is usually not necessary to print the source code in hard copy form unless needed for a specific purpose. However, it is very important to archive computer-readable copies of source code according to the policies of each Office, Region, National Center, or Laboratory.

AG3.3 Audits and Testing

As with any project involving generation or handling of environmental data, audits can be used to verify that goals and objectives are being met. Audits of the Information System development process, audits of security, and data verification audits may be particularly helpful when conducted by personnel outside the immediate project team. Security audits by someone with expertise in this field can be valuable when data confidentiality and prevention of tampering are important issues. Data verification audits can be conducted using a known data set. Such a data set might be developed by an end-user or an outside expert to verify that the information system produces the expected results.

Testing procedures and criteria need not be specified in detail by the QA Project Plan (or equivalent document); however, the general extent and approach to testing should be described. QA planning documents for developing a new information system should generally provide the following project elements:

- a list of planned test documentation to be written;
- a description of the types of testing that will be conducted;
- a schedule for testing and audits; and
- a section on corrective actions.

The purpose of testing is not simply to detect errors but also to verify that the completed software meets user requirements. In designing any test, the “correct” or “acceptable” outputs should be known in advance, if possible. Testing should be planned in an orderly, structured way and documented. A phased approach to testing, which is often employed in larger scale information system development projects, might employ a sequence of testing procedures such as those presented in Sections AG3.3.1 through AG3.3.5.

AG3.3.1 Individual Module Tests

Individual module tests are applied to individual functions. For sequential programming languages, such as FORTRAN, BASIC, or C, individual modules might include functions and subroutines. For other types of software (e.g., spreadsheets), defining a functional module is more problematic, because the software may not be designed in a modular way. However, well-planned design strategies, such as compartmentalized design, can ease the testing effort.

AG3.3.2 Integration Tests

Integration tests are done to check the interfaces between modules and to detect unanticipated interactions between them. Integration testing should be done in a hierarchical way, increasing the number of modules tested and the subsystem complexity as testing proceeds. Each level of subsystem integration should ideally correspond to a unified subset of system functions such as the "user interface." Because all the elements may not be present, it may be necessary to develop test data sets or hardware/software test beds to conduct the tests effectively.

When problems are encountered at any level of integration or system testing, it is necessary to track the errors back to their origin, which may be any phase of the project. When the original reason for the problem is identified, all affected modules and subsystems should be corrected and retested as described in the next section.

AG3.3.3 Regression Testing

After a system module has been modified, all testing performed on the original version of the module should be repeated, including all integration tests that include the module. This reduces the chance that any new “bugs” introduced by the changes will go undetected while modifying the code to correct an existing problem. Spreadsheets may be particularly difficult to test thoroughly after changes have been made because their data dependencies are often difficult to trace. In such cases, it may be useful to have a suite of tests that can be run whenever a change is made to verify that other functions are not affected.

AG3.3.4 System Testing

Testing the full system is the ultimate level of integration testing and should be done in a realistic simulation of the end-user’s operational environment. If a detailed requirements document was written, each requirement should be tested systematically. It is often helpful for a representative end-user to participate in the system test to verify that all requirements have been implemented as intended. Elements of the special tests described in Section AG3.3.5 can be incorporated into the system test.

For some projects, the in-house system test may be the final stage of testing. For larger or more critical projects, formal acceptance tests or beta testing would follow. The system test should exercise all functions possible, and the data sets used to demonstrate the software should be as realistic as possible.

AG3.3.5 Other Special Testing

AG3.3.5.1 *Stress Testing* should be included in the system-level testing whenever a system might be load-sensitive (e.g., real-time data acquisition and control systems). The stress test should attempt to simulate the maximum input, output, and computational load expected during peak usage. The specific rates of input, output, and processing for which the system is designed are important criteria in the original requirements specification. The maximum load is a key quality indicator and should have been specified early in planning. The load can be defined quantitatively using criteria such as the frequency of inputs and outputs or the number of computations or disk accesses per unit of time. Developing an artificial test bed to supply the necessary inputs may be necessary. The test bed can consist of hardware, software, or a combination of the two that presents the system with realistic inputs to be processed. The project team can write programs to carry out this testing, or automated tools may be available commercially. Test data sets may be necessary if the software needs external inputs to run.

AG3.3.5.2 *Acceptance Testing* refers to contractually required testing that must be done before acceptance by the customer and final payment. Specific procedures and the criteria for passing the acceptance test should be listed before the test is done. A stress test is a recommended part of the acceptance test, along with thorough evaluation of the user interface.

AG3.3.5.3 *Beta Testing* refers to a system-level verification in which copies of the software are distributed outside the project group. In beta testing, the users typically do not have a supplied testing protocol to follow; instead, they use the software as they would normally and record any anomalies encountered. Users report these observations to the developers, who address the problems before release of the final version.

AG3.3.5.4 *Spreadsheet testing* is particularly difficult because of an inherent lack of readability and structure. One of the best ways to test spreadsheets is to challenge them with known data, although this can be very time-consuming. Another approach is to independently recode some or all of the spreadsheet and compare results. Software packages for spreadsheet analysis exist, but their usefulness for testing must be evaluated on a case-by-case basis.

AG3.4 Examples

The following examples present three different data management projects: a computer model , a spreadsheet, and a local-area-network-distributed database. Some of the QA, management, and testing issues peculiar to each type of project are discussed.

AG3.4.1 <u>Model Development</u>

Mathematical models are widely used in the environmental sciences. Modeling is necessary when the complexity of a particular situation makes a simple solution impossible, as when many different processes are closely coupled and occur simultaneously. Some models are used to generate data that may be used for planning and regulatory purposes.

A high level of mathematical and scientific expertise is required to develop and test the algorithms used to represent the different physical processes. This expertise is often a scarce and valuable resource. Consequently, a team approach may be used under which the senior scientific staff concentrates on developing, testing, and documenting the "core" algorithms, while support staff take care of other duties on the development project, including developing the user interface, communications, coding, and documentation. Quality Assurance planning for developing a new model should include the following:

- The staffing section of the QAPP should state the relevant qualifications for the key scientific personnel. The need for peer review of novel algorithms should be addressed if new research developments are to be incorporated in the model. Guidance documents on conducting peer review of models are referenced in Section AG4.5. The topics addressed include verification testing, model code documentation, and review of the conceptual and mathematical performance of a model.

- The end use of the data produced will dictate how exhaustively the models must be tested and the types of demonstrations that should be done before release. A regulatory model should be compared with existing regulatory models using identical or similar data sets. Environmental models such as air dispersion models can be compared with actual field data. However, care should be taken in evaluating discrepancies between model results and the field data, because differences between monitoring data and model results can arise from a variety of sources.

- Capabilities and needs of the end-users will dictate how much effort is spent developing and testing the user interface and on providing user documentation and online help functions. User interface issues should be addressed in the requirements definition, and these functions should be tested exhaustively. Beta testing results should be reviewed carefully to identify problems with the user interface.

- It may be possible to develop specific objectives for parameters such as bias and precision by modeling cases that have known and accurate results. This is usually possible only in relatively simple cases, since new models are usually developed to expand beyond the capabilities of currently available models.

AG3.4.2 Spreadsheet for Data Processing in an Ongoing Project

Spreadsheets have replaced hand calculators for many simple applications but can sometimes grow to approach the complexity of a database management system. Spreadsheets developed on an ad hoc basis are usually not tested in any systematic way and may not be archived with project data. Consequently, there can be little accountability for the correctness of calculations, even when those results are used for sensitive applications such as regulatory reporting. This lack of testing and verification can present significant risks. The following QA guidelines are suggested for spreadsheets developed or used in support of projects involving environmental data:

- QA or other project planning documents should indicate all data processing tasks to be done using spreadsheets. The origin of any spreadsheets obtained from outside the project group should be documented.

- Spreadsheets should be developed by personnel with the appropriate education and training. Personnel who maintain or use the spreadsheet should also have appropriate qualifications and training.

- Documentation should be provided for correct use and maintenance of the spreadsheet.

- Data quality audits for projects processing environmental data should examine all spreadsheets used to produce reportable data for the project. Questions such as the following should be asked during the audit:

    - Have all critical calculations performed by the spreadsheet been verified (i.e., has the spreadsheet been tested)? Is there a record of validation including the date and the specific inputs and outputs?

- Have significant changes been made to the spreadsheet since the last time its output was validated?
- Are users properly trained in the use of the spreadsheet? Do they have sufficient reference material? An interview with users other than the spreadsheet developer may be helpful in determining this.
- What provisions are there for quality control of manual data input? As with any other type of manual data entry situation, duplicate key entry or similar means of quality control should be used when entering large data sets.
- Does the spreadsheet incorporate complex table lookup functions or macros? These features significantly complicate spreadsheets and can make their detailed operation virtually impossible to understand fully. In such cases, the auditor should review the reasonableness of outputs produced by the spreadsheet using a known data set.

• Provisions should be made for archiving the spreadsheet in a format that is usable in case data have to be reprocessed. The time window in which data may have to be reprocessed should be considered. Some spreadsheets (as well as other types of computer software) can sometimes remain in use long after the original project has ended, and documentation must be provided so that the spreadsheet's functions can be understood at a later time.

AG3.4.3 A Local-Area-Network-Distributed Database Application

Communication software is complex and is evolving rapidly. This leads to fundamental concerns in the areas of security, privacy, and accountability. The following example, based on a real system now in use for reporting and distributing environmental data, will illustrate some of the QA considerations relevant to a relatively simple distributed application:

> The data base application resides on a centralized server with PC- or workstation-based clients accessing the data over a local area network (LAN). Users can also communicate with the server using dial-up access or via the Internet. By relying on a commercially available communications product, the system has been developed by existing project personnel, none of whom have formal training in computer science. The database programming was done using a popular, commercially available data base development product. Individual project team members and some outside users can log on remotely and are able to add and modify data, query the data base, and generate reports.

Management and QA planning for this project should address the normal concerns of ensuring that the system is acquired and installed within budget and on-schedule, and that calculations and reports are correct. QA concerns specific to this system include the following:

AG3.3.4.1 *Security*. There are many potential security vulnerabilities, and planners should identify as many of these as possible and state explicitly how they will be prevented. Specific tests should be conducted that address the security features of the system. Some specific methods for addressing security vulnerabilities include the following:

• Using separate passwords for user log on, for remote dial-in, and for access to sensitive portions of the database.

• Restricting downloads of files that could contain viruses and performing regular virus checks on all machines on the network. Viruses are easily transmitted over the Internet, and can spread rapidly over LANs. Viruses represent both an operational and a security risk. Recent viruses have infected wordprocessor macros. Because word processing files are frequently interchanged via the WWW and e-mail, even such "nonexecutable" files can pose a danger.

AG3.4.3.2 *Privacy*. Since this system may contain records of proprietary business data and voluntarily submitted emissions information, the records must be kept private. The means for ensuring that privacy is protected was a fundamental requirement for the system. Regular QA reviews are done to verify that established privacy-related procedures are being followed. These include encrypting the identifying records and restricting use only to personnel with special password-protected access.

AG3.4.3.3 *Personnel Qualifications and Training*. Although it is common for technical or clerical personnel to develop small information systems using currently available “User-friendly” software and systems environments, this practice can represent a significant risk to a larger project. On the project described in the example, the qualifications of project staff had been carefully evaluated with respect to experience with similar information-systems development projects of comparable magnitude. A key person with this experience was identified and was made the lead programmer/developer. The QA Officer also had significant computer background and was able to provide additional support during project implementation. A number of books, utility programs, and other aids were purchased for the project.

AG3.4.3.4 *Data Defensibility and Traceability*. With many different users having read/write access to a common data set, assurance of data integrity was a concern. If absolute traceability of each data item had been required, an Audit Trail, which records each transaction and includes the date, time, and person responsible for the change, would be a fundamental part of the requirement. However, an audit trail was not deemed necessary for this particular project. Backup copies of the data base are being maintained on a weekly basis and are archived. This serves the dual purpose of providing a backup as well as to trace any data tampering that might occur. Backups have proved valuable in this relatively open environment when a user inadvertently overwrites or deletes files. Occasional internal audits are performed to detect any unexplained changes in the data set over time.

AG4. REFERENCES

This section provides references that were used in developing this appendix along with documents that provide more detailed coverage of the topics listed below.

AG4.1 General

U.S. Environmental Protection Agency. 1995. *Air Pollution Prevention and Control Division Quality Assurance Procedures Manual, Appendix G Quality Assurance Planning for Software and Data Management Projects.* Revision 1. Research Triangle Park, NC.

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AG4.2 Legislation

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AG4.3 Executive Orders and Policy Directives

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MANAGING FLOODPLAIN DEVELOPMENT

IN

APPROXIMATE ZONE A AREAS

A GUIDE FOR OBTAINING AND DEVELOPING BASE (100-YEAR) FLOOD ELEVATIONS

APRIL 1995

FOREWORD

This guide was developed for use by community officials, property owners, developers, surveyors, and engineers who may need to determine Base (100-year) Flood Elevations (BFEs) in special flood hazard areas designated as approximate Zone A on the Federal Emergency Management Agency's Flood Insurance Rate Maps published as part of the National Flood Insurance Program. One of the primary goals of this document is to provide a means of determining BFEs at a minimal cost.

The guidance provided herein is primarily intended for use in riverine and lake areas where flow conditions are fairly uniform, and do not involve unusual flow regimes (rapidly varying flow, two-dimensional flow, supercritical flow, hydraulic jumps, etc.).

This guide is not to be used for areas that experience alluvial fan flooding or areas that contain characteristics of alluvial fan flooding. In addition, this guide is not to be used in Zone V (velocity) areas or coastal Zone A areas that are subject to flooding due to storm surge from hurricanes and other coastal storms. Furthermore, guidance on determining regulatory floodways is not provided in this guide.

Notes on the .PDF version of the Zone A Manual

Appendices 8 and 9 (hand calculations) were not included in the .PDF (Internet) version of this Manual. The information was not in a text format. The scanned images of Appendices 8 & 9 would have made the file size of this document much larger. To keep the file size down they were omitted.

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APPENDICES

I. INTRODUCTION

This guide is primarily intended to assist local community officials in administering and enforcing the floodplain management requirements of the National Flood Insurance Program (NFIP). This document provides guidance for determining Base (100-year) Flood Elevations (BFEs) in special flood hazard areas that have been identified and designated as approximate Zone A on a community's NFIP maps. Zone A identifies an approximately studied special flood hazard area for which no BFEs have been provided. Although BFEs are not provided, the community is still responsible for ensuring that new development within approximate Zone A areas is constructed using methods that will minimize flood damages. This often requires obtaining or calculating BFEs at a development site.

Developers, property owners, engineers, surveyors, and others at the local level who may be required to develop BFEs for use in approximate Zone A areas should also find this guide useful. Included in this guide are methodologies that can be used to develop BFEs, which can be used to determine the elevation or floodproofing requirements for buildings. The detailed methodologies described in this guide can also be used to develop the BFE information necessary to obtain a Letter of Map Amendment or a Letter of Map Revision Based on Fill from the Federal Emergency Management Agency (FEMA) to remove a legally defined property or structure from a special flood hazard area. In addition, Letter of Map Revision requestors may use the detailed methods in this document to develop the BFE information that must be submitted to FEMA to demonstrate that an area will not be flooded during the 100-year flood.

II. NATIONAL FLOOD INSURANCE PROGRAM BACKGROUND

In 1968, the United States Congress passed the National Flood Insurance Act, which created the NFIP. Congress recognized that the success of this program required that community participation be widespread, that studies be conducted to accurately assess the flood risk within each participating flood-prone community, and that insurance premium rates be established based on the risks involved and accepted actuarial principles. To meet these objectives, the 1968 Act called for: 1) the identification and publication of information within five years for all floodplain areas that have special flood hazards; and 2) the establishment of flood-risk zones in all such areas to be completed over a 15-year period following the passage of the act.

Within the first year of NFIP operation, it became evident that the time required to complete the detailed flood insurance studies would markedly delay implementation in many flood-prone communities. As a result, an interim means for more rapid community participation in the NFIP had to be provided. The Housing and Urban Development Act of 1969 expanded participation by authorizing an Emergency Program under which insurance coverage could be provided at non-actuarial, federally-subsidized rates in limited amounts during the period prior to completion of a community's flood insurance study.

Until engineering studies could be conducted for these communities, Flood Hazard Boundary Maps, such as the one shown in Figure 1, "Flood Hazard Boundary Map," which delineated the boundaries of the community's special flood hazard areas, were prepared using available data or approximate methods. The Flood Hazard Boundary Maps identified, on an approximate basis, the areas within a community subject to inundation by the 100-year flood (i.e., Zone A). The 100-year flood has a one-percent chance of being equalled or exceeded in any given year. The Flood Hazard Boundary Map was intended to assist communities in managing floodplain development, and insurance agents and property owners in identifying those areas where the purchase of flood insurance was advisable.

The Flood Disaster Protection Act of 1973, which also amended the 1968 Act, required that flood-prone communities be notified of their flood hazards to encourage program participation. This notification was accomplished through the publication of Flood Hazard Boundary Maps for all communities that were identified as containing flood hazard areas. In addition, the 1973 Act required the purchase of flood insurance by property owners who were being assisted by

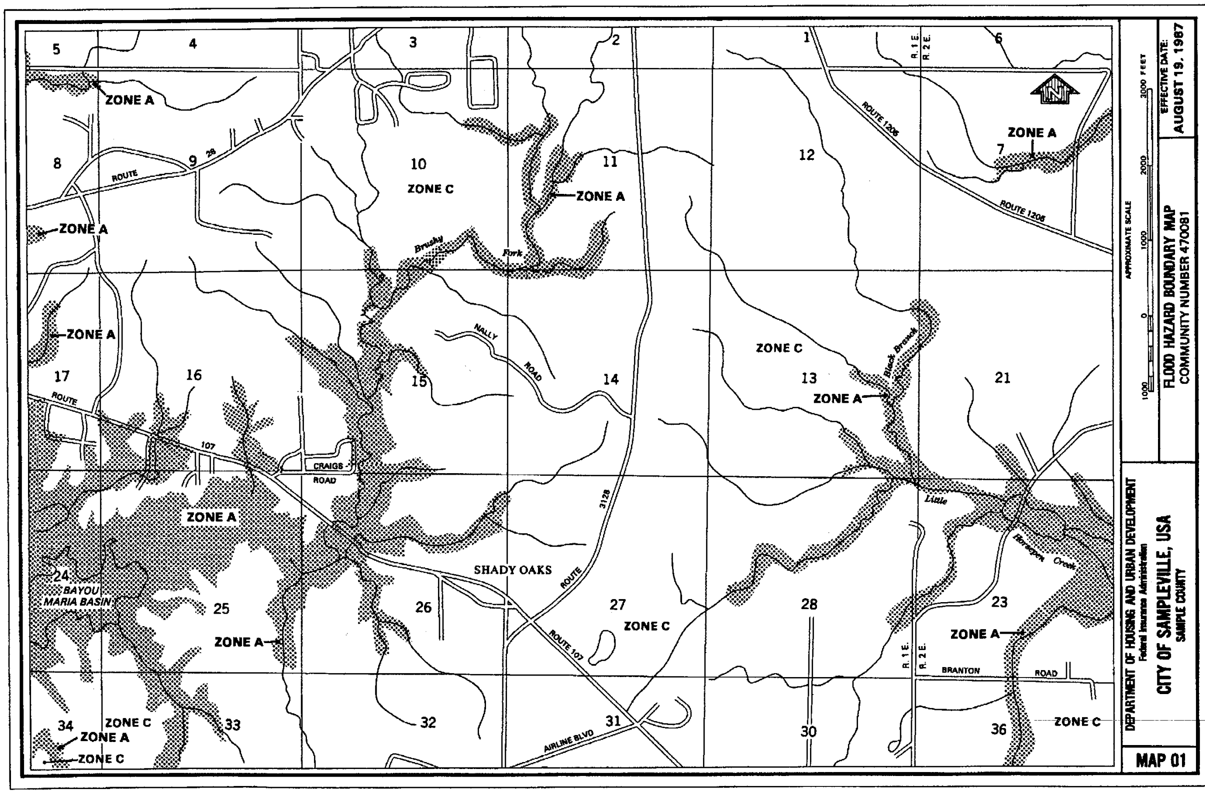


Figure 1 - Flood Hazard Boundary Map

Federal programs, or by Federally supervised, regulated, or insured agencies or institutions, in the acquisition or improvement of land or facilities located, or to be located, in special flood hazard areas. This act also severely limited Federal financial assistance in the flood hazard areas of communities which did not join the NFIP.

The initial Flood Hazard Boundary Maps for communities identified as having flood hazards were prepared using available floodplain data contained in reports developed by a variety of Federal, State, and local sources. For those communities that had no available flood information, approximate hydrologic and hydraulic methods or historical flood data were used to determine the extent of the special flood hazard areas.

Flood Insurance Studies that used detailed hydrologic and hydraulic analyses to develop BFEs and designate floodways and risk zones were subsequently developed for most NFIP communities. The results of a Flood Insurance Study were issued to the community in the form of a Flood Insurance Rate Map (FIRM), such as the one shown in Figure 2, "Flood Insurance Rate Map," and, in most cases, a Flood Boundary and Floodway Map and a Flood Insurance Study report. Once more detailed risk data were provided, the community could enter the Regular Program whereby more comprehensive floodplain management requirements were imposed and higher amounts of insurance could be purchased by owners of structures.

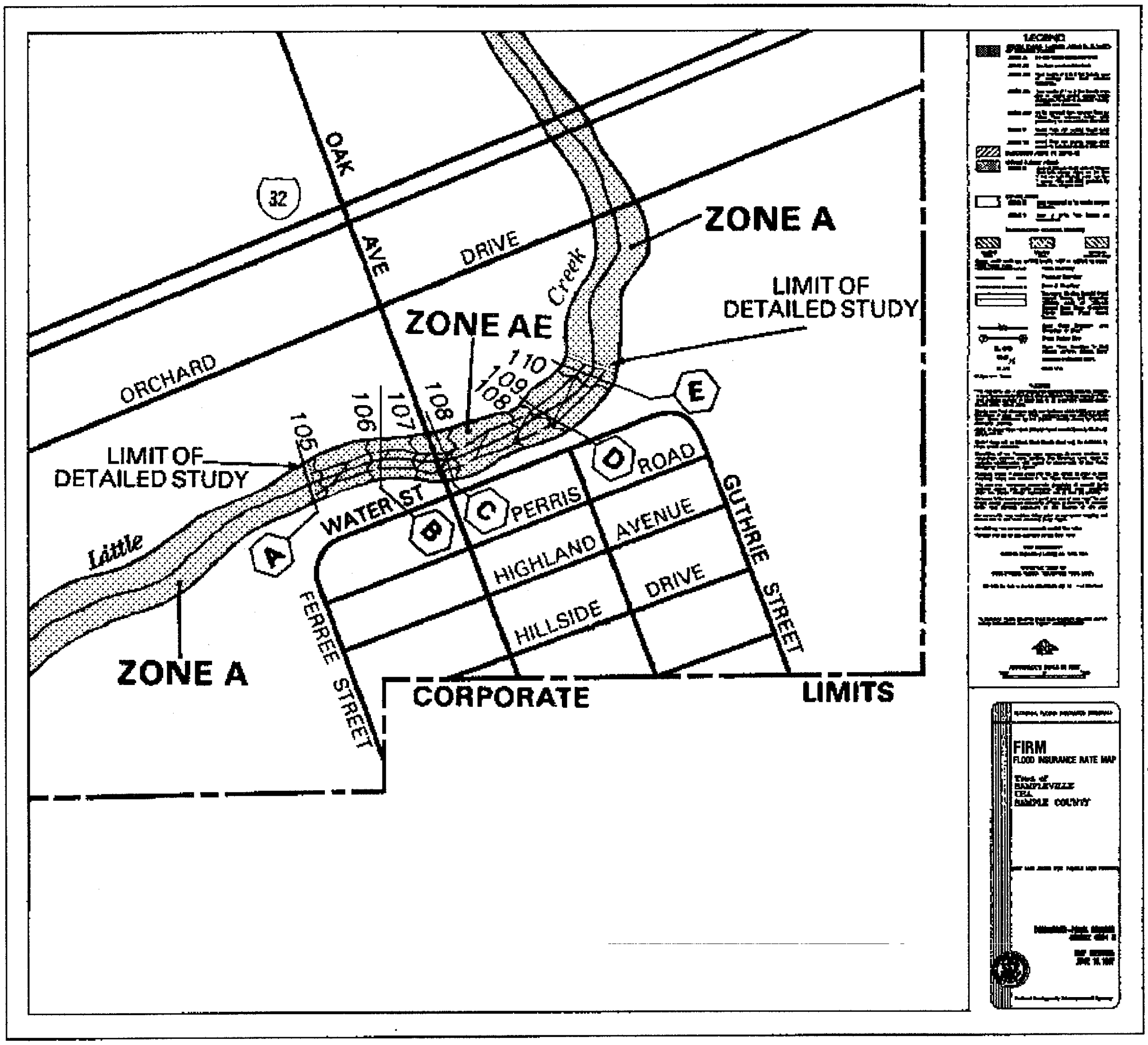


Figure 2 - Flood Insurance Rate Map

As early as 1976, FEMA recognized that some communities did not require a detailed Flood Insurance Study because there were few existing buildings in the floodplain and minimal development pressure. Shortly thereafter, FEMA began utilizing a special conversion process whereby communities were converted to the Regular Program without a Flood Insurance Study. Consequently, these communities were converted using FIRMs in which all of the special flood hazard areas were designated as approximate Zone A, without BFEs.

Although over 10,000 communities have now been provided detailed Flood Insurance Studies and issued FIRMs that include BFEs, many floodplains are still designated as approximate Zone A without BFEs. Due to the costs of developing detailed risk data, areas not subject to development pressure are studied using approximate methodologies and continue to be shown on the FIRM as approximate Zone A areas. FEMA only provides BFEs for the floodplains of those flooding sources that are currently subject to development pressure or are projected at the initiation of a Flood Insurance Study or Flood Insurance Study restudy to be subject to development pressure during the immediate future. Generally, a planning period of approximately five years is used. Even in these cases, BFEs are provided on a priority basis due to funding constraints. The community plays a major part in the determination of the level of detail required in the study of selected streams. As a result, most communities will have FIRMs that include special flood hazard areas for flooding sources that have been studied in detail with BFEs and special flood hazard areas for flooding sources that have been studied using approximate methods, and have been designated as approximate Zone A.

III. APPLICABLE NATIONAL FLOOD INSURANCE PROGRAM FLOODPLAIN MANAGEMENT REQUIREMENTS IN APPROXIMATE ZONE A AREAS

The primary requirement for community participation in the NFIP is the adoption and enforcement of floodplain management regulations that meet the minimum standards of the NFIP regulations in Title 44 of the Code of Federal Regulations (CFR) Section 60.3. These minimum standards vary depending on the type of flood risk data provided to the community by FEMA. The intent of floodplain management regulations is to minimize the potential for flood damages to new construction and to avoid aggravating existing flood hazard conditions that could increase potential flood damages to existing structures. To protect structures in riverine and lacustrine areas, the NFIP regulations require that the lowest floor (including basement) of all new construction and substantial improvements of residential structures be elevated to or above the BFE. New or substantially improved non-residential structures in riverine areas must either be elevated or floodproofed (made watertight) to or above the BFE.

Requirements for Obtaining BFE Data

In areas designated as approximate Zone A, where BFEs have not been provided by FEMA, communities must apply the provisions of Paragraph 60.3(b) of the NFIP regulations. Subparagraph 60.3(b)(4) requires that communities:

> Obtain, review and reasonably utilize any base flood elevation and floodway data available from a Federal, State, or other source... [44 CFR 60.3 (b)(4)]

Section IV describes the sources from which BFE data may be obtained. These data are to be used as criteria for requiring that new construction, substantial improvements, and other development within all approximate Zone A areas meet the applicable requirements in Paragraphs 60.3(c) and (d) of the NFIP regulations, including the requirement that structures have their lowest floors elevated to or above the BFE (or floodproofed to or above the BFE for non-residential structures). These data should be used as long as they reasonably reflect flooding conditions expected during the base (100-year) flood, are not known to be scientifically or technically incorrect, and represent the best data available. Communities should consider formally adopting these data by reference as part of their floodplain management regulations.

Requirements for Developing BFE Data

Under Subparagraph 60.3(b)(3) of the NFIP regulations, communities must also:

> Require that all new subdivision proposals and other proposed development (including proposals for manufactured home parks and subdivisions) greater than 50 lots or 5 acres, whichever is the lesser, include within such proposals base flood elevation data; [44 CFR 60.3 (b)(3)]

This means that any subdivision which meets this threshold must be evaluated to determine if the subdivision proposal is affected by an approximate Zone A area and whether BFE data are required. BFE data are required for the affected lots in the subdivisions shown in Figure 3, "Proposed 76-Lot Subdivision," and Figure 4, "Proposed 6.7-Acre Subdivision." Figure 3 clearly shows a 76-lot subdivision with several lots affected by an approximate Zone A area. The subdivision depicted in Figure 4 is only 12 lots, but because the subdivision is greater than 5 acres and clearly shows buildable sites affected by an approximate Zone A area, BFE data are required.

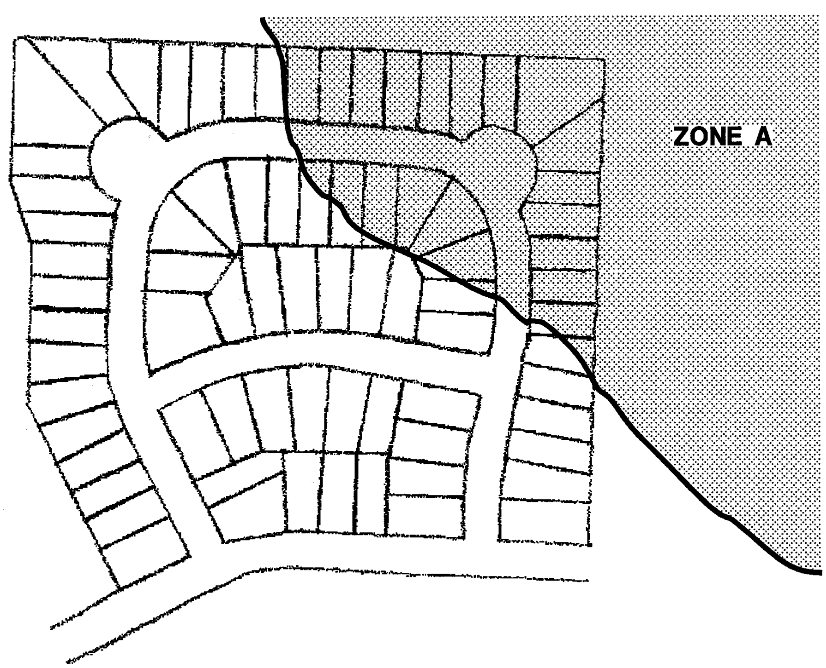


Figure 3 - Proposed 76-Lot Subdivision

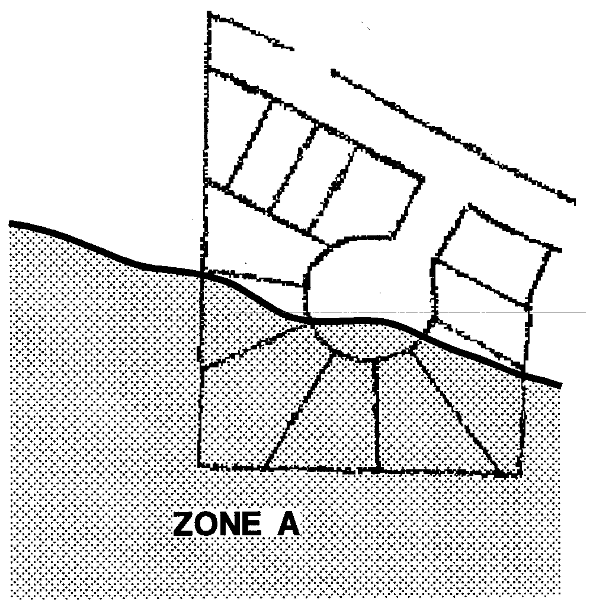


Figure 4 - Proposed 6.7-Acre Subdivision

Communities are encouraged to address the flood hazards at the earliest stages of subdivision planning rather than at the actual placement of individual structures. If a community can work with the developer and others when land is being subdivided, many long-term floodplain management benefits can be achieved, particularly if the floodplain is avoided altogether. In Figure 5, "Proposed 76-Lot Subdivision," the entire approximate Zone A area is to be dedicated as open space. If the planned subdivision shows the floodplain is contained entirely within an open space lot, it may not be necessary to conduct a detailed engineering analysis to develop BFE data.

Also, it may not be necessary to develop detailed BFE data in large-lot subdivisions or single-lot subdivisions that are within the thresholds under Subparagraph 60.3(b)(3) of the NFIP regulations when the actual building sites are clearly outside of the Zone A area. In Figure 6, "Proposed 5.6-Acre Subdivision," it is evident from the topographic features of this 5.6-acre subdivision that the building sites would be clearly out of the floodplain since the proposal indicates a steep grade between the approximate Zone A area and the building sites which are located on natural high ground.

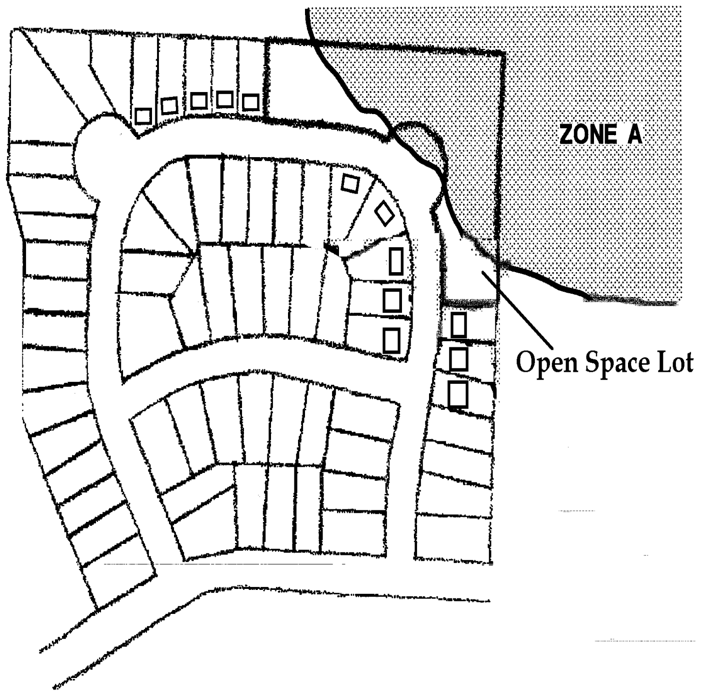


Figure 5 - Proposed 76-Lot Subdivision

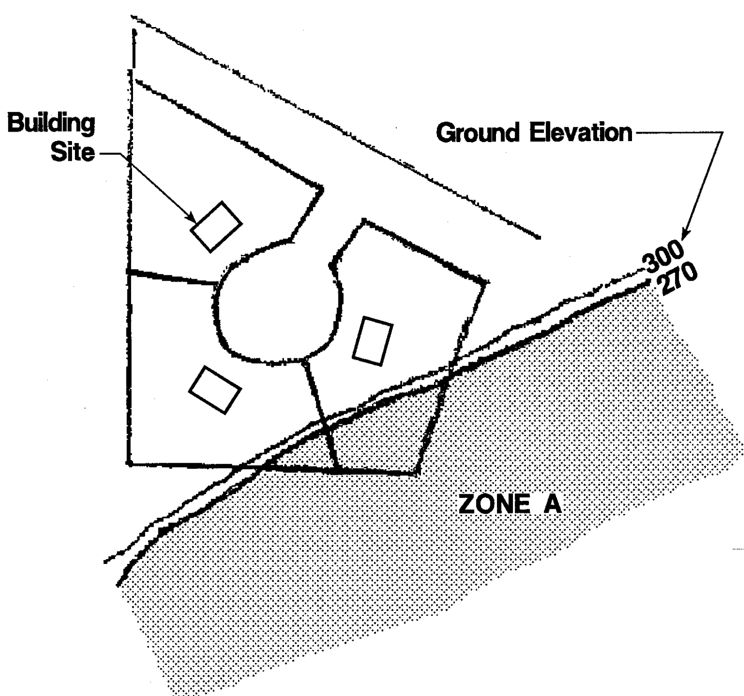


Figure 6 - Proposed 5.6-Acre Subdivision

If the grade between the actual building sites and the approximate Zone A area of the proposed subdivision is relatively gradual, asshown in Figure 7, "Proposed 6.7-Acre Subdivision," the floodplain could extend beyond what is shown on the Flood Insurance Rate Map. It is very likely that flooding could affect the building sites.In this case, an analysis should be conducted to determine the location of the 100-year floodplain and the BFE.

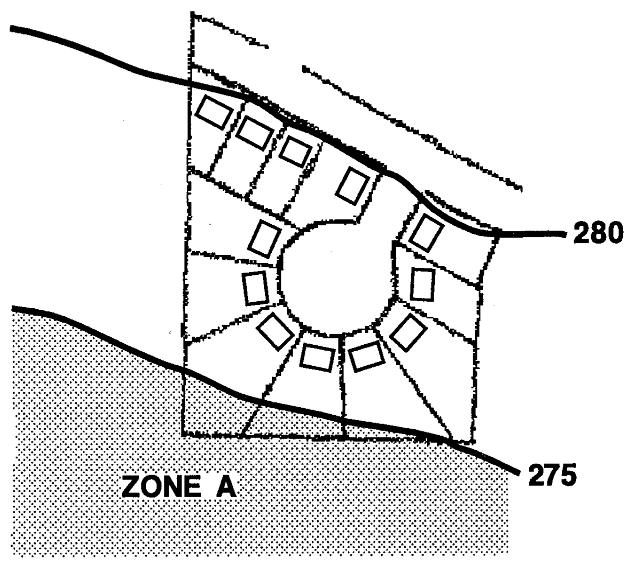


Figure 7 - Proposed 6.7 Acre Subdivision

For developments that exceed the thresholds identified in NFIP regulations Subparagraph 60.3(b)(3), BFEs must be either obtained from other sources or developed using detailed methodologies comparable to those contained in a Flood Insurance Study. Section V describes some of the detailed methodologies available that can be used to develop BFE data when none are available from the sources listed in Section IV.

If the size of the new subdivision or other proposed development falls below the thresholds specified in NFIP regulations Subparagraph 60.3(b)(3) and no BFE data are available from the sources listed in Section IV, the community must still apply, at a minimum, the requirements of Subparagraph 60.3(a)(3) to proposed structures or Subparagraph 60.3(a)(4) to subdivisions and other developments within approximate Zone A areas. These paragraphs require that permit officials:

> Review all permit applications to determine whether proposed building sites will be reasonably safe from flooding. If a proposed building site is in a flood-prone area, all new construction and substantial improvements shall (i) be designed (or modified) and adequately anchored to prevent floatation, collapse, or lateral movement..., (ii) be constructed with materials resistant to flood damage, (iii) be constructed by methods and practices that minimize flood damages, and (iv) be constructed with electrical, heating, ventilation, plumbing, and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding. [44 CFR 60.3(a)(3)]

> Review subdivision proposals ... including manufactured home parks or subdivisions ... to assure that (i) all such proposals are consistent with the need to minimize flood damage within the flood-prone area, (ii) all public utilities and facilities ... are located and constructed to minimize or eliminate flood damage, and (iii) adequate drainage is provided to reduce exposure to flood hazards; [44 CFR 60.3(a)(4)]

One way that communities can ensure that building sites will be reasonably safe from flooding for proposed developments that fall below the thresholds in Subparagraph 60.3(b)(3) is to use the simplified methods outlined in Section V for estimating a BFE. Another approach to ensure that a building site is reasonably safe from flooding is to require the structure to be elevated above the highest adjacent grade by a specified number of feet based on the local official's knowledge of flood conditions in the area. In the absense of available BFE data from other sources, the community may require the permit applicant to elevate the structure two or more feet above the highest adjacant grade which qualifies the structure for reduced flood insurance rates. Elevation of the structure to four feet above the highest adjacant grade will enable the structure to qualify for substantially reduced flood insurance rates.

However, some states and communities require that BFE data be developed for all subdivisions and/or floodplain development within approximate Zone A areas, not just those subdivisions which meet the 50-lot or 5-acre threshold. A community may, at its discretion, require the use of detailed methods for such development. While this requirement is more restrictive than NFIP minimum requirements, the NFIP regulations specifically recognize and encourage states and communities to adopt and enforce more restrictive floodplain management regulations in those instances where the state or community believes that it is in the best interest of its citizens.

No matter what the size of the subdivision or other development proposal, requests to revise or amend effective Flood Insurance Study information through the procedures outlined in Part 65 and Part 70 of the NFIP regulations must be based on detailed methodologies presented in Section V or other methodologies comparable to those found in a Flood Insurance Study. The analysis used to develop the BFEs must be certified by a registered professional engineer or licensed land surveyor, as appropriate, if the BFEs are to be used to revise or amend an NFIP map.

Use of Draft or Preliminary Flood Insurance Study Data

The data from a draft or preliminary flood insurance study constitutes "available data" under Subparagraph 60.3(b)(4). Communities must reasonably utilize the draft or preliminary flood insurance study data under the section of their ordinance that requires the use of other base flood data when detailed BFE data has not been published in a flood insurance study. Communities are given discretion in using draft or preliminary flood insurance study data only to the extent that the technical or scientific validity of the proposed flood elevation data is questioned. If a community decides not to use the draft or preliminary flood insurance data in a FIS because it is questioning the data through a valid appeal, the community must still assure that buildings are constructed using methods and practices that minimize flood damages in accordance with the requirements under Subparagraphs 60.3(a)(3) and (4).

When all appeals have been resolved and a notice of final flood elevations has been provided by FEMA, communities are required to use the data from the flood insurance study for regulating floodplain development in accordance with Subparagraph 60.3(b)(4) since the data represents the best data available. Communities must regulate floodplain development using the flood insurance study data under Subparagraph 60.3(b)(4) until such time as the community has adopted the effective FIRM and flood insurance study.

Advantages of Developing BFE Data

While the NFIP regulations do not require that communities develop BFE data in approximate Zone A areas when proposed development is below the thresholds in NFIP regulations Subparagraph 60.3(b)(3), there are significant advantages and financial benefits for communities and individual property owners that develop BFE data. These advantages and benefits include:

- protecting structures up to the BFE will minimize and reduce future flood losses, resulting in long-term savings to the individual, the community, and the National Flood Insurance Fund;

- flood insurance policies in approximate Zone A areas that are rated using a BFE will often qualify for significantly lower insurance rates than policies that are rated without a BFE. The difference in flood insurance premiums could be substantial;

- less burden will be placed on the permit official because he or she can require protection to a specified elevation. Without a BFE, the permit official must make judgements as to what constitutes "reasonably safe from flooding" and "constructed with materials and practices that minimize flood damages";

- the NFIP's Community Rating System establishes flood insurance premium discounts of up to 45 percent for policy holders within communities that have a floodplain management program that exceeds NFIP minimum requirements. Sizable Community Rating System credits are available for Community Rating System communities that develop BFEs for areas designated as approximate Zone A on their Flood Hazard Boundary Map or FIRM, or that require site-specific engineering analyses for development proposals; and

- by specifying a BFE in an approximate Zone A area, a building or property can, in some circumstances, be removed from the floodplain by issuance of a Letter of Map Amendment or Letter of Map Revision in accordance with Part 65 and Part 70 of the NFIP regulations. *While these procedures eliminate the requirement that flood insurance be purchased as a condition of obtaining a loan from a Federally insured or regulated lender, a lending institution may, at its discretion, require the purchase of flood insurance*.

IV. OBTAINING EXISTING BASE (100-YEAR) FLOOD ELEVATIONS

The NFIP Regulations at 44 CFR 60.3 require that structures be elevated or floodproofed (non-residential structures only) to provide protection from flood damage. A BFE must be established before such flood protection measures can be used. There are a variety of computational methods that can be employed to determine BFEs. However, these methods can be costly. Before computational methods are used, every attempt should be made to obtain information, in the form of floodplain studies or computations, from Federal, State, or local agencies. Data obtained from these agencies may be adequate to determine BFEs with little or no additional research, computation, or cost.

Local officials who obtain BFE data should maintain the information for future reference. Local officials should also consider making a search for BFE data for the entire community. By doing so, the local officials may not have to conduct a search each time a floodplain development permit is requested. If the data reasonably reflect flooding conditions, a community should consider adopting the information into its floodplain management ordinance.

Provided below are a list of agencies that can be contacted to determine if any BFE data have already been developed. When obtained, these data should be evaluated to ensure that they reasonably reflect flooding conditions expected at the site during the 100-year flood, are scientifically or technically correct, and represent the best data available.

Three major sources of existing data are highlighted in this section: FEMA, other Federal agencies, and State and local agencies.

FEMA

FEMA's technical evaluation contractors maintain libraries that contain technical and administrative data developed during the preparation of Flood Insurance Studies, as well as the resulting Flood Insurance Study reports and NFIP maps. FEMA can be contacted to determine whether or not sufficient information exists in the back-up data to calculate BFEs. For some flooding sources that are designated as approximate Zone A, FEMA may have detailed flooding information that has not yet been incorporated into the community's Flood Insurance Study. FEMA can be contacted to obtain this information where it exists.

FEMA regularly conducts restudies of flood hazards in an effort to keep Flood Insurance Studies accurate and up-to-date. As part of these restudies, detailed BFE data for approximate Zone A areas may be developed. During the time that elapses between FEMA obtaining restudy data and the incorporation of BFE data areas into a revised Flood Insurance Study, a community may reasonably use the BFE data from the restudy in approximate Zone A areas in accordance with Subparagraph 60.3(b)(4).

In addition, flooding sources restudied by FEMA may often impact several communities. FEMA may be unable to immediately update the Flood Insurance Study for every community impacted due to funding constraints. Therefore, BFEs may have been developed for streams within a community that have not yet been incorporated into the Flood Insurance Study.

It is also possible that a previous request to revise flood hazards along a stream or lake may be on file with FEMA, and that BFEs, which may be applicable to other areas of the same stream or lake, may have been computed for that request.

FEMA data should be sought when trying to obtain or determine BFEs for an approximate Zone A area, so that if BFEs have already been determined for an approximate Zone A area, then other BFE determinations in the same area can be based on the same methodology. However, if it is determined that a more scientifically or technically accurate determination than that which is available in FEMA's back-up data is warranted, then a more detailed methodology, such as those described in Section V, should be utilized.

Data requests should be directed to the appropriate FEMA technical evaluation contractor at the address listed on the following page:

FEMA Regions I-V
(States East of the Mississippi
River and Minnesota)

Flood Insurance Information Specialist
c/o Dewberry & Davis
2953 Prosperity Avenue
Fairfax, Virginia 22031
FAX: (703) 876-0073
Phone: (703) 876-0148

FEMA Regions VI-X
(States West of the
Mississippi River)

FEMA Project Library
c/o Michael Baker, Jr., Inc.
3601 Eisenhower Avenue
Suite 600
Alexandria, Virginia 22304
FAX: (703) 960-9125
Phone: (703) 960-8800

An instruction sheet entitled Flood Insurance Study (FIS) Data Requests is provided in Appendix 2. This sheet contains pertinent information and instructions for requesting Flood Insurance Study data.

A fee is charged for locating, retrieving, copying, and mailing Flood Insurance Study back-up data based on the cost of materials and a standard hourly rate for time spent to fill the request. FEMA will inform the requestor if the requested data are available and of the required fee. The requestor should allow two to four weeks for the request to be processed.

Other Federal Agencies

Information regarding BFEs may be obtained from other Federal agencies involved in floodplain management. A fee may be required to obtain some of the products or services available through these agencies. The following is a list of some of the Federal Agencies involved in floodplain management and the information, which may be useful in obtaining and determining BFEs, that they produce.

AGENCY	PRODUCT
U.S. Army Corps of Engineers	Floodplain Information Reports Technical Manuals Computer Programs Computational Assistance
U.S. Department of the Interior, Geological Survey	Topographic Maps Water Resource Investigations Technical Bulletins Water Supply Papers Computer Programs
U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS)	Watershed Studies Technical Releases Computer Programs
U.S. Department of Transportation, Federal Highway Administration	Floodplain Studies Design Manuals Computer Programs
U.S. Department of Commerce National Technical Information, Service	Design Manuals Computer Programs
Tennessee Valley Authority	Floodplain Studies

Other State and Local Agencies

If back-up data from Federal agencies are unavailable or are not useful, information regarding BFEs may be obtained from State or local agencies involved in floodplain management. On the following page is a list of State and local agencies involved in floodplain management that may be contacted to obtain BFE information. Again, fees may be applicable for this information.

For example, some state agencies, such as a Department of Natural Resources or a Geological Survey, may conduct floodplain studies using state funds. In some states, these agencies may maintain a repository for flood data. The NFIP state coordinating agency can also be contacted. A list of the State coordinating agencies is provided in Appendix 3. Other state agencies, such as a Department of Transportation, do engineering for specific types of projects, such as road and bridge construction, in which BFE data may have been developed for these projects. In general, when calling these agencies, the caller should ask for a copy of any back-up data (reports, computations, computer models, maps) associated with a FLOODPLAIN STUDY or DRAINAGE STUDY, for the area of the particular stream of interest. In addition, some state agencies, such as a Department of Natural Resources, may maintain historic lake level data.

The local public works department or the local transportation department may have developed flood data in designing sewer and storm drainage systems and local roads. For example, plans for a sanitary sewer line which runs parallel to the stream and area of interest may have 100-year flood elevations on the profile of the sanitary sewer. Also, if there are culverts or bridges which cross the same stream within 1,000 feet of the area of interest, there may be hydrologic and hydraulic information pertaining to the 100-year flood discharge and elevation which may be pertinent to the site. Finally, if there are any nearby residential or commercial developments along the same stream, the development (site) plans for these projects may also include information about the 100-year flood.

Other possible sources of data include regional organizations, such as Flood Control Districts, Levee Improvement Districts, Watershed Districts, or Soil and Water Conservation Districts. These organizations may have developed flood profiles for smaller streams or for reaches of streams impacted by flood control or drainage projects.

State Agencies:
Departments of Environmental Conservation
Departments of Environmental Protection
Departments of Floodplain Management
Departments of Natural Resources
Departments of Transportation
Departments of Water Resources
Geological Survey

Local or Regional Agencies:
Flood Control Districts
Levee Improvement Districts
Local Planning Commissions
Local Public Works Departments
Municipal Utility Districts
River Basin Commissions
Water Control Boards

A partial list of Federal and State agencies is provided in Appendix 3.

V. DEVELOPING BASE (100-YEAR) FLOOD ELEVATIONS

If sufficient BFE information cannot be obtained from the sources described in Section IV, then the community should consider conducting, or requiring the applicant to conduct, a site specific engineering analysis to determine a BFE. This section describes several simplified and detailed methods for estimating or developing BFE data, and provides guidance for using them.

As noted in Section III, a detailed method is required under Subparagraph 60.3(b)(3) of the NFIP regulations for proposed development greater than 50 lots or 5 acres, whichever is the lesser. If the BFEs developed will be used to revise or amend NFIP maps, they must be developed using the detailed methodologies described in this section or other methods comparable to those in a Flood Insurance Study.

If no BFE data are available and the proposed development is below the thresholds specified in Subparagraph 60.3(b)(3) of the NFIP regulations, the simplified methods for estimating BFEs described in the following section may be used. Simplified methods are less expensive and less time consuming than the detailed methods described later in this section. However, communities have the discretion to determine which method should be used when a proposed development is below the aforementioned thresholds.

Simplified Methods

There are situations in which a simplified approach for estimating the BFE may yield an acceptable level of accuracy. For simplified methods to be used, very specific conditions must be met as discussed below.

Simplified methods are appropriate for floodplain management purposes only. These methods may be used for the purpose of meeting the requirements of NFIP regulations Subparagraphs 60.3(a)(3) and 60.3(a)(4) for developments, such as isolated small subdivisions in rural areas which are below the threshold in Subparagraph 60.3(b)(3), or single lots. Subparagraphs 60.3(a)(3) and 60.3(a)(4) require the community to determine whether proposed building sites are reasonably safe from flooding and ensuring that subdivision proposals are consistent with the need to minimize flood damage within flood-prone areas.

Simplified methods may not be used by the community to complete an Elevation Certificate used for flood insurance rating. Communities must use the detailed methodologies described in this section or other methods comparable to those in a Flood Insurance Study for completing the Elevation Certificate. A flood insurance policy for a structure for which a simplified method is used may be rated without an elevation certificate. However, the flood insurance rate may be higher than if the structure is rated using an Elevation Certificate.

Contour Interpolation

Contour interpolation involves superimposing approximate Zone A boundaries onto a topographic map in order to estimate a BFE. BFEs obtained by this method can only be assumed to be as accurate as one-half of the contour interval of the topographic map that is used. Therefore, the smaller the contour interval of the topographic map, the higher the accuracy of the BFE determined from the map. The procedures for using this method are outlined below. Steps 1 through 5 are the same for both riverine and lacustrine (lake) flooding sources.

Step 1 - Obtain a topographic map showing the site being analyzed

Step 2 - Reduce or enlarge the FIRM or topographic map as necessary so that the two are at the same scale

Step 3 - Superimpose the approximate Zone A (100-year) floodplain boundary from the FIRM onto the topographic map

Step 4 - Determine if this method is within the acceptable accuracy limits. The floodplain boundary must generally conform with the contour lines along the flooding source in question. The difference between the water-surface elevations determined on the right overbank and the left overbank must be within one-half of the map contour interval. For lacustrine flooding sources, the difference between the highest and lowest determined water-surface elevations around the flooding source must be within one-half of the map contour interval. Otherwise, this method is not acceptable.

Step 5 - If the method is acceptable, then determine the BFE. Detailed guidance for determining the BFE is provided below.

Determining BFEs for Riverine flooding:

On each side of the stream in the vicinity of the site, determine the ground elevation at which the superimposed Zone A boundary lies by interpolating between two contour lines. Add one-half of the map contour interval to the lower of the two interpolated elevations. This is the approximate BFE for the site (be sure to perform this method at each structure location).

By adding one-half of the contour interval to the lowest interpolated water-surface elevation, two things are achieved: 1) the final BFE is within one-half of the contour interval of both interpolated water-surface elevations and, therefore, is still within the acceptable tolerance of the topographic map (generally regarded as ± one-half of the map contour interval); 2) it is a conservative estimate of the BFE. If the BFE determined under this procedure seems too high, then a detailed analysis may be performed to justify lowering it.

Example 1

Using a county topographic map with a contour interval of 5 feet, the approximate Zone A boundary crosses contour elevations on the left and right bank at 323 and 325 feet, respectively, as shown in Figure 8, "Contour Interpolation Method - Riverine Flooding Example 1." The difference between these two water-surface elevations is 2 feet, which is less than one-half of the contour interval or 2.5 feet. Therefore, this method is acceptable for use on this portion of the stream. Add 323 feet (lowest interpolated water-surface elevation) plus 2.5 feet (one-half of the contour interval), which yields a BFE of 325.5.

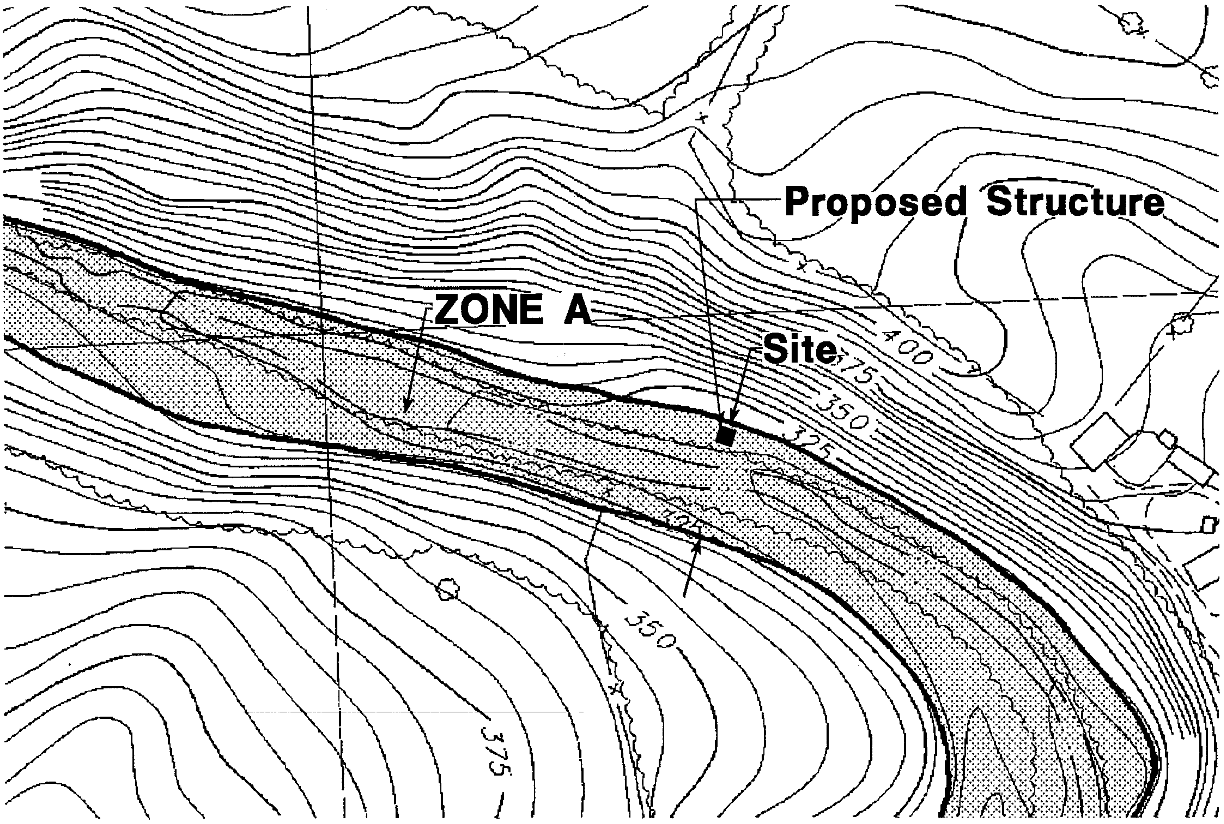


Figure 8 - Contour Interpolation Method -
Riverine Flooding Example 1

Example 2

Using a U.S. Geological Survey quadrangle map with a contour interval of 10 feet, the approximate Zone A boundary crosses contour elevations on the left and right bank of 422 and 430 feet, respectively, as shown in Figure 9, "Contour Interpolation Method - Riverine Flooding Example 2." The difference between these two water-surface elevations is 8 feet, which is greater than one-half of the contour interval or 5 feet. Therefore, this method is not acceptable for use on this portion of the stream, and another method must be used to determine the BFE.

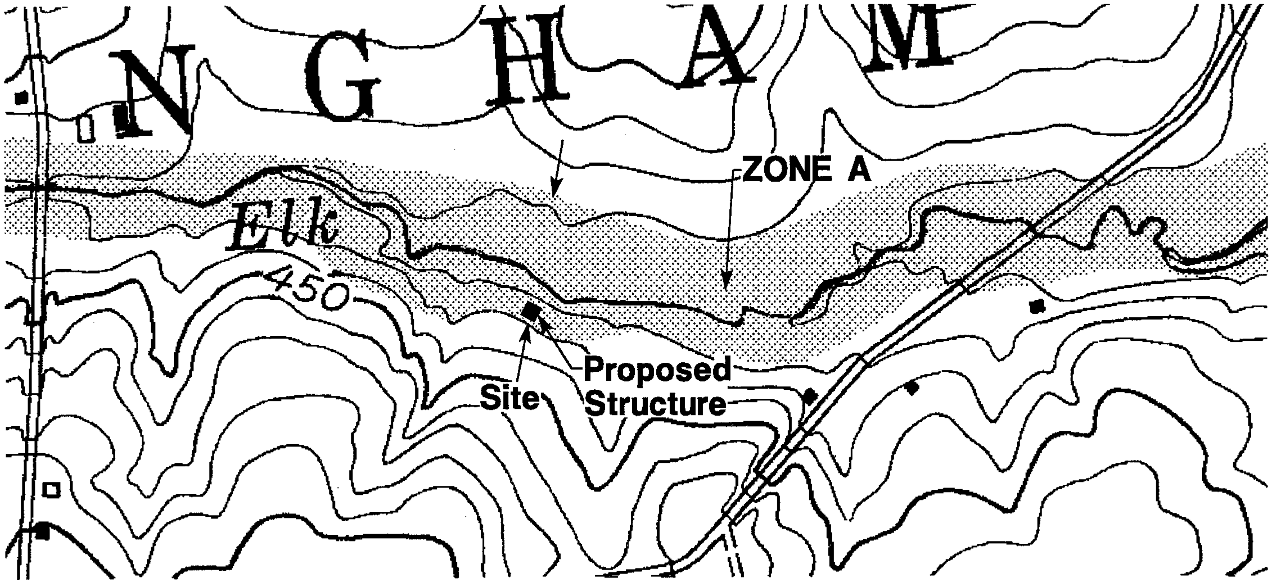


Figure 9 - Contour Interpolation Method -
Riverine Flooding Example 2

Determining BFEs for Lacustrine (Lake) flooding:

Determine the contour elevations that the approximate Zone A boundary crosses (i.e. the BFE) around the perimeter of the lake or ponding area. Assuming that the highest and lowest determined water-surface elevations are within one-half of the map contour interval of each other, add one-half of the map contour interval to the **lowest** water-surface elevation to determine the BFE for the site.

Example 3

Using a U.S. Geological Survey quadrangle map with a contour interval of 10 feet, the approximate Zone A boundary crosses low and high determined water-surface elevations along the perimeter of the ponding area of 280 and 283 feet, respectively, as shown in Figure 10, "Contour Interpolation Method - Lacustrine Flooding Example 3." The difference between these two water-surface elevations is 3 feet, which is less than one-half of the contour interval or 5 feet. Therefore, this method is acceptable for use on this ponding area. Add 280 feet (lowest water-surface elevation) and 5 feet (one-half of the contour interval), which yields a BFE of 285 feet.

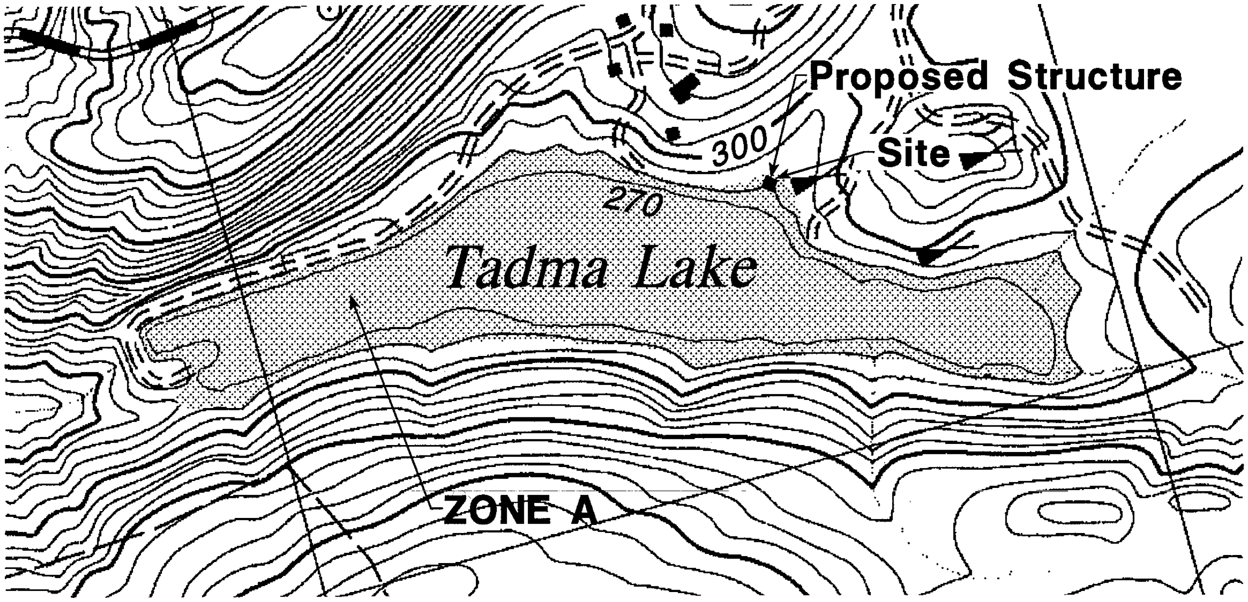


Figure 10 - Contour Interpolation Method -
Lacustrine Flooding Example 3

Data Extrapolation

If a site is within 500 feet upstream of a stream reach for which a 100-year flood profile has been computed by detailed methods, and the floodplain and channel bottom slope characteristics are relatively similar to the downstream reaches, data extrapolation may be used to determine the BFE. The stream in the vicinity of the site, however, must be free of backwater effects from downstream hydraulic structures. The procedure for using this method is outlined below.

Step 1 - Determine the location of the site on the flood profile for the detailed study stream

Step 2 - Extrapolate the last segment of the 100-year flood profile that has a constant water-surface slope to the location of the site. The BFE at the site can then be obtained directly from the profile

Figures 11-12 on the following pages depict situations (i.e., properties "Y" and "Z"), in which the data extrapolation method may and may not be used. Figures 13-14 depict a situation in which the data extrapolation method may not be used because the highway may have an effect on the 100-year water-surface elevations. If the 100-year flood profile changes just prior to the limit of detailed study, as shown in Figure 15, the data extrapolation method should not be used.

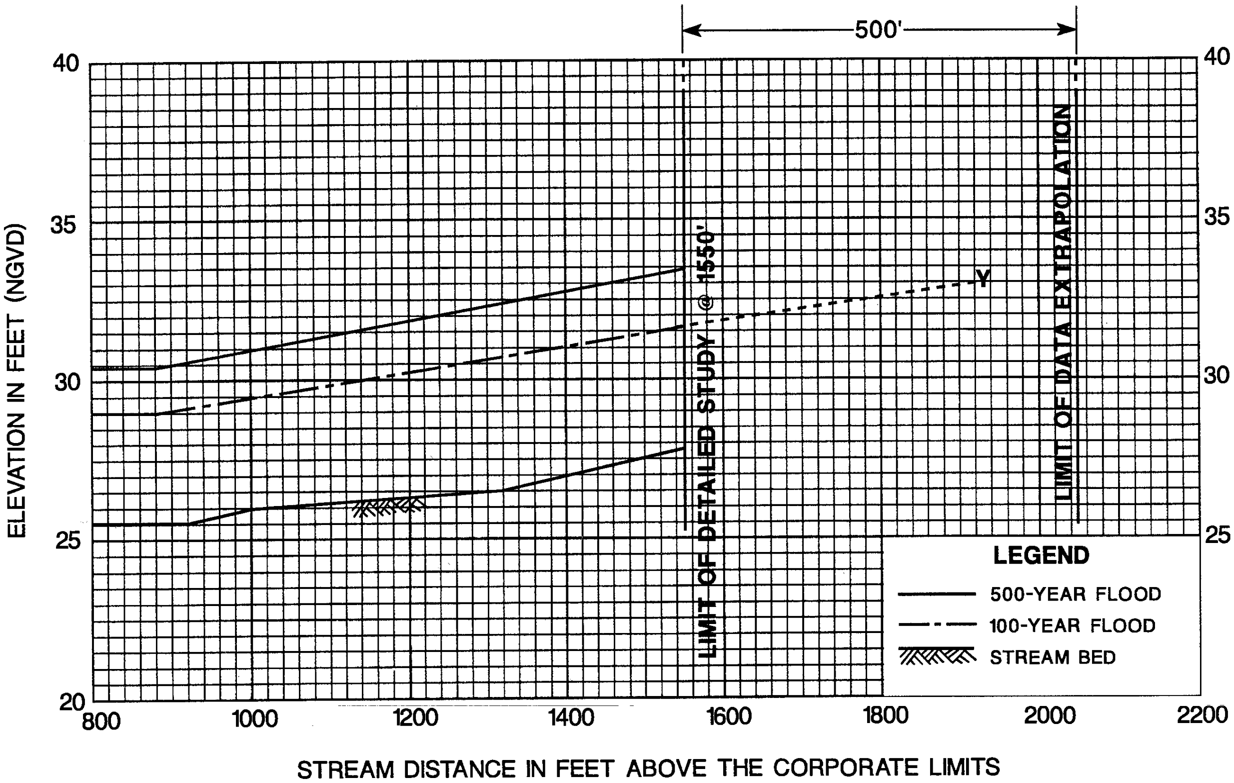


Figure 11 - Data Extrapolation Method - Profile

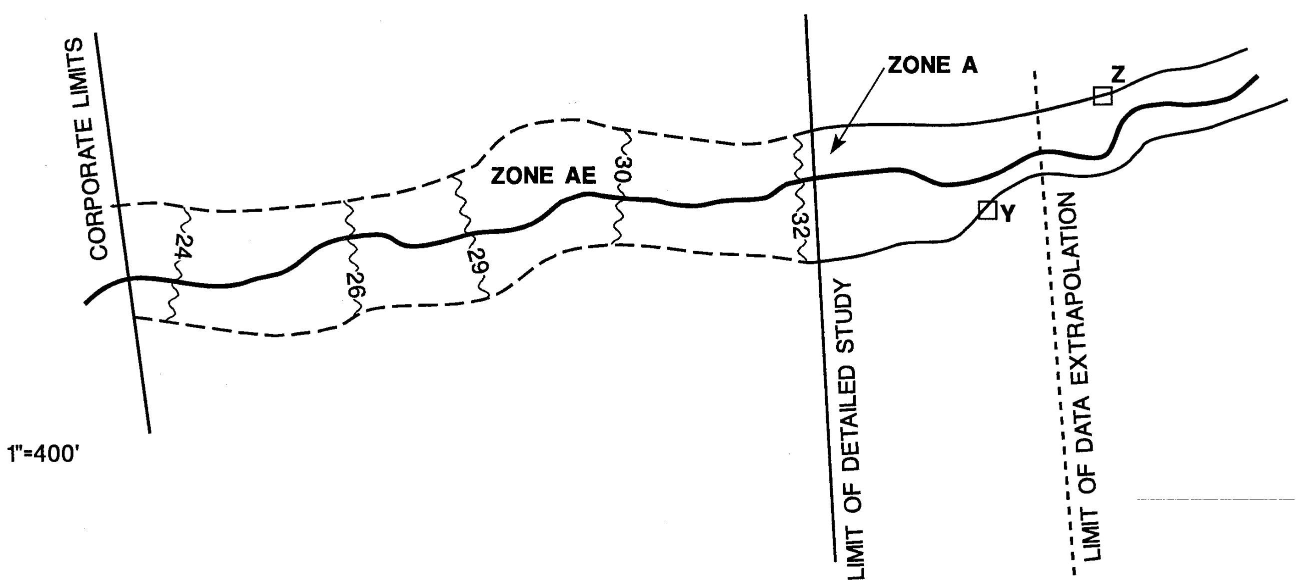


Figure 12 - Data Extrapolation Method - Plan View

-Property Y is approximately 370' upstream of the limit of detailed study (as measured along the streamline). Using the profile below, we can extrapolate the 100-year flood profile to determine that the BFE for property Y is equal to 33'.

-Property Z is approximately 700' upstream of the limit of detailed study (as measured along the streamline), and is therefore beyond the limit of data extrapolation.

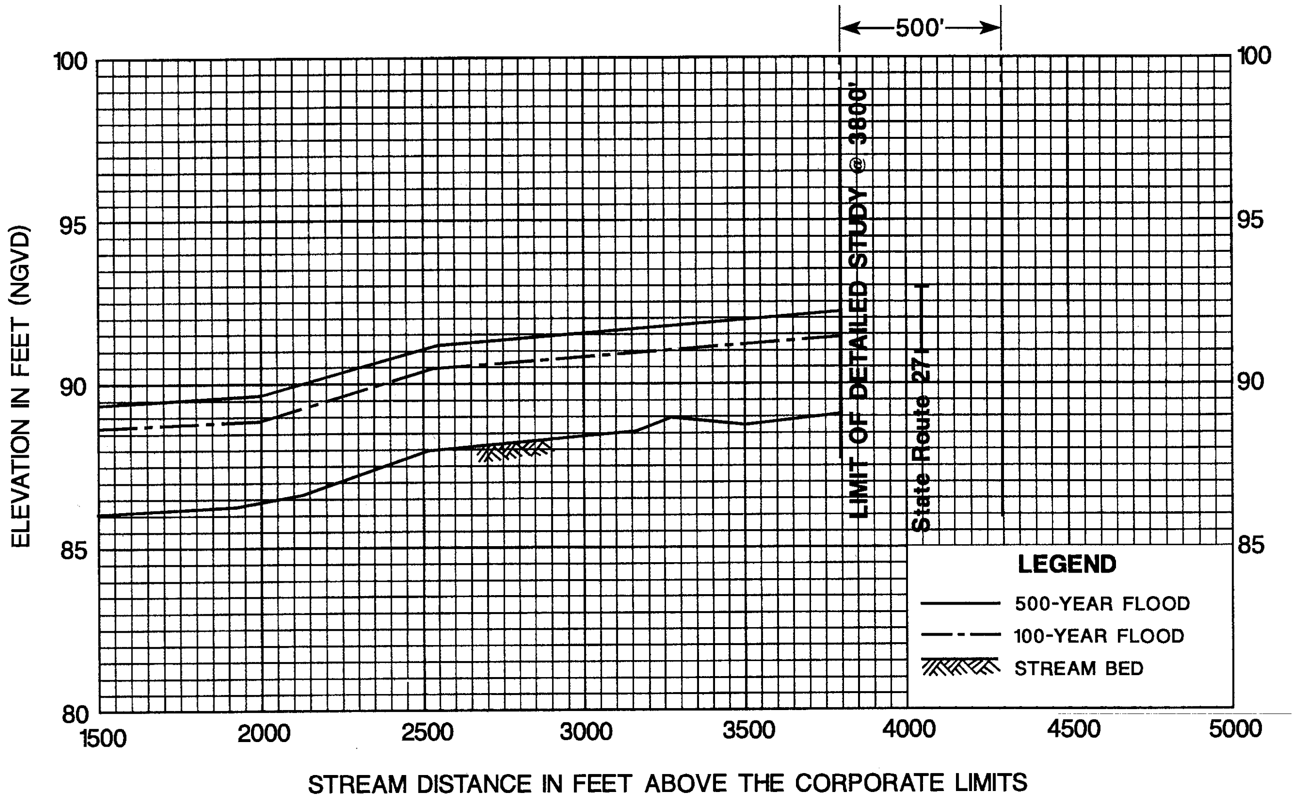


Figure 13 - Data Extrapolation Method - Profile

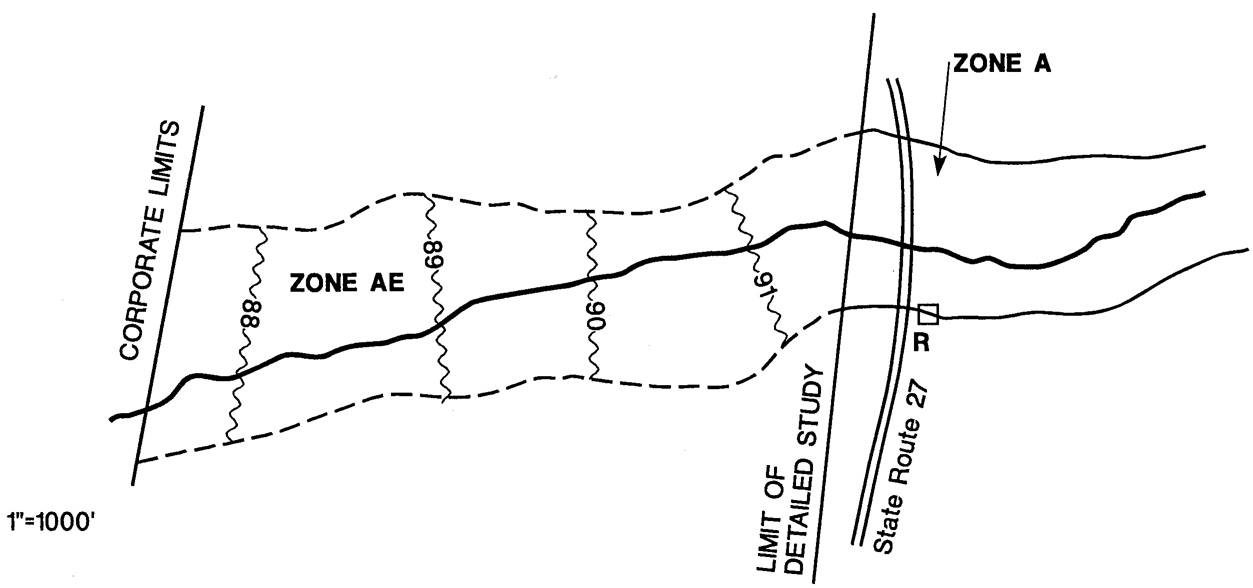


Figure 14 - Data Extrapolation Method - Plan View

-State Route 27 may have an effect on the 100-year water-surface elevations. Therefore, data extrapolation should not be used to obtain a BFE for property R.

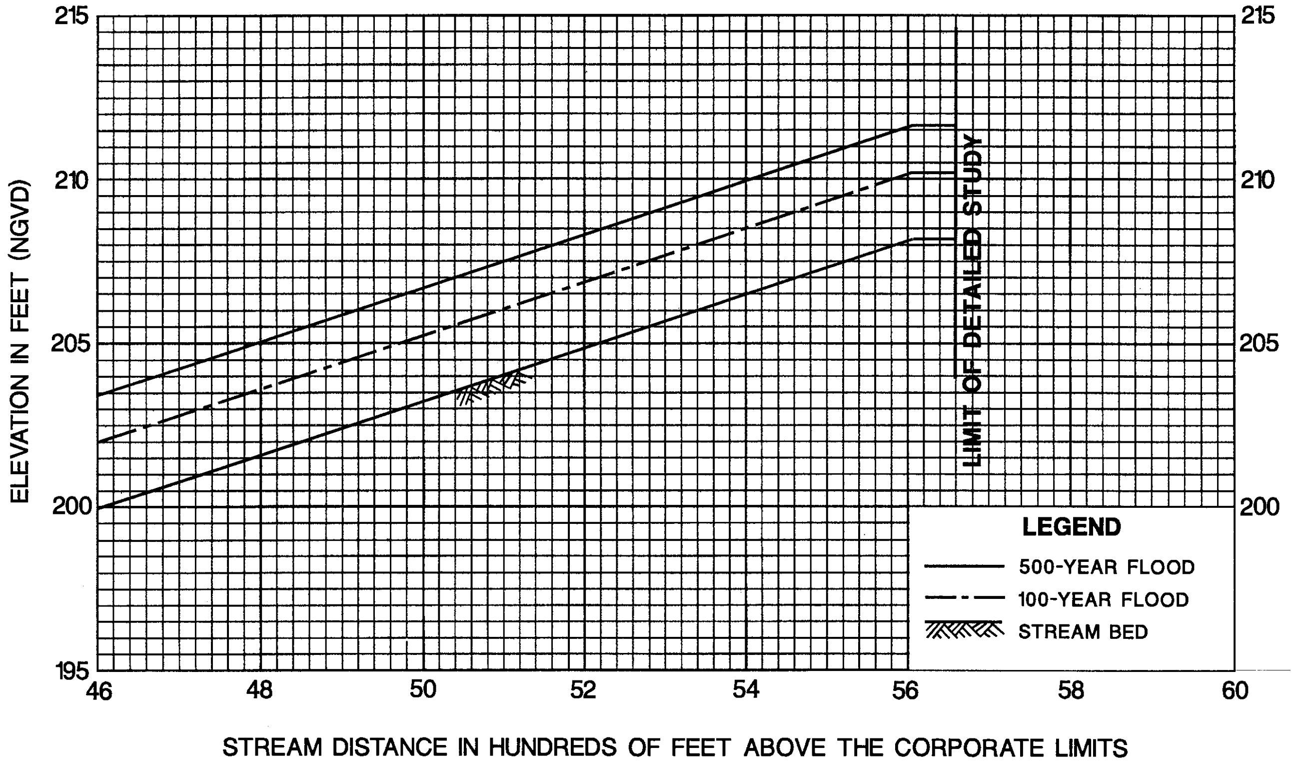


Figure 15 - Data Extrapolation Method - Profile

Detailed Methods

Three essential factors must be determined either by hand calculations or by computer model to determine a BFE by detailed methods. These factors are: 1) floodplain geometry (topography); 2) flood discharge and/or volume (hydrology); and 3) flood height (hydraulics).

Topography involves the measurement of the geometry of a cross section(s) of the floodplain, which includes horizontal and vertical coordinates. The vertical coordinate, or elevation, is related to a vertical datum, such as the National Geodetic Vertical Datum of 1929 or North American Vertical Datum of 1988. The horizontal coordinate, or station, is measured from a reference point along the cross section to establish actual ground points.

Hydrology for the particular location along a stream involves the determination of the peak rate of stream flow [usually measured in cubic feet per second (cfs)] that will occur during a flood (for purposes of determining the BFE, the 100-year flood). When determining lake or pond elevations, a 100-year flood hydrograph is required to determine the BFE.

Hydraulics involves the determination of the water-surface elevation that will occur during a flood (for purposes of determining the BFE, the 100-year flood), the selection of a method to relate the flood discharge to a flood depth, and the selection of Manning's roughness coefficients or "n" values. These "n" values vary depending on the type of materials; degree of irregularity; variation of shape, obstructions, and vegetation; and degree of meandering related to the channel and the floodplain of a stream.

The following sections discuss various methods for determining the topography, hydrology, and hydraulics for a particular location in order to determine a BFE.

Topography

Existing Topographic Maps

Before initiating field surveys, determine if there is existing detailed topographic mapping that can be used to generate cross-section data. To adequately describe a floodplain and for use with a hydraulic method to calculate a BFE, topographic map scales and contour intervals must be the same as, or more detailed than, those used to prepare the community's Flood Insurance Study. The greater the level of detail on the topographic map, the more accurate the BFE determination. If the community does not have a Flood Insurance Study, an existing topographic survey should, at a minimum, be as detailed as the U.S. Geological Survey quadrangle map for the area. Regardless of the level of detail of the existing topographic map used, it is suggested that the geometry of the actual stream channel be obtained by a site visit if the cross sections are to be used for hydraulic analyses.

Datum Requirements for Field Surveys

If a greater level of detail is desired than is available from existing topographic mapping, then a field survey should be performed. If it is necessary to establish a BFE for insurance purposes or to meet the requirements of 60.3 of the NFIP Regulations, the survey must be referenced to the same datum that is used to produce the FIRM, which is usually the National Geodetic Vertical Datum of 1929 or the North American Vertical Datum of 1988. Reference marks giving elevations to this datum are given in the published Flood Insurance Studies. If the reference marks cannot be located in the field, or are simply too far away, additional reference mark information may be obtained from the State's U.S. Geological Survey or Transportation office. Local surveyors are generally familiar with nearby reference marks. In approximate Zone A areas, if it is not economically feasible to reference survey information to a known reference mark, an assumed datum may be used, provided that the BFE, structure, and lot elevations are referenced to the same assumed datum; however, data developed using such an assumed datum may not be sufficient to revise a FIRM. All surveys must be certified by a registered professional engineer or land surveyor.

If the sole purpose of determining relative flood heights is to meet the requirements set forth in Section 60.3(a) of the NFIP regulations, any assumed datum may be used. In this instance, a depth of flooding can be established at a particular location without having to reference it to a datum (i.e., National Geodetic Vertical Datum). However, in order for an insurable structure to be eligible for a lower insurance rate based on the BFE, the survey may need to be referenced to the same datum that was used for the FIRM (i.e., National Geodetic Vertical Datum or North American Vertical Datum).

Number of Cross Sections Required

If the determination of the BFE is for only one lot, one cross section is required across the 100-year floodplain through the property in question. For large parcels and multi-lot subdivisions, at least one cross section is required at each end of the parcel or subdivision. Additional cross sections must be added if the difference in the computed 100-year water-surface elevations at the two cross sections is more than one foot and the distance between the cross sections is greater than 500 feet.

Proper Location of Cross Sections

The following guidelines should be used to determine the proper location for cross sections:

- Flow Path: Cross sections must be oriented perpendicular to the anticipated flow path of the 100-year flood, as shown in Figure 16, "Cross Section Orientation."

- Channel Characteristics: Cross sections should be located where changes in channel characteristics, such as slope, shape, and roughness, occur.

- Discharge: Cross sections should be located at points along a stream where changes in flood discharge occur, such as upstream of tributaries, as shown in Figure 17, "Locate Cross Sections at Points of Flood Discharge Changes."

- Structures: A minimum of two cross sections are required to compute a BFE at or near a structure, such as a bridge or dam. If the floodplain configurations upstream and downstream of the structure are similar, two cross sections may be used. One cross section should represent the structure profile including the profile of the road or embankment. When obtaining the structure profile in the field, measurements of the structure opening, if there is one, and any piers should also be obtained. The other cross section should represent the natural valley cross section downstream of the structure and should not include any part of the structure or embankment. The natural valley cross section should be located at a distance equal to the width of the structure opening, W, measured from the downstream foot of the embankment or wing walls, as shown in Figure 18, "Cross Section Locations at Structures."

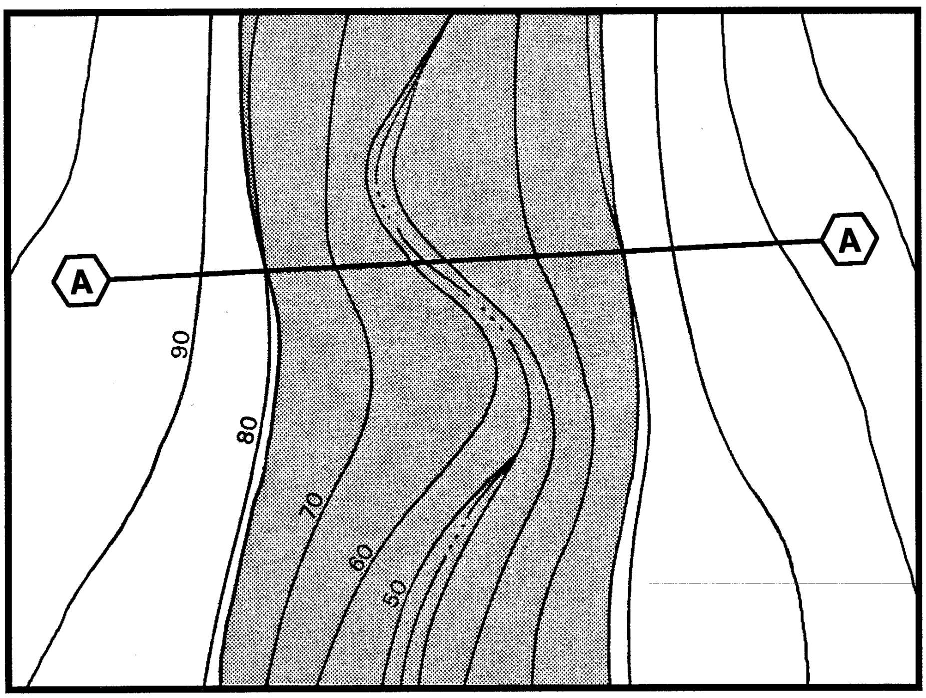


Figure 16 - Cross Section Orientation

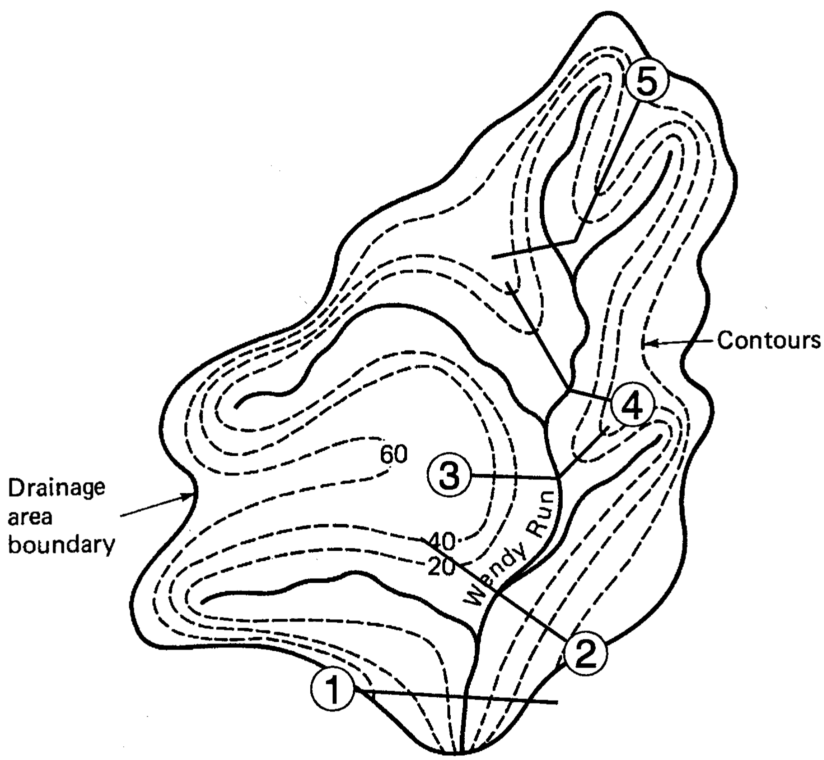


Figure 17 - Locate Cross Sections at Points of Flood Discharge Changes

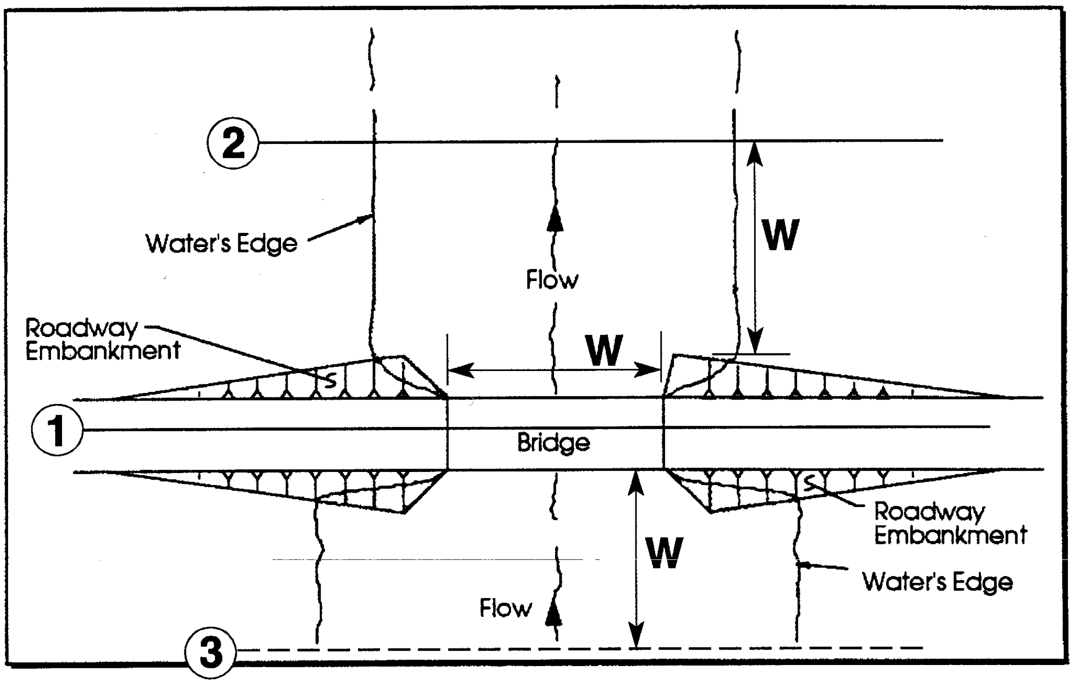


Figure 18 - Cross Section Locations at Structures

If the floodplain configurations upstream and downstream of the structure are different and the structure is a bridge, an additional cross section should be used upstream of the structure. The cross section should be located at a distance equal to the width of the structure opening upstream of the structure as measured from the foot of the embankment or wing walls.

The stations and elevations for cross section ground points outside of the stream channel may be obtained from a topographic map. The size of the structure opening, piers, and channel geometry, however, should be obtained by field survey.

Hydrology

There are a number of methodologies that may be used to develop flood discharges for approximate Zone A areas. The methods discussed below were selected because they are fairly simple to use, require information that is easily obtainable, and provide reasonable discharge estimates for streams where more detailed hydrologic analyses have not been performed. These methods, which have been ordered based on ease of use and expected level of accuracy, include discharge-drainage area relationships, regression equations, the NRCS TR-55 graphical peak discharge and tabular hydrograph methods, and the rational formula. Other hydrograph methods will also be noted but not described in detail due to their complexity.

Discharge-Drainage Area Relationships

This method is suggested for approximate Zone A areas because it is straightforward and the only data needed are drainage areas and corresponding 100-year flood discharges. These data can be obtained from the Summary of Discharges table in a Flood Insurance Study report.

The relationship between drainage area and discharge is non-linear in most cases; therefore, the drainage areas and corresponding 100-year flood discharges from the Flood Insurance Study should be plotted on log-log paper as shown in Figure 20 from the example which begins on the following page. The streams plotted may have varying drainage areas; however, other watershed characteristics should be similar. A straight line should be drawn through the plotted points as shown in Figure 21. The 100-year flood discharge for a particular location can then be estimated based on the drainage area at the location as shown in Figure 21 from the example.

Limitations - If the relationship of plotted points cannot be approximated by a straight line, then this method should not be used. In addition, this method is not appropriate when the stream along which the site is located is regulated by dams, detention ponds, canals, or other flow control structures or diversions.

EXAMPLE: DISCHARGE-DRAINAGE AREA RELATIONSHIPS

The following is a Summary of Discharges table from a Flood Insurance Study report.

TABLE 1 - SUMMARY OF DISCHARGES

FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	PEAK DISCHARGES (cfs)			
		10-YEAR	50-YEAR	100-YEAR	500-YEAR
PINE CREEK					
At confluence with Saddle River	20.39	2,220	4,165	5,310	9,010
At Calvin Street	16.3	1,907	3,617	4,612	7,300
At Caitlin Avenue	14.9	1,860	3,285	4,090	6,570
ROCK RUN					
Downstream of confluence of Ramsey Brook	12.6	1,640	2,895	3,605	5,795
Upstream of confluence of Ramsey Brook	10.1	1,390	2,455	3,055	4,910
GOOSE CREEK					
Downstream of confluence of Valentine Brook	9.1	1,285	2,270	2,825	4,540
Upstream of confluence of Valentine Brook	6.2	965	1,700	2,120	3,405
COON CREEK					
Downstream of confluence of Allendale Brook	14.3	1,805	3,185	3,965	6,370
Upstream of confluence of Allendale Brook	12.9	1,670	2,950	3,670	5,900

Assume that Wendy Run is a stream within the same community as the streams listed in the table, and that the Wendy Run drainage basin, shown in Figure 19, has similar characteristics to the stream basins from the table. First, plot the drainage areas and corresponding 100-year discharges on log-log paper as shown in Figure 20 on the following page. Then draw a straight line through the plotted points as shown in Figure 21.

At Property A, the drainage area for Wendy Run is 8.5 square miles. Using the drainage area curve created from the Flood Insurance Study Summary of Discharges table, the 100-year discharge at Property A is estimated to be 2,750 cfs, as shown on Figure 21. At Property B, with a drainage area of 12.0 square miles, an estimated 100-year discharge of 3,600 is obtained, as shown on Figure 21.

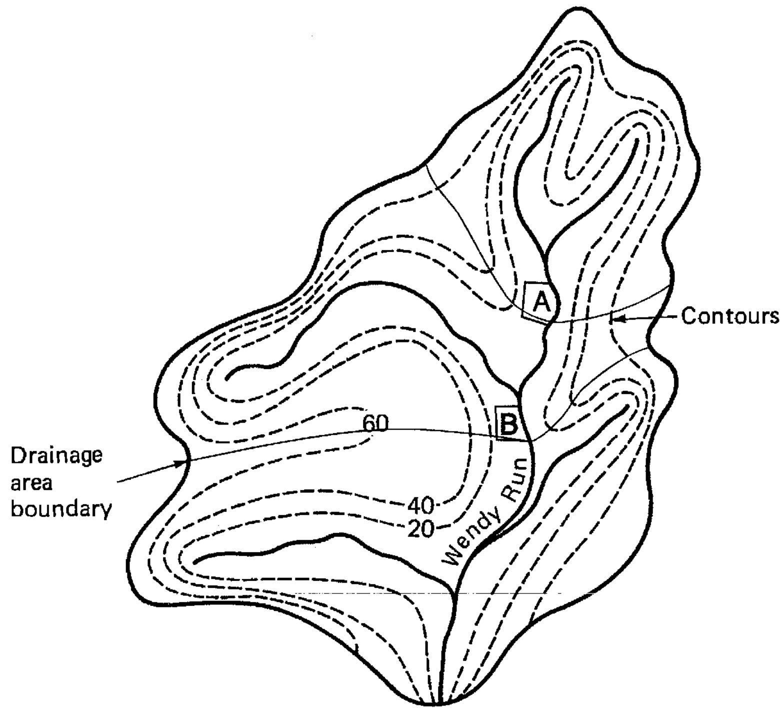


Figure 19 - Wendy Run Drainage Basin

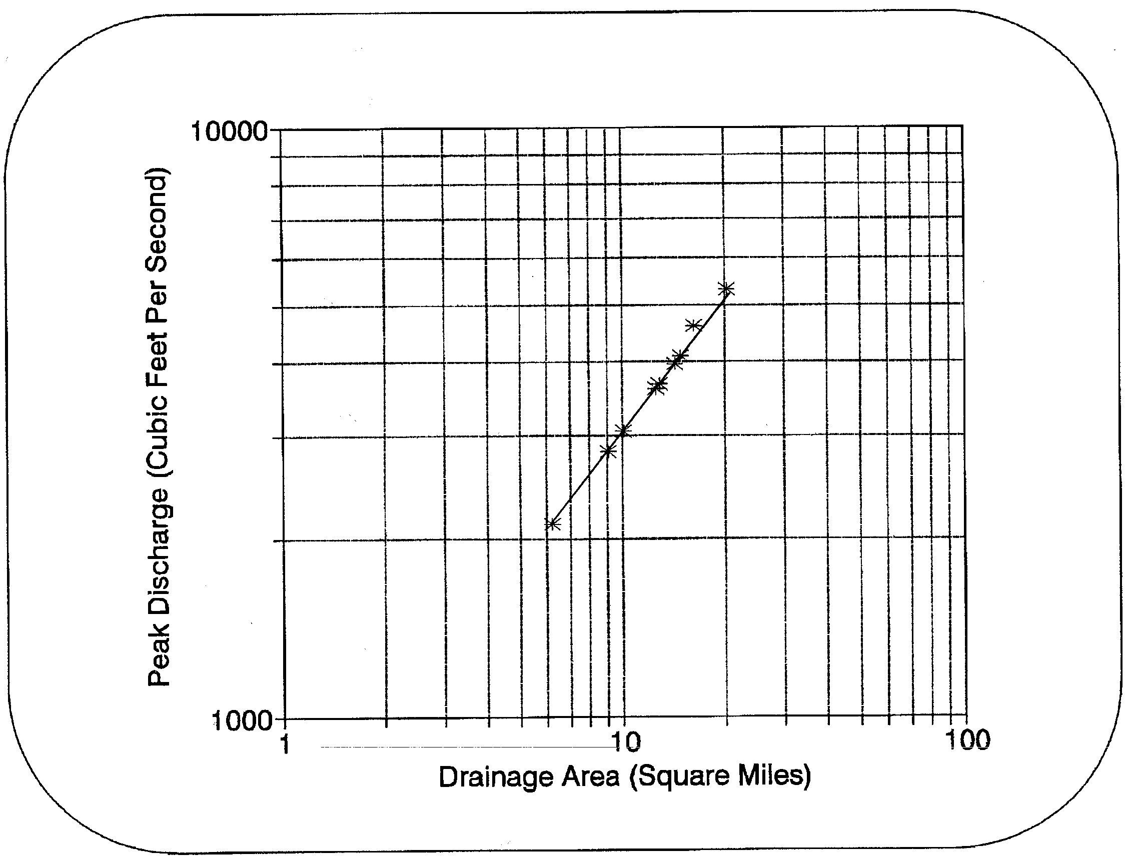


Figure 20 - Discharge-Drainage Area Plot

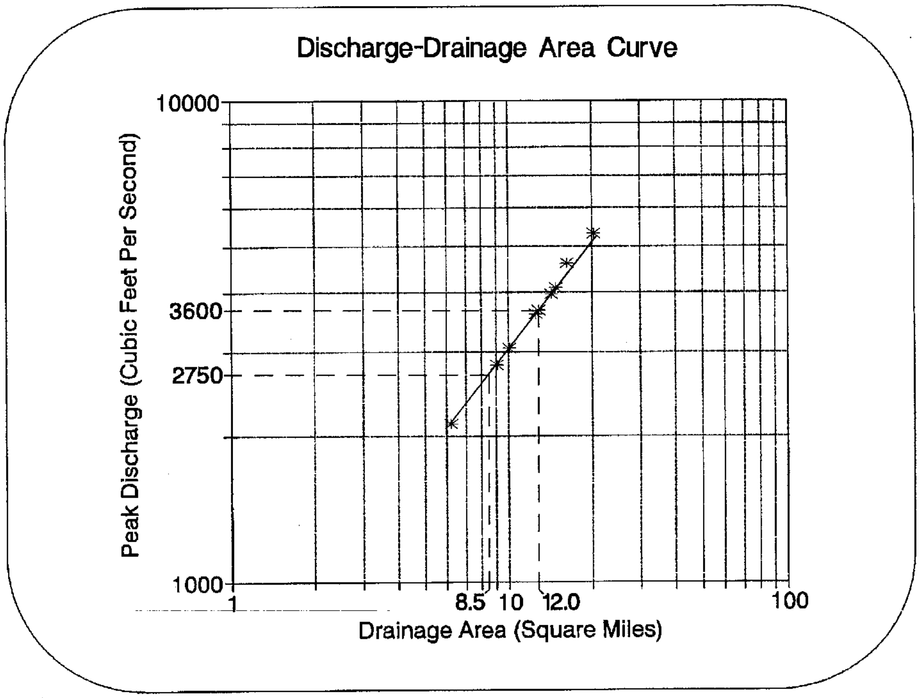


Figure 21 - 100-year Discharge Estimates for Site A and Site B

Regression Equations

Another methodology that can be used for determining discharges for approximate Zone A areas is the application of the appropriate regression equation found in a U.S. Geological Survey publication (Water Resources Investigation or Open File report). A list of these publications applicable to each State is in Appendix 4. The U.S. Geological Survey has also released Version 1.1 of the National Flood Frequency Computer Program. The National Flood Frequency Program contains the regression equations for all of the continental United States.

The use of regression equations involves the determination of specific variables for a watershed (drainage area, mean annual precipitation, forest cover, stream slope, etc.). Regression equations are based on actual stream gage data and are usually developed to determine discharges for the 2-year event up to the 100-year event (for purposes of determining the BFE, determine the 100-year discharge).

The general form of these regression equations is:

$$Q = K * A^x * B^y * C^z$$

where: Q = discharge (cfs)
K = regression equation constant
A,B,
and C = watershed variables
X,Y,
and Z = exponents

Watershed variables may include parameters such as drainage area (in square miles), stream slope (in feet/mile), and impervious area (in percent).

Limitations - Care must be taken when using these publications because restrictions generally apply when the watershed is heavily urbanized (i.e., high percentage of impervious land), or where the runoff is regulated by the use of dams, detention ponds, canals and other flow diversions. Other restrictions based on the physical parameters of the watershed, such as drainage area or stream slope, may also apply. Limitations of these equations are normally stated in each report and should be examined closely.

TR-55

The NRCS TR-55 "Urban Hydrology for Small Watersheds" contains two methods for computing flood discharges: the Graphical Peak Discharge method and the Tabular Hydrograph method. TR-55 is straightforward in its approach and method of computation. TR-55 takes into account the effects of urbanization, rainfall distribution, soil types and conditions, ground cover types, and other watershed characteristics. A method for estimating the effects of storage on peak flood discharges is also included in TR-55.

Limitations - In general, TR-55 should not be used in areas where flow is divided between closed storm sewer systems and overland conveyance areas, or where drainage areas exceed 2,000 acres. More specific limitations for using TR-55 are contained in Chapters 2 through 6 of the NRCS TR-55 manual.

Rational Formula

This method estimates peak discharge rates for small watershed areas not covered by regression equations and for areas where the NRCS TR-55 method is not applicable. The Rational Formula is based on the drainage area, rainfall intensity, watershed time of concentration, and a runoff coefficient. The generalized equation is:

$$Q = C * I * A$$

where: Q = discharge (cfs)
C = runoff coefficient
I = rainfall intensity (inches/hour)
A = drainage area (acres)

The runoff coefficient, C, varies with soil type, land use, and terrain slope and can be obtained from text books on hydrology. The intensity of rainfall, I, is determined based on the total rainfall for a selected exceedence probability and a duration equal to the time of concentration for the watershed. The time of concentration for the watershed can be computed using the method described in the NRCS TR-55 manual or methods described in hydrology text books. For approximate Zone A areas, the exceedence probability is equal to 1 percent (100-year storm frequency). The 1 percent exceedence probability total rainfall (100-year rainfall) for the computed duration can be obtained from Technical Paper No. 40, Hydro 35, and precipitation-frequency atlases published by the National Weather Service. Dividing the total rainfall by the computed duration will yield the intensity of rainfall.

Limitations - This method must not be used where the runoff is regulated by the use of dams, detention ponds, canals and other flow diversions. Also, this method is not recommended for drainage areas greater than 200 acres, but can be used with caution for drainage areas up to 640 acres (one square mile).

Other Hydrograph Methods

There are numerous other methods that can be used to determine flood discharges based on rainfall-runoff relationships. The following hydrograph methods are described in detail within their respective technical reports and, therefore, will not be described in detail within this guide. These methodologies in general are good for any size watershed, and most of the methods include computations that take into consideration areas where the runoff is regulated by the use of dams, detention ponds, canals and other flow diversions. These methods are recommended for determining BFEs for ponds or lakes that are designated as approximate Zone A. Besides TR-55, two of the more widely used hydrograph methods are the NRCS' TR-20 and the U.S. Army Corps of Engineers' HEC-1 computer programs.

TR-20 and HEC-1 provide a very detailed calculation of discharge through the generation, addition, and routing of runoff hydrographs. The effect on peak flood discharges due to dams, road crossings, and large floodplain storage areas is more accurately assessed with these programs. These models require experience on the part of the user if they are to produce realistic determinations of peak discharge.

Limitations - The limitations of these methods are thoroughly described in their manuals. Because these methods involve many variables and assumptions, the potential for error is great. The users of these models must be thoroughly versed in the limitations and assumptions of the computational methods contained in these models. As with any synthetic model depicting rainfall-runoff relationships, extreme care needs to be taken to ensure that the results of the model are reasonable. It is highly recommended that the discharges produced by these hydrograph methods be compared to discharges produced by another hydrologic method of equal accuracy or by calibrating the model to an actual storm event.

Hydraulics

There are various hydraulic methods that may be used to determine BFEs along riverine flooding sources. The appropriate method to use depends on flow conditions and the size of the area that is being analyzed. For developments of equal to or less than 50 lots or 5 acres, the normal depth method, which is described in greater detail below, is usually adequate for determining BFEs. After normal depth has been computed, flow conditions should be analyzed. If flow is classified as subcritical (i.e., normal depth is greater than critical depth), normal depth is used as the BFE. If flow is classified as supercritical (i.e., normal depth is less than critical depth), then critical depth is used as the BFE for natural channels. For engineered channels, supercritical (normal) depth may be used for the BFE, provided that the backwater from the normal depth of the downstream cross section is considered properly. If more than one cross section is required, step-backwater computations should be used to determine BFEs along riverine flooding sources.

The procedures for computing normal depth, critical depth, and step-backwater by hand are outlined below. As an alternative to hand calculations, the QUICK-2 computer program may be used.

QUICK-2 is a user-friendly computer program developed by FEMA that may be used for normal depth, critical depth, or step-backwater computations for regular or irregular shaped cross sections. To aid the users of this guide in computing BFEs, the QUICK-2 computer program and user's manual are located in Appendix 6. The user's manual contains a tutorial section which leads a new user through the calculation process using "real life" examples. For those not using the QUICK-2 program, the following sections on Normal Depth and Critical Depth illustrate how to compute these depths by hand (see Appendix 8 for an example of a Normal Depth hand calculation).

Normal Depth

Normal depth is the depth expected for a stream when the flow is uniform, steady, one-dimensional, and is **not affected by downstream obstructions or flow changes**. For uniform flow, the channel bottom slope, water-surface slope, and energy slope are parallel and are, therefore, equal. For normal depth computations, the flow is considered steady because the discharge is assumed to be constant; therefore, the depth of flow does not change during the time interval under consideration.

Normal depth calculations (also called the "slope/area method") compute BFEs at a cross section. The standard formula for determining normal depth at a cross section is Manning's formula. The standard Manning's equation is:

$$Q = 1.486 \times A \times (R^{.667}) \times S^{.5} / n$$

where: Q = discharge (cfs)
A = cross section area (ft^2)
R = hydraulic radius (ft) = A/WP
WP = wetted perimeter (ft)
S = energy slope (ft/ft)
n = Manning's roughness coefficient

The cross section area refers to the area below the water-surface elevation, and the wetted perimeter refers to the length of the ground surface along the cross section below the water-surface elevation. The channel bottom slope is used in lieu of the energy slope.

As noted earlier, Manning's "n" values vary depending on the physical features of the stream channel and the channel overbanks. The results of normal depth calculations can differ significantly depending on the Manning's "n" values used; therefore, care should be taken to ensure that the Manning's "n" values selected accurately reflect conditions at the site being analyzed. Manning's "n" values should be selected based on field inspection, field photographs, and topographic mapping. A list of accepted Manning's "n" values has been included in Appendix 5. Various methods for computing normal depth are described below.

Computer Programs for Computing Normal Depth

In addition to QUICK-2, the following Federal Government computer programs have the capability to perform normal depth computations:

Computer Program	Agency
HEC-2	U.S. Army Corps of Engineers
HEC-RAS	U.S. Army Corps of Engineers
WSPRO	U.S. Geological Survey
WSP2	NRCS
SFD	FEMA
PSUPRO	FEMA

Please note that HEC-RAS is still being tested and had not yet been released to the general public when this guide was published. Furthermore, FEMA has not yet approved the model for requests to revise NFIP maps. Please contact our Headquarters office to determine the current status of HEC-RAS.

In addition to the above-referenced programs, there are other engineering computer programs and models, which perform normal depth calculations, that are available through various commercial vendors. References for the hydraulic computer programs listed above are in Appendix 7.

Normal Depth Hand Calculations

If a computer is not available, it is possible to perform hand computations to calculate normal depth for the 100-year flood at a cross section by following steps 1-11 listed below.

Step 1 - Obtain a topographic map or conduct a field survey to obtain a cross section at the site where normal depth should be determined. If a topographic map is used, the channel geometry should be obtained from measurements taken in the field. The cross section should be oriented perpendicular to the expected 100-year floodplain.

Step 2 - Compute the 100-year discharge by applying one of the methods described in the hydrology section of this guide.

Step 3 - Plot the cross section on graph paper with the stations and the corresponding elevations. (The stations and elevations are obtained from the topographic map and/or from field survey).

Step 4 - Select the left and right channel bank stations. The channel bank stations are those stations where the ground slope becomes flatter moving away from the channel bottom as shown in Figure 22, "Channel Bank Stations." Photographs taken in the field and the contours on the topographic maps are also helpful when defining the channel bank stations. Do not place the channel bank stations at the bottom of the channel.

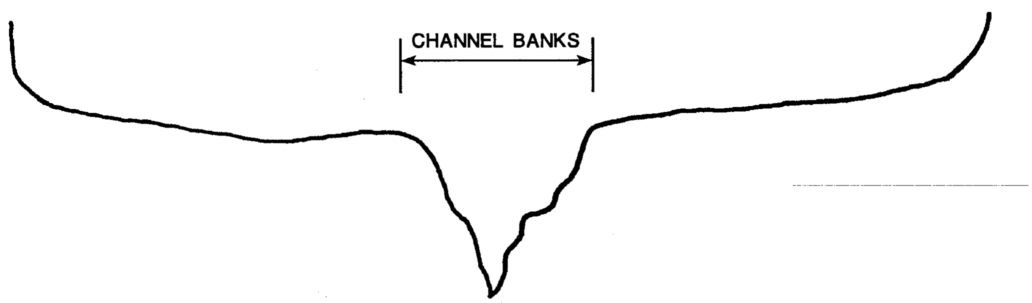


Figure 22 - Channel Bank Stations

Step 5 - Select appropriate Manning's roughness coefficients for the left overbank, channel, and right overbank from the "n" values given in Appendix 5. These values should be determined by reviewing the field photographs and visiting the site.

Step 6 - Compute the cross section area, wetted perimeter, hydraulic radius, and conveyance for each segment (i.e., left overbank, channel, and right overbank) for at least three elevations. The conveyance, K, of a segment is given as:

$$K = (1.486/n) \times A \times R^{0.667}$$

where:
A = cross section area (ft^2)
R = hydraulic radius (ft)
WP = wetted perimeter (ft)
R = A/WP

Step 7 - Compute the channel bottom slope, S, from the topographic map or from field survey.

Step 8 - Compute the discharge, Q, for each segment of the cross section at each elevation by multiplying K by $S^{0.5}$.

Step 9 - Add the discharges from each segment at the same elevation to obtain the total discharge.

Step 10 - Plot the total discharges and the corresponding elevations on graph paper.

Step 11 - The BFE can be determined from this graph for the 100-year flood discharge computed in Step 2.

An example of a normal depth hand calculation is included in Appendix 8.

Critical Depth

After computing normal depth, the type of flow should be checked. If the velocity head from the normal depth computation is equal to or more than half the hydraulic depth, the flow is supercritical and the critical depth should be used to establish the BFE. The velocity head, HV, for an irregular cross section is computed using the following equation:

$$HV = \alpha V^2/2g$$

where: α = velocity coefficient
V = mean velocity = Q_T / A_T (fps)
Q_T = total discharge (cfs)

A_T = total flow area (ft^2)

g = acceleration due to gravity = 32.2 ft/sec^2

The velocity coefficient, α, is determined using the following equation:

$$\frac{[(K_L^3/A_L^2) + (K_C^3/A_C^2) + (K_R^3/A_R^2)]}{K_T^3/A_T^2}$$

where: K_L, K_C, K_R, K_T = conveyance for left overbank, channel, right overbank, and total conveyance, respectively

A_L, A_C, A_R, A_T = flow area for left overbank, channel, right overbank, and total flow area, respectively

Hydraulic depth, h, is computed by using the following relationship:

$$h = A_T / T$$

where: T = top water-surface width at the normal depth
A_T = Total Flow Area

If the velocity head is greater than or equal to one-half the hydraulic depth, the flow is supercritical.

For **prismatic channels**, the following equation can be used to determine the critical depth:

$$\frac{Q^2}{g} = \frac{A^3}{T} \quad \text{or} \quad Q = \sqrt{gA^3 / T}$$

For a series (3 or more) of water-surface elevations, compute the corresponding total area, A, water-surface topwidth, T, and the critical discharge, Q, using $Q = \sqrt{gA^3 / T}$. Compute the value of right hand side of the above equation. Plot the water-surface elevations and the corresponding discharge values on graph paper. The critical water-surface elevation and, therefore, critical depth, can be determined from this graph for a range of discharge values.

For **rectangular channels**, critical depth can be computed directly from the above equation and is expressed in the following relationship:

$$D_C = \{ Q / (5.67\ T)\}^{0.667}$$

The energy is minimum at the critical depth. For **irregular cross sections**, critical depth is determined from the relationship between the water-surface elevation and the energy. The energy is computed by adding the water-surface elevation and the corresponding velocity head (or energy grade elevation). For irregular cross sections, the velocity coefficient, a(α), must be considered when computing velocity head (HV). Several water-surface elevations should be assumed and corresponding energy grade elevations computed. These values are then plotted on a graph of water-surface elevation versus energy grade elevation. The critical water-surface elevation and, therefore, critical depth, can be determined from this graph where the energy (i.e., energy grade elevation) is minimum.

Step-Backwater Analysis

Step-backwater computations are based on the principle of conservation of energy, which states that the energy at the upstream cross section is equal to the energy at the downstream cross section plus the losses between the two cross sections. The losses considered in the step-backwater analysis are the friction loss and the transition loss.

The equations and the procedure used in the step-backwater analysis are explained in the QUICK-2 user's manual in Appendix 6. Although hand computations can be done to perform the step-backwater analysis, it is advisable to use the QUICK-2 program or other Federally approved programs for ease of computation. The QUICK-2 program currently does not model the effects of bridges or culverts or supercritical flow.

The QUICK-2 program uses the default friction slope method, which is the average conveyance method, from the HEC-2 program to compute friction losses. For transition losses, a contraction coefficient of 0.1 and an expansion coefficient of 0.3 should be used in the computations.

The reach lengths between the two cross sections for the left overbank, channel, and right overbank are required for step-backwater computations. The distance for the left overbank should be measured between the center of the floodplains of the left overbank at each cross section. The same is true for the right overbank. The channel distance should be measured along the streambed, and therefore will account for the meandering of the stream channel.

In general, starting water-surface elevations are obtained from normal depth computations (slope/area method) at the first cross section. If there is a structure downstream of the study area, the backwater effects of the structure must be considered in determining the starting water-surface elevation. If there is a known 100-year water-surface elevation at the downstream end of the study area, that water-surface elevation should be used as the starting water-surface elevation.

Hydraulic Structures

As stated earlier, normal depth is the depth expected for a stream when the flow is uniform, steady, one-dimensional, and is not affected by downstream obstructions or flow changes. However, there are situations in which a physical structure located downstream of a particular site will cause an obstruction or alteration of the flow, resulting in a flood depth at the site higher than the normal depth. The discussion below describes the appropriate methods for determining BFEs for reaches that include hydraulic structures.

Hydraulic structures that are common in approximate Zone A areas include road and railroad crossings, including embankments, dams, bridges and culverts, and canal crossings. The flow over the road, railroad, embankment, dam or canal can be described as weir flow. Weir flow can be calculated by hand or by computer program in order to determine the BFE. When flow passes through a bridge or culvert, the BFE can be determined through the use of nomographs or computer programs. The BFE at a structure where flow travels through a bridge or culvert and over the crossing can be determined by nomographs, but is more easily determined with a computer program.

Weir Flow

Determination of the water-surface elevation for weir flow requires at least two cross sections. The first cross section represents the natural valley section downstream of the structure, and the second cross section represents the road profile and the opening of the structure (refer to Figure 18, "Cross Section Locations at Structures." If the approach velocity head is to be considered, then a third cross section is required that represents the natural valley section upstream of the structure. In most situations, however, the velocity head can be assumed to be negligible, and a third cross section is not necessary.

The water-surface elevation downstream of the structure should be determined by using normal depth computations at the first cross section, provided there are no structures further downstream that can create backwater effects (refer to the methods for determining normal depth described previously).

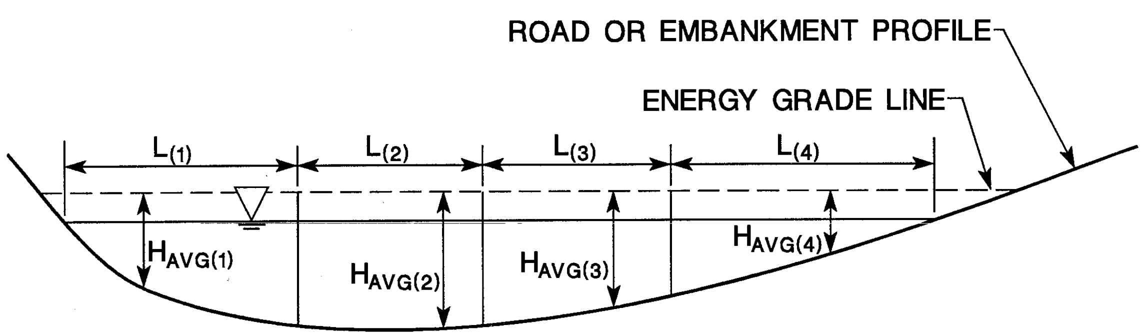
The second cross section, which represents the profile along the top of the structure including the road or the embankment, should be used to determine the weir length for use in the equation for weir flow, as shown on the following page.

$$Q = @ \times C \times L \times H^{3/2}$$

where: Q = discharge (cfs)
@ = submergence factor
C = weir coefficient, varies from 2.6 to 3.0 and can be obtained from hydraulic text books
L = weir length (ft)
H = available head (ft), measured from top of weir to the selected energy grade elevation

Several values for H should be selected and the corresponding discharge computed until the total weir flow is larger than the 100-year flood discharge. Plot the discharges and the corresponding energy grade elevations on graph paper. The 100-year flood energy grade elevation can be determined from this graph. For an approximate analysis, the computed energy gradient elevation can be considered the BFE.

If the structure profile is not horizontal, as shown in Figure 23, "Weir Flow - Embankment Profile is Not Horizontal," several structure segments should be used and an average energy depth, H, for that segment should be determined for use in the above equation for selected energy grade elevations. The sum of the weir flow from each segment will then be equal to the total weir flow for the selected energy grade elevation.



$$Q = (@\ CL_{(1)}\ H_{AVG(1)}^{3/2}) + (@\ CL_{(2)}\ H_{AVG(2)}^{3/2}) + (@\ CL_{(3)}\ H_{AVG(3)}^{3/2}) + (@\ CL_{(4)}\ H_{AVG(4)}^{3/2})$$

Figure 23 - Weir Flow - Embankment Profile is Not Horizontal

If the downstream water-surface elevation is higher than the minimum road elevation, a submergence factor may be considered in the weir flow computation. The submergence factor is dependent upon the D/H ratio, where D is the downstream depth of water above the road and H is the upstream energy grade depth above the road, as shown in Figure 24, "Weir Flow Over Road." The submergence factor must be considered when the D/H ratio is more than 0.79. For a non-horizontal road profile, the D/H ratio must be computed for each road segment. The submergence factor, @, can be determined from the curve in "Hydraulics of Bridge Waterways" (Reference 1, Figure 24) and some typical values are given in the table below.

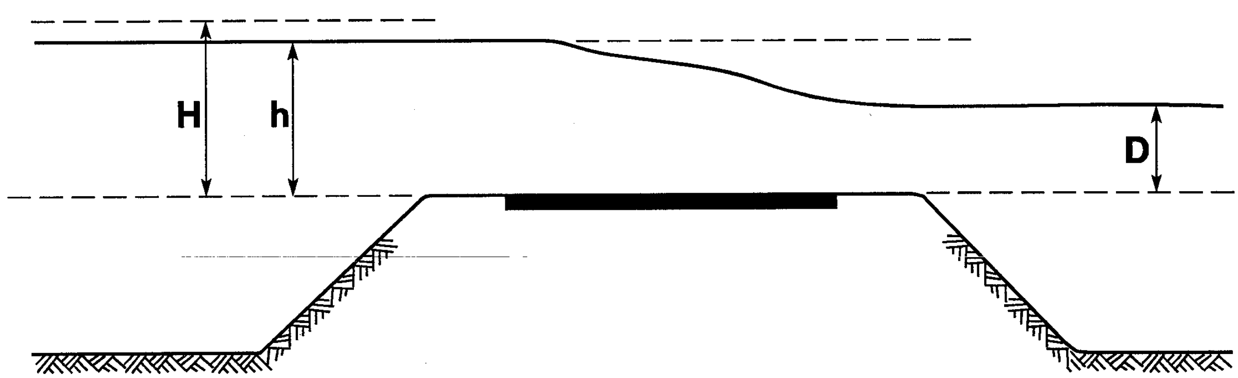


Figure 24 - Weir Flow Over Road

D/H	@	D/H	@
0.998	0.30	0.944	0.80
0.992	0.40	0.932	0.85
0.986	0.50	0.915	0.90
0.976	0.60	0.889	0.95
0.962	0.70	0.700	1.00

Other procedures used in Federal agency backwater computer programs can also be used to determine the submergence factor.

A third cross section may be used to determine a more accurate water-surface elevation upstream of the structure. This may be done by assuming water-surface elevations and calculating the corresponding velocity heads (HV) until an assumed water-surface elevation plus its velocity head at that elevation equal the same energy gradient elevation obtained from the weir flow equation. The velocity head, HV, can be calculated using the following equation:

$$HV = \alpha \ (Q/A)^2/2g$$

where: α = velocity coefficient
Q = 100-year flood discharge (cfs)
A = cross section area (ft^2) at the assumed water-surface elevation
g = Acceleration due to gravity = 32.2 ft/sec^2

An example of a weir flow computation is included in Appendix 9.

Flow Through Structures

Culverts

At least two cross sections are required to determine the water-surface elevation upstream of a culvert. The first cross section should represent the natural valley cross section downstream of the culvert, and the second cross section should represent the top of the embankment profile and the opening of the structure (refer to Figure 13, "Cross Section Locations at Structures"). The size, type, length, and upstream and downstream invert elevations of the culvert should be obtained by field survey. The wing wall angle and the entrance opening configuration, such as sharp edge or rounded edge, should also be determined from a field survey. The Federal Highway Administration publication "Hydraulic Design of Highway Culverts" (Reference 2) should be referenced before going to the field so that all the necessary information for culvert flow computations can be collected during one field survey. Water-surface elevations upstream of the culvert can then be computed using the nomographs contained in the above-mentioned publication and the procedures outlined below.

The first cross section should be used to determine the normal depth downstream of the culvert, which will be considered as the tailwater (refer to section on normal depth computations).

Two computations are required to determine the headwater when using Federal Highway Administration nomographs. One computation is for inlet control, and the other computation is for outlet control. The headwater elevations from the two computations are then compared. The higher of the two should be selected as the upstream headwater elevation. If this headwater elevation is higher than the top of embankment profile, weir flow will occur. Perform at least three weir flow computations for headwater elevations between the headwater that assumes that all the flow is culvert flow (the first computation) and the minimum top of embankment elevation. For each selected headwater elevation, compute the culvert flow using Federal Highway Administration nomographs. Combine the weir flow and culvert flow for each selected headwater elevation and plot on graph paper. The BFE for the 100-year flood discharge can then be obtained from this graph.

If the site in question is not located immediately upstream of a structure, a normal depth should be computed at the site. The 100-year water-surface elevation at the site should be the higher of the two elevations from the culvert computation and the normal depth computation.

Federal Highway Administration nomographs predict only the energy grade elevation upstream of the culverts. In most applications, the velocity head is assumed to be negligible and, therefore, the energy grade elevation approximates the actual water-surface elevation. If a more accurate water-surface elevation is desired, a hydraulic computer model, such as HEC-2, should be used to determine the BFE. The procedure outlined in the weir flow section to compute a water-surface elevation that corresponds to a certain energy grade elevation may also be used to determine a BFE upstream of a culvert.

Bridges

Although hand computations can be performed by following the procedures for bridge routines in Federal agency computer models, it is recommended that the water-surface elevation upstream of bridges be determined using a computer model. The number of cross sections required at the structure depends upon the type of bridge routine used. Four cross sections are required if the special bridge routine in the HEC-2 program is used, and six cross sections are required if the normal bridge routine in the HEC-2 program is used. Three cross sections are required if the bridge routines in the WSPRO program and the WSP2 program are used. A step-backwater analysis is also required to compute the water-surface elevations with these bridge routines. The following programs are recommended to compute the water-surface elevation upstream of a bridge:

Computer Program	Agency
HEC-2	U.S. Army Corps of Engineers
*HEC-RAS	U.S. Army Corps of Engineers
WSPRO	U.S. Geological Survey
WSP2	NRCS

*Not available for general use when this guide was published; please contact our Headquarters office for current status.

REFERENCE

1. U.S. Department of Transportation, Federal Highway Administration, Hydraulics of Bridge Waterways, Washington, D.C., March 1978.

2. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design of Highway Culverts, Washington, D.C., September 1985.

VI. OBTAINING LETTERS OF MAP CHANGE

Once detailed methods have been applied to develop BFE data, these data may be suitable for revising an NFIP map via a Letter of Map Correction. On October 1, 1992, FEMA implemented the use of detailed application and certification forms for requesting revisions to NFIP maps. Therefore, if a map revision is requested, the appropriate forms should be submitted.

FEMA has implemented a procedure to recover costs associated with reviewing and processing requests for modifications to published flood information and maps. Specific information about these fees is presented in the application and certification forms.

These forms, along with other useful documents pertaining to the NFIP, may be obtained from our technical evaluation contractors at the addresses listed below:

<u>FEMA Regions I-V</u>

Dewberry & Davis
Management Engineering and
Technical Services Division
8401 Arlington Boulevard
Fairfax, Virginia 22031
FAX: (703) 876-0073

<u>FEMA Regions VI-X</u>

Michael Baker, Jr., Inc.
3601 Eisenhower Avenue
Suite 600
Alexandria, Virginia 22304
FAX: (703) 960-9125

This information is also available through the FEMA Regional Offices listed in Appendix 3.

To provide additional assistance to those who develop BFE data, a worksheet that synopsizes the procedures detailed in this guide is found in Appendix 10.

Appendix 1

Glossary of Floodplain Analysis Terms

1-Percent Annual Chance Flood: the flood that has a one-percent chance of being equaled or exceeded on the average in any given year; equivalent to the 100-year flood.

100-Year Flood: the flood that is equaled or exceeded once in 100 years on the average; equivalent to the one percent annual chance flood.

Alluvial Stream: a stream that has formed its channel by the process of aggradation. The sediment in the stream is similar to the material in the bed and banks.

Base Flood: the flood having a one percent chance of being equalled or exceeded in any given year (the 100-year flood).

Base Flood Elevation (BFE): the water-surface elevation associated with the base flood.

Conveyance: a measure of the carrying capacity of the channel section. Flow (Discharge (Q)) is directly proportional to conveyance (K). The proportional factor is the square root of the energy slope; expressed as $Q = K * S^{½}$.

Cross Section: a vertical profile of the ground surface taken perpendicular to the direction of flood flow. The profile is defined by coordinates of ground elevation and horizontal distance (station).

Discharge: a measure of flow volume per unit of time. In hydrology, units of flow are usually cubic feet per second (cfs).

Exceedence Frequency: the frequency that a flood of a certain discharge will be equaled or exceeded in any given year; equal to the inverse of the recurrence interval.

Flood: (a) a general and temporary condition of partial or complete inundation of normally dry land areas from: (1) the overflow of inland or tidal waters; (2) the unusual and rapid accumulation or runoff of surface waters from any source; (3) mudslides (i.e., mudflows), which are proximately caused by flooding as defined in (a)(2) above and are akin to a river of liquid and flowing mud on the surfaces of normally dry land areas, as when earth is carried by a current of water and deposited along the path of the current. (b) The collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels or suddenly caused by an unusually high water level in a natural body of water, accompanied by a severe storm, or by an unanticipated force of nature, such as flash flood or abnormal tidal surge, or by some similarly unusual and unforeseeable event, which results in flooding as defined in (a) (1) above.

Flood Crest: the maximum height of a flood, usually measured as an elevation or depth.

Flood Hazard: the potential for inundation that involves the risk to life, health, property, and natural floodplain values.

Glossary of Floodplain Analysis Terms

Floodplain: any land area, such as the lowland and relatively flat areas adjoining inland and coastal waters, susceptible to being inundated by water from any source.

Floodway: the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water-surface elevation more than a designated height. The base flood is defined as the one-percent chance flood and the designated height is usually one foot above the base flood elevation; however, this height may vary (but is not more than one foot) depending on what the State has adopted.

Floodway Fringe: the area between the floodway boundary and the 100-year floodplain boundary.

Flow: equivalent to *discharge*.

Flow Area: the cross section (see discharge) area of the floodplain below a given water-surface elevation.

Hazardous Flow: conditions that exist when the product of the depth of flow and its corresponding velocity are greater than ten (10). For example a flow depth of 3 feet and a flow velocity of 4 feet per second (3 x 4 = 12) would be considered hazardous flow.

Hydraulic Depth: an average depth computed as the *Flow Area* divided by the top width of the floodplain for a given water-surface elevation.

Lacustrine Flooding: Flooding produced by a lake or pond.

Peak Discharge: the maximum instantaneous discharge of a flood at a given location.

Recurrence Interval: the average interval of time required for a flood of a specific discharge to occur or be exceeded; equal to the inverse of the exceedence frequency.

Riverine Flooding: Flooding produced by a river or stream.

Shallow Flooding: a designated AO, AH, or VO zone on a community's Flood Insurance Rate Map with a one percent or greater annual chance of flooding to an average depth of one to three feet where a clearly defined channel does not exist, the path of flooding is unpredictable, and velocity flow may be evident. Such flooding is characterized by ponding or sheet flow.

Slope (Energy): the rate of energy loss of a watercourse.

Slope (Ground): the change in vertical ground elevation over a horizontal distance, usually based on the change in the vertical elevation of the stream bottom.

Steady Flow: state of flow where the depth of flow does not change with time.

Subcritical Flow: state of flow where the gravitational forces are more pronounced than the inertial forces. The flow tends to have a low velocity. In general, in this flow regime, the hydraulic depth is more than twice the *velocity head*.

Supercritical Flow: state of flow where the inertial forces become dominant. The flow tends to have a high velocity. In general, in this flow regime, the *velocity head* is equal to or more than half the *hydraulic depth*.

Glossary of Floodplain Analysis Terms

Unsteady Flow: state of flow where the depth of flow changes with time.

Uniform Flow: depth is constant over channel length, and the channel shape, slope and boundary roughness are constant over the channel length.

Varied Flow: depth of flow changes along the channel length.

Gradually Varied Flow: depth of flow changes gradually over the channel length.

Rapidly Varied Flow: depth changes abruptly over a short channel length.

Velocity: a rate of movement (i.e., distance divided by time). For water, the rate is expressed in feet per second. Because water in a channel does not all move at the same velocity at every point, an average value is used to described flow velocity. This average velocity equals the discharge divided by the flow area (Q/A).

Velocity Head: the kinetic energy term ($\alpha V^2 / 2g$), in the total energy of flow. The velocity coefficient (α) is used to adjust for the distribution of velocity in a cross section of differing roughness.

Appendix 2

Flood Insurance Study Data Request Form

FLOOD INSURANCE STUDY (FIS) DATA REQUESTS

Requests for FIS data should be made in writing to:

Regions I-V

Flood Insurance Information Specialist
c/o Dewberry & Davis
2953 Prosperity Avenue
Fairfax, Virginia 22031
FAX: (703) 876-0073

Regions VI-X

FEMA Project Library
c/o Michael Baker, Jr., Inc.
3601 Eisenhower Avenue
Suite 600
Alexandria, Virginia 22304
FAX: (703) 960-9125

The following information should be included in your written request:

- Complete community name (including county)
- Community Identification Number
- Name(s) of flooding source(s) and specific location(s) for which data are needed
- Specific data needed:

  HEC-2 input and output files
  Topographic data
  etc.

- Effective date of FIRM/FBFM for which data are requested (enclose an annotated copy of FIRM/FBFM if available identifying area of interest)
- Agreement to pay costs associated with processing the request
- Fee limit after which authorization is needed
- Contact person's name, address, and phone number

The average request takes approximately 2 to 4 weeks to fill and may cost between $100 to $200.

You will be contacted after we have determined if the data are available and the cost to fill the request has been determined.

Do not include payment with your request letter.

Checks or money orders should be made payable to the National Flood Insurance Program and sent to:

Federal Emergency Management Agency
Fee Collection System
P.O. Box 398
Merrifield, Virginia 22116

Data will be released upon receipt of payment.

Appendix 3

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Federal Emergency Management Agency Offices

HEADQUARTERS

500 C Street, SW
Washington, D.C. 20472
(202) 646-3680
FAX: (202) 646-4596

REGION I
(Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island & Vermont)

J.W. McCormack Post Office & Courthouse Building, Room 462
Boston, MA 02109
(617) 223-9561
FAX: (617) 223-9574

REGION II
(New Jersey, New York, Puerto Rico & Virgin Islands)

26 Federal Plaza, Room 1349
New York, NY 10278
(212) 225-7200
FAX: (212) 225-7262

REGION III
(Delaware, District of Columbia, Maryland, Pennsylvania, Virginia & West Virginia)

Liberty Square Building, Second Floor
105 South Seventh Street
Philadelphia, PA 19106
(215) 931-5512
FAX: (215) 931-5501

REGION IV
(Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina & Tennessee)

1371 Peachtree Street, N.E., Suite 700
Atlanta, GA 30309
(404) 853-4400
FAX: (404) 853-4440

REGION V
(Illinois, Indiana, Michigan, Minnesota, Ohio & Wisconsin)

175 West Jackson Boulevard
Fourth Floor
Chicago, IL 60604
(312) 408-5552
FAX: (312) 408-5551

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Federal Emergency Management Agency Offices (continued)

REGION VI
(Arkansas, Louisiana, New Mexico, Oklahoma & Texas)

Federal Regional Center
800 North Loop 288
Denton, TX 76201-3698
(817) 898-5165
FAX: (817) 898-5195

REGION VII
(Iowa, Kansas, Missouri & Nebraska)

Federal Office Building, Room 300
911 Walnut Street
Kansas City, MO 64106
(816) 283-7002
FAX: (816) 283-7018

REGION VIII
(Colorado, Montana, North Dakota, South Dakota, Utah & Wyoming)

Denver Federal Center, Bldg. 710
P.O. Box 25267
Denver, CO 80225-0267
(303) 235-4830
FAX: (303) 235-4849

REGION IX
(Arizona, California, Hawaii & Nevada)

Presidio of San Francisco
Building 105
San Francisco, CA 94129
(415) 923-7100
FAX: (415) 923-7147

REGION X
(Alaska, Idaho, Oregon & Washington)

Federal Regional Center
130 - 228th Street, SW
Bothell, WA 98021-9796
(206) 487-4678
FAX: (206) 487-4613

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Other Federal and State Agencies

ALABAMA

Alabama Department of Economics
and Community Affairs
State Planning Division
401 Adams Avenue
Montgomery, AL 36103
(205) 242-5442

U.S. Geological Survey
District Chief
Water Resources Division
520 19th Avenue
Tuscaloosa, AL 35401
(205) 752-8104

U.S. Department of Agriculture
Natural Resources Conservation
Service
665 Opelika Rd.
P.O. Box 311
Auburn, AL 36830
(205) 887-4506

NFIP State Coordinator

Mr. Gene Anderson
Director, Alabama Department
of Economic and Community Affairs
P.O. Box 5690
401 Adams Avenue
Montgomery, AL 36103-5690
(205) 242-5499

ALASKA

Alaska Department of
Community and Regional Affairs
Municipal and Regional
Assistance Division
333 West 4th Avenue, Suite 220
Anchorage, AK 99501
(907) 269-4500

U.S. Geological Survey
District Chief
Water Resources Division
4230 University Drive, Suite 201
Anchorage, AK 99508-4138
(907) 786-7100

U.S. Department of Agriculture
Natural Resources Conservation
Service
949 East 36th Avenue
Suite 400
Anchorage, AK 99504
(907) 271-2424

NFIP State Coordinator

Mr. Bob Walsh
Municipal and Regional
Assistance Division
333 West 4th Avenue, Suite 220
Anchorage, AK 99501
(907) 269-4500

ARIZONA

Arizona Department of Water Resources
15 South 15th Avenue
Phoenix, AZ 85004
(602) 242-1553

U.S. Geological Survey
District Chief
Water Resources Division
375 South Euclid
Tucson, AZ 85719
(602) 670-6671

U.S. Department of Agriculture
Natural Resources Conservation
Service
3008 Federal Building
230 N. 1st Avenue
Phoenix, AZ 85025
(602) 261-6711

NFIP State Coordinator

Ms. Elizabeth A. Rieke
Director, Arizona Department
of Water Resources
15 South 15th Avenue
Phoenix, AZ 85007
(602) 542-1540

ARKANSAS

Arkansas Soil and Water
Conservation Commission
1 Capitol Mall, Suite 2D
Little Rock, AR 72201
(501) 371-1611

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Other Federal and State Agencies

U.S. Geological Survey
Water Resources Division
401 Hardin Road
Little Rock, AR 72211
(501) 228-3600

U.S. Department of Agriculture
Natural Resources Conservation
Service
Federal Office Bldg.
700 West Capitol
P.O. Box 2323
Little Rock, AR 72203
(501) 324-6335

NFIP State Coordinator

Mr. Randy Young
Director
Arkansas Soil & Water
Conservation Commission
101 East Capitol
Little Rock, AR 72201
(501) 682-1611

CALIFORNIA

California Department of
Water Resources
P.O. Box 942836
Sacramento, CA 94236-0001
(916) 653-5791

U.S. Geological Survey
District Chief
Water Resources Division
Federal Building, Room W-2233
2800 Cottage Way
Sacramento, CA 95825
(916) 978-4633

U.S. Department of Agriculture
Natural Resources Conservation
Service
2121 C 2nd Street
Davis, CA 95616
(916) 757-8200

NFIP State Coordinator

Mr. David Kennedy, Director
California Department of
Water Resources
P.O. Box 942836
Sacramento, CA 94236-0001
(916) 653-7007

COLORADO

Urban Drainage and Flood Control
District
2480 West 26th Avenue
Suite 156B
Denver, CO 80211

Colorado Water Conservation Board
State Centennial Building, Room 721
1313 Sherman Street
Denver, CO 80203
(303) 866-3441

U.S. Geological Survey
District Chief
Water Resources Division
Denver Federal Center, Building 53
Box 25046 (Mail Stop 415)
Lakewood, CO 80225-0046
(303) 236-4882

U.S. Department of Agriculture
Natural Resources Conservation
Service
655 Parfait Street
Room E200C
Lakewood, CO 80215
(303) 236-2886

NFIP State Coordinator

Mr. Daries C. Lile, P.E.
Director, Colorado Water
Conservation Board
State Centennial Building
1313 Sherman Street
Denver, CO 80203
(303) 866-3441

CONNECTICUT

State Department of
Environmental Protection
79 Elm Street, 3rd Floor
Hartford, CT 06106
(203) 424-3706

U.S. Geological Survey
Hydrologist-in-Charge
Connecticut Office
Water Resources Division
Abraham A. Ribicoff Federal
Building, Room 525
450 Main Street
Hartford, CT 06103
(203) 240-3060

Other Federal and State Agencies

U.S. Department of Agriculture
Natural Resources Conservation Service
16 Professional Park Road
Storrs, CT 06268
(203) 429-9361

NFIP State Coordinator

Mr. Timothy Keeney, Commissioner
State Department of Environmental Protection
165 Capitol Avenue
State Office Building
Hartford, CT 06106
(203) 566-2110

DELAWARE

Department of Natural Resources and Environmental Control
Division of Soil and Water Conservation
P.O. Box 1401
89 Kings Highway
Dover, DE 19903
(302) 739-4403

U.S. Geological Survey
Hydrologist-in-Charge
Delaware Office
Water Resources Division
Federal Building, Room 1201
300 South New Street
Dover, DE 19904
(302) 734-2506

U.S. Department of Agriculture
Natural Resources Conservation Service
3500 South DuPont Highway
Dover, DE 19901
(302) 697-6176

NFIP State Coordinator

Mr. John A. Hughes, Director
Delaware Department of Natural & Environmental Control
Richardson and Robbins Building
P.O. Box 1401
Dover, DE 19903
(301) 736-4411

DISTRICT OF COLUMBIA

Department of Consumer Regulatory Affairs
614 H Street Northwest
Washington, DC 20001
(202) 727-7170

U.S. Geological Survey
District Chief
Water Resources Division
208 Carroll Building
8600 La Salle Road
Towson, MD 21286
(410) 828-1535

NFIP State Coordinator

Mr. Donald G. Murray, Director
Department of Consumer Regulatory Affairs
Office of the Director
614 H Street, NW., Suite 1120
Washington, D.C. 20001
(202) 727-7170

FLORIDA

Department of Community Affairs
East Howard Building
2740 Centerview Drive
Tallahassee, FL 32399-2100
(904) 488-8466

U.S. Geological Survey
District Chief
Water Resources Division
227 North Bronough Street, Suite 3015
Tallahassee, FL 32301
(904) 942-9500

U.S. Department of Agriculture
Natural Resources Conservation Service
P.O. Box 141510
Gainesville, FL 32614
(904) 338-9500

NFIP State Coordinator

Ms. Linda Lomis Shelley, Secretary
Florida Department of Community Affairs
2740 Centerview Drive
Tallahassee, FL 32399-2100
(904) 488-8466

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

GEORGIA

Department of Natural Resources
Environmental Protection Division
Floyd Towers East, Suite 1252
205 Butler Street Southeast
Atlanta, GA 30334
(404) 656-4713

U.S. Geological Survey
District Chief
Water Resources Division
3039 Amwiler Road, Suite 130
Atlanta, GA 30360
(404) 447-9803

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building
355 East Hancock Avenue
P.O. Box 832
Athens, GA 30613
(404) 546-2272

NFIP State Coordinator

Mr. Joe D. Tanner, Commissioner
Georgia Department of Natural Resources
205 Butler Street, S.E.
Floyd Towers East, Suite 1252
Atlanta, GA 30334
(404) 656-3500

HAWAII

Hawaii Board of Land and Natural Resources
1151 Punchbowl Road, Room 220
Honolulu, HI 96813
(808) 587-0446

U.S. Geological Survey
District Chief
Water Resources Division
677 Ala Moana Boulevard, Suite 415
Honolulu, HI 96813
(808) 522-8290

U.S. Department of Agriculture
Natural Resources Conservation Service
300 Ala Moana Boulevard
P.O. Box 50004
Honolulu, HI 96850
(808) 546-3165

NFIP State Coordinator
Mr. William W. Paty, Chairperson
Commission on Water Resource Management and Board of Land and Natural Resources
State of Hawaii
P.O. Box 621
Honolulu, HI 96809
(808) 587-0401

IDAHO

Department of Water Resources
State House
1301 North Orchard Street
Boise, ID 83706
(208) 327-7900

U.S. Geological Survey
District Chief
Water Resources Division
230 Collins Road
Boise, ID 83702
(208) 387-1300

U.S. Department of Agriculture
Natural Resources Conservation Service
3244 Elder Street
Room 124
Boise, ID 83705
(208) 334-1601

NFIP State Coordinator

Mr. R. Keith Higginson, Director
Idaho Department of Water Resources
1301 N. Orchard
Boise, ID 83706
(208) 327-7900

ILLINOIS

Illinois Department of Transportation
Local Flood Plains Programs
310 South Michigan, Room 1606
Chicago, IL 60604
(312) 793-3123

U.S. Geological Survey
District Chief
Water Resources Division
Champaign County Bank Plaza
102 East Main Street
Fourth Floor
Urbana, IL 61801
(217) 398-5353

Federal Emergency Management Agency Offices
and Other Federal and State Agencies

Other Federal and State Agencies

U.S. Department of Agriculture
Natural Resources Conservation
Service
Federal Building
2110 West Park Court
Suite C
Champaign, IL 61821
(217)398-5212

NFIP State Coordinator

Mr. Michael Lene, Secretary
Illinois Department of Transportation
2300 S. Dirksen Parkway
Springfield, IL 62764
(217) 728-5597

INDIANA

Department of Natural Resources
608 State Office Building W-256
402 West Washington Street
Indianapolis, IN 46204-2748
(317) 232-4020

U.S. Geological Survey
District Chief
Water Resources Division
5957 Lakeside Boulevard
Indianapolis, IN 46278
(317) 290-3333

U.S. Department of Agriculture
Natural Resources Conservation
Service
6013 Lakeside Boulevard
Indianapolis, IN 46275
(317) 290-3030

NFIP State Coordinator

Mr. James B. Ridenour, Director
Indiana Department of Natural
Resources
608 State Office Building
Indianapolis, IN 46204
(317) 232-4020

IOWA

Iowa Department of Natural Resources
Wallace State Office Building
Des Moines, IA 50319-0034
(515) 281-5385

U.S. Geological Survey
District Chief
Water Resources Division
P.O. Box 1230
Iowa City, IA 52244-1230
(Street Address:
Federal Building, Room 269
400 South Clinton Street)
(319) 337-4191

U.S. Department of Agriculture
Natural Resources Conservation
Service
Wallace Building
Des Moines, IA 50319
(515) 284-5851

NFIP State Coordinator

Mr. Larry Wilson, Director
Iowa Department of Natural Resources
Wallace State Office Building
Des Moines, IA 50319
(515) 281-5385

KANSAS

Division of Water Resources
Kansas State Board of Agriculture
901 South Kansas Avenue, 2nd Floor
Topeka, KS 66612-1283
(913) 296-3717

U.S. Geological Survey
District Chief
Water Resources Division
4821 Quail Crest Place
Lawrence, KS 66049
(913) 842-9901

U.S. Department of Agriculture
Natural Resources Conservation
Service
P.O. Box 600
760 South Broadway
Salina, KS 67401
(913) 823-4500

NFIP State Coordinator

Mr. David L. Pope, P.E.
Chief Engineer & Director
Kansas State Board of Agriculture
Division of Water Resources
901 S. Kansas, 2nd Floor
Topeka, KS 66612-1283
(913) 296-3717

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Other Federal and State Agencies

KENTUCKY

Kentucky Department
of Natural Resources
Division of Water
Fort Boone Plaza
14 Reilly Road
Frankfort, KY 40601
(502) 564-3410

U.S. Geological Survey
District Chief
Water Resources Division
2301 Bradley Avenue
Louisville, KY 40217
(502) 582-5241

U.S. Department of Agriculture
Natural Resources Conservation
Service
771 Corporate Drive, Suite 110
Lexington, KY 40503
(606) 224-7350
FTS 355-2749

NFIP State Coordinator

Mr. Jack Wilson, Director
Kentucky Division of Water
18 Reilly Road
Fort Boone Plaza
Frankfort, KY 40601
(502) 564-3410

LOUISIANA

Louisiana Department of
Urban and Community Affairs
P.O. Box 94455, Capitol Station
Baton Rouge, LA 70804
(504) 342-9794

U.S. Geological Survey
District Chief
Water Resources Division
P.O. Box 66492
Baton Rouge, LA 70896
(Street Address:
6554 Florida Boulevard
Baton Rouge, LA 70806)
(504) 389-0281

U.S. Department of Agriculture
Natural Resources Conservation
Service
3636 Government Street
Alexandria, LA 71301
(318) 487-8094

NFIP State Coordinator

General Jude W. P. Patlin, Secretary
Louisiana Department of
Transportation & Development
P.O. Box 94245
Baton Rouge, LA 70804-9245
(504) 379-1200

MAINE

Maine State Planning Office
State House Station 38
184 State Street
Augusta, ME 04333
(207) 287-3261

U.S. Geological Survey
Hydrologist-in-Charge
Maine Office
Water Resources Division
26 Ganneston Drive
Augusta, ME 04330
(207) 622-8208

U.S. Department of Agriculture
Natural Resources Conservation
Service
USDA Building
University of Maine
5 Godfrey Drive
Orono, ME 04473
(207) 866-7241

NFIP State Coordinator

Mr. Michael W. Aube, Commissioner
Department of Economic and
Community Development
State House Station 59
State Street
Augusta, ME 04333
(207) 287-2656

MARYLAND

Maryland State Resources
Administration
Tawes State Office Building, D-2
501 Taylor Avenue
Annapolis, MD 21401
(410) 974-3041

U.S. Geological Survey
District Chief
Water Resources Division
208 Carroll Building
8600 La Salle Road
Towson, MD 21286
(410) 828-1535

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

Other Federal and State Agencies

U.S. Department of Agriculture
Natural Resources Conservation Service
339 Busch's Frontage Road
Suite 301
Annapolis, MD 21401-5534
(410) 757-0861

NFIP State Coordinator

Ms. Catherine Pieper Stevenson
Director, Maryland Water Resources Administration
Tawes State Office Building D-2
Annapolis, MD 21401
(301) 974-3896

MASSACHUSETTS

Massachusetts Water Resources Commission
State Office Building
100 Cambridge Street
Boston, MA 02202
(617) 727-3267

U.S. Geological Survey
District Chief
Water Resources Division
28 Lord Road
Marlborough, MA 01752
(508) 485-6360

U.S. Department of Agriculture
Natural Resources Conservation Service
451 West Street
Amherst, MA 01002
(413) 253-4350

NFIP State Coordinator

Mr. Peter C. Webber, Commissioner
Massachusetts Department of Environmental Management
State Office Building
100 Cambridge Street
Boston, MA 02202
(617) 727-3180 x600

MICHIGAN

Engineering Water Management Commission
Michigan Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909
(517) 373-3930

U.S. Geological Survey
District Chief
Water Resources Division
6520 Mercantile Way, Suite 5
Lansing, MI 48910
(517) 887-8903

U.S. Department of Agriculture
Natural Resources Conservation Service
Room 101
1405 S. Harrison Road
East Lansing, MI 48823
(517) 337-6701

NFIP State Coordinator

Mr. Roland Harms, Director
Michigan Department of Natural Resources
Land and Water Management Division
P.O. Box 30028
Lansing, MI 48909
(517) 373-3930

MINNESOTA

Flood Plains/Shoreline Management Section
Division of Waters
Department of Natural Resources
500 Lafayette Road, Box 30
St. Paul, MN 55515-4032
(612) 297-2405

U.S. Geological Survey
District Chief
Water Resources Division
2280 Woodale Road
Moundsville, MN 55112
(612) 783-3100

U.S. Department of Agriculture
Natural Resources Conservation Service
600 Farm Credit Building
375 Jackson Street
St. Paul, MN 55101
(612) 290-3675

NFIP State Coordinator

Mr. Ronald Nargang, Director
Minnesota Department of Natural Resources
Division of Water
500 LaFayette Road, Box 32
St. Paul, MN 55515-0432
(612) 296-4800

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

MISSISSIPPI

Mississippi Research and
Development Center
3825 Ridgewood Road
Jackson, MI 39211
(601) 982-6376

U.S. Geological Survey
District Chief
Water Resources Division
Federal Office Building, Suite 710
100 West Capitol Street
Jackson, MS 39269
(601) 965-4600

U.S. Department of Agriculture
Natural Resources Conservation
Service
100 W. Capitol
Suite 1321
Federal Building
Jackson, MS 39269
(601) 969-5205

NFIP State Coordinator

Mr. J. E. Maher, Director
Mississippi Emergency Management
Agency
1410 Riverside Drive
P.O. Box 4501
Jackson, MS 39216
(601) 352-9100

MISSOURI

Department of Natural Resources
P.O. Box 176
205 Jefferson Street
Jefferson City, MO 65102
(314) 751-4422

U.S. Geological Survey
District Chief
Water Resources Division
1400 Independence Road,
(Mail Stop) 200
Rolla, MO 65401
(314) 341-0824

U.S. Department of Agriculture
Natural Resources Conservation
Service
601 Business Loop
70 West Parkdale Center, Suite 250
Columbia, MO 65202
(314) 876-0903

NFIP State Coordinator

Director
Missouri Department of Natural
Resources
101 N. Jefferson Street
P.O. Box 176
Jefferson City, MO 65102
(314) 751-4422

MONTANA

Montana Department of Natural
Resources and Conservation
1520 East Sixth Avenue
Helena, MT 59620
(406) 444-6646

U.S. Geological Survey
Federal Building, Room 428
Drawer 10076
301 South Park Avenue
Helena, MT 59626-0076
(406) 449-5302

U.S. Department of Agriculture
Natural Resources Conservation
Service
10 E. Babcock
Room 443
Bozeman, MT 59715
(406) 587-6811

NFIP State Coordinator

Mr. Mark Simonich, Director
Montana Department of Natural
Resources and Conservation
1520 East 6th Ave.
Helena, MT 59620
(406) 444-6699

NEBRASKA

Nebraska Natural Resources
Commission
P.O. Box 94876
Lincoln, NE 68509-4876
(402) 471-2081

U.S. Geological Survey
District Chief
Water Resources Division
Federal Building, Room 406
100 Centennial Mall North
Lincoln, NE 68508
(402) 437-5082

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building, Rm. 345
U.S. Courthouse
100 Centennial Mall, North
P.O. Box 82502
Lincoln, NE 68508-3866
(402) 437-5300

NFIP State Coordinator

Mr. Dayle Williamson, Director
Nebraska Natural Resources Commission
P.O. Box 94876
Lincoln, NE 68509
(402) 471-2081

NEVADA

Division of Emergency Management
State of Nevada
Capitol Complex
Carson City, NV 89710
(702) 885-4240

U.S. Geological Survey
Hydrologist-in-Charge
Nevada Office
Water Resources Division
Federal Building, Room 224
705 North Plaza Street
Carson City, NV 89701
(702) 882-1388

U.S. Department of Agriculture
Natural Resources Conservation Service
5301 Longway Lane
Building F, Suite 201
Reno, NV 89511
(702) 784-5863

NFIP State Coordinator

Mr. David McNinch
Nevada Division of Emergency Management
2525 S. Carson
Capitol Complex
Carson City, NV 89710
(702) 885-4240

NEW HAMPSHIRE

Office of Emergency Management
State Office Park South
107 Pleasant Street
Concord, NH 03301
(603) 271-2231

U.S. Geological Survey
Hydrologist-in-Charge
New Hampshire Office
Water Resources Division
525 Clinton Street, RFD 2
Bow, NH 03304
(603) 225-4681

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building
2 Madbury Road
Durham, NH 03824
(603) 868-7581

NFIP State Coordinator

Col. George L. Iverson, Director
Governor's Office of Emergency Management
State Office Park South
107 Pleasant Street
Concord, NH 03301
(603) 271-2231

NEW JERSEY

New Jersey Department of Environmental Protection and Energy
Flood Plain Management Section
CN 419
Trenton, NJ 08625-0419
(609) 292-2296

New Jersey Department of Environmental Protection and Energy
Division of Natural and Historic Resources Engineering and Construction Element
Floodplain Management Section
Station Plaza 5
501 East State Street, 1st Floor
Trenton, New Jersey 08625-0419
(609) 292-2296

Federal Emergency Management Agency Offices and Other Federal and State Agencies

<u>**Other Federal and State Agencies**</u>

U.S. Geological Survey
District Chief
Water Resources Division
Mountain View Office Park,
Suite 206
810 Bear Tavern Road
West Trenton, NJ 08628
(609) 771-0065

U.S. Department of Agriculture
Natural Resources Conservation
Service
1370 Hamilton Street
Somerset, NJ 08873
(908) 725-3848

<u>NFIP State Coordinator</u>

Mr. Scott A. Weiner, Commissioner
New Jersey Department of
Environmental Protection and Energy
CN 402
Trenton, NJ 08625
(609) 292-2885

NEW MEXICO

New Mexico State Engineer's Office
Bataan Memorial Building
P.O. Box 25102
Santa Fe, NM 87504-5102
(505) 827-6091

U.S. Geological Survey
District Chief
Water Resources Division
4501 Indian School Road, NE
Suite 200
Albuquerque, NM 87110
(505) 262-5300

U.S. Department of Agriculture
Natural Resources Conservation
Service
P.O. Box 2007
517 Gold Avenue, SW., Rm. 301
Albuquerque, NM 87102
(505) 766-3277

<u>NFIP State Coordinator</u>

Mr. Keith Lough
Office of Emergency Planning
and Coordination
Department of Public Safety
P.O. Box 1628
Santa Fe, NM 87503
(505) 827-6091

NEW YORK

Flood Protection Bureau
New York Department of
Environmental Conservation
50 Wolf Road
Albany, NY 12233-3507
(518) 457-3157

U.S. Geological Survey
District Chief
Water Resources Division
445 Broadway, Room 343
Albany, NY 12201
(518) 472-3107

U.S. Department of Agriculture
Natural Resources Conservation
Service
441 South Salina Street
5th floor, Suite 354
Syracuse, NY 13202
(315) 477-6508
FTS 950-5521

<u>NFIP State Coordinator</u>

Mr. James F. Kelly, Director
Flood Protection Bureau
New York State Department of
Environmental Conservation
50 Wolf Road, Room 330
Albany, NY 12233-3507
(518) 457-3157

NORTH CAROLINA

North Carolina Department of
Crime Control and Public Safety
Division of Emergency Management
116 West Jones Street
Raleigh, NC 27603
(919) 733-3867

U.S. Geological Survey
District Chief
Water Resources Division
P.O. Box 30728
3916 Sunset Ridge Road
Raleigh, NC 27622
(919) 856-4510

U.S. Department of Agriculture
Natural Resources Conservation
Service
4405 Bland Avenue
Suite 205
Raleigh, NC 27609
(919) 790-2888

Federal Emergency Management Agency Offices
and Other Federal and State Agencies

Other Federal and State Agencies

NFIP State Coordinator

Mr. Joseph F. Myers, Director
North Carolina Division of
Emergency Management
116 West Jones Street
Raleigh, NC 27603
(919) 733-3867

NORTH DAKOTA

State Water Commission
900 East Boulevard
Bismarck, ND 58505
(701) 224-2750

U.S. Geological Survey
District Chief
Water Resources Division
821 East Interstate Avenue
Bismarck, ND 58501
(701) 250-4601

U.S. Department of Agriculture
Natural Resources Conservation
Service
Federal Building, Rm. 270
Rosser Ave. & Third St.
P.O. Box 1458
Bismarck, ND 58502
(701) 250-4435

NFIP State Coordinator

Mr. David A. Sprycnzynatyk
State Engineer
North Dakota State Water Commission
900 E. Boulevard
Bismark, ND 58505
(701) 224-4940

OHIO

Ohio Department of Natural Resources
Flood Plain Planning Unit
Division of Water
1939 Fountain Square
Columbus, OH 43224
(614) 265-6750

U.S. Geological Survey
District Chief
Water Resources Division
975 West Third Avenue
Columbus, OH 43212
(614) 469-5553

U.S. Department of Agriculture
Natural Resources Conservation
Service
Room 522
Federal Building
200 North High Street
Columbus, OH 43215
(614) 469-6962

NFIP State Coordinator

Mrs. Frances S. Buchholzer, Director
Ohio Department of Natural
Resources
Fountain Square
Columbus, OH 43224
(614) 264-6875

OKLAHOMA

Oklahoma Water Resources Board
600 North Harvey Avenue
P.O. Box 150
Oklahoma City, OK 73101-0150
(405) 231-2500

U.S. Geological Survey
District Chief
Water Resources Division
202 NW Sixty Sixth, Building 7
Oklahoma City, OK 73116
(405) 843-7570

U.S. Department of Agriculture
Natural Resources Conservation
Service
100 USDA
Suite 203
Stillwater, OK 74074
(405) 742-1200

NFIP State Coordinator

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600 N. Harvey
Oklahoma City, OK 73101
(405) 231-2500

OREGON

Department of Land Conservation
and Development
1175 Court Street Northeast
Salem, OR 97310
(503) 373-0050

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

U.S. Geological Survey
Hydrologist-in-Charge
Oregon Office
Water Resources Division
847 Northeast 19th Avenue, Suite 300
Portland, OR 97323
(503) 251-3200

U.S. Department of Agriculture
Natural Resources Conservation Service
2115 SE Morrison
Portland, OR 97214
(503) 231-2270

NFIP State Coordinator

Mr. Richard Benner
Oregon Department of Land Conservation and Development
1175 Court Street, N.E.
Salem, OR 97310
(503) 378-4928

PENNSYLVANIA

Department of Community Affairs
317 Forum Building
Harrisburg, PA 17120
(717) 787-7160
U.S. Geological Survey
District Chief
Water Resources Division
840 Market Street
Harrisburg, PA 17043-1586
(717) 730-6900

Ms. Karen A. Miller, Secretary
Pennsylvania Department of Community Affairs
P.O. Box 155
317 Forum Building
Harrisburg, PA 17120
(717) 787-7160

U.S. Department of Agriculture
Natural Resources Conservation Service
One Credit Union Place
Suite 340
Harrisburg, PA 17110-2993

NFIP State Coordinator

Federal Building
U.S. Courthouse
805 985
Federal Square Station
Harrisburg, PA 17108
(717) 782-2202
FTS 590-2202

PUERTO RICO

Puerto Rico Planning Board
1492 Ponce De Leon Avenue, Suite 417
Santurce, Puerto Rico 00907
(809) 729-6920

U.S. Geological Survey
District Chief
Water Resources Division
GPO Box 4424
San Juan, PR 00936
(Street Address:
GSA Center, Building 652
Highway 28, Pueblo Viejo)
(809) 783-4660

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building, Rm. 639
Chardon Avenue
GPO Box 4868
San Juan, PR 00936
(809) 753-4206

NFIP State Coordinator

Ms. Norma N. Burgos, President
Puerto Rico Planning Board
P.O. Box 41119
San Juan, PR 00940-9985
(809) 727-4444

RHODE ISLAND

Statewide Planning Program
Rhode Island Office of State Planning
1 Capitol Hill
Providence, RI 02908
(401) 277-2656

U.S. Geological Survey
Hydrologist-in-Charge
Rhode Island Office
Water Resources Division
275 Promanade Street, Suite 150
Providence, RI 02908
(401) 331-9050

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

U.S. Department of Agriculture
Natural Resources Conservation Service
40 Quaker Lane, Suite 46
West Warwick, RI 02886
(401) 828-1300

NFIP State Coordinator

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Associate Director
Department of Transportation
Office of Systems Planning
1 Capitol Hill
Providence, RI 02908-5872
(401) 277-6578

SOUTH CAROLINA

South Carolina Water and Natural Resources Commission
1201 Main Street, Suite 1100
Columbia, SC 29201
(803) 737-0800

U.S. Geological Survey
District Chief
Water Resources Division
Stevenson Center, Suite 129
720 Gracern Road
Columbia, SC 29210-7651
(803) 750-6100

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Bldg., Rm. 950
1835 Assembly St.
Columbia, SC 29201
(803) 765-5681

NFIP State Coordinator

Mr. Danny Johnson, Director
Surface Water Division
South Carolina Water Resources Commission
1201 Main Street, Suite 1100
Columbia, SC 29201
(803) 737-0800

SOUTH DAKOTA

Disaster Assistance Programs
Emergency and Management Services
500 East Capitol
Pierre, SD 57501
(605) 773-3231

U.S. Geological Survey
District Chief
Water Resources Division
Federal Building, Room 317
200 Fourth Street Southwest
Huron, SD 57350-2469
(605) 353-7176

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building, Rm. 203
200 4th Street, SW
Huron, SD 57350
(605) 353-1092

NFIP State Coordinator

Mr. Gary N. Whitney, Director
South Dakota Department of Military and Veteran Affairs
Division of Emergency and Disaster Services
500 E. Capitol
Pierre, SD 57501
(605) 773-3231

TENNESSEE

Tennessee Department of Economic and Community Development
Division of Community Development
320 Sixth Avenue North, Sixth Floor
Nashville, TN 37243-0405
(615) 741-1888

U.S. Geological Survey
District Chief
Water Resources Division
810 Broadway, Suite 500
Nashville, TN 37203
(615) 736-5424

U.S. Department of Agriculture
Natural Resources Conservation Service
U.S. Courthouse, Rm. 675
801 Broadway Street
Nashville, TN 37203
(615) 736-5471
FTS 852-5471

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

NFIP State Coordinator

Mr. Michael McGuire
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320 Sixth Avenue
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TEXAS

Texas Natural Resource Conservation Commission
P.O. Box 13087
Capitol Station
Austin, TX 78711-3087
(512) 239-1000

U.S. Geological Survey
District Chief
Water Resources Division
8011 Cameron Road
Austin, TX 78754
(512) 873-3000

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Bldg.
101 S. Main Street
Temple, TX 76501
(817) 774-1214

NFIP State Coordinator

Mr. Jesus Galza
Executive Director
Texas Water Commission
P.O. Box 13087
Capitol Station
Austin, TX 78711-3087
(512) 463-7791

UTAH

Office of Comprehensive Emergency Management
State Office Building, Room 1110
Salt Lake City, UT 84114
(801) 538-3400

U.S. Geological Survey
District Chief
Water Resources Division
2363 Foothill Drive
Salt Lake City, UT 84109
(801) 467-7970

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Building
125 S. State Street
P.O. Box 11350
Salt Lake City, UT 84147
(801) 524-5068

NFIP State Coordinator

Ms. Lorayne Frank, Director
Department of Public Safety
Division of Comprehensive Emergency Management
State Office Building, Room 1110
450 North Main
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VERMONT

Agency of Natural Resources
Department of Environmental Conservation
Water Quality Division
103 South Main Street - 10N
Waterbury, VT 05671-0408
(802) 241-3777

U.S. Geological Survey
District Chief
Water Resources Division
P.O. Box 628
Montpelier, VT 05602
(802) 828-4479

U.S. Department of Agriculture
Natural Resources Conservation Service
69 Union Street
Winooski, VT 05404
(802) 951-6795

NFIP State Coordinator

Mr. Chuck Clarde, Secretary
Agency of Natural Resources
Center Building
103 South Main Street
Waterbury, VT 05671-0301
(802) 244-7347

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

VIRGIN ISLANDS

Virgin Islands of the U.S.
Virgin Islands Planning Department
and Natural Resources
Charlotte Amalie
Nisky Center, Suite 231
St. Thomas, VI 00802
(809) 774-3320

U.S. Geological Survey
District Chief
Water Resources Division
GPO Box 4424
San Juan, PR 00936
(Street Address:
GSA Center, Building 652
Highway 28, Pueblo Viejo)
(809) 783-4660

NFIP State Coordinator

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Virgin Islands Department of
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Suite 231, Nisky Center
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VIRGINIA

Virginia State Department of
Environmental Quality
4900 Cot Road
Glen Allen, VA 23060
(804) 527-5000

U.S. Geological Survey
Hydrologist-in-Charge
Virginia Office
Water Resources Division
3600 West Broad Street
Room 606
Richmond, VA 23230
(804) 771-2427

U.S. Department of Agriculture
Natural Resources Conservation
Service
1606 Santa Rosa Road
Suite 209
Richmond, VA 23229
(804) 287-1689

NFIP State Coordinator

Mr. Roland B. Geddes, Director
Department of Conservation and
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(804) 786-4356

WASHINGTON

Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
(206) 407-6000

U.S. Geological Survey
District Chief
Water Resources Division
1201 Pacific Avenue, Suite 600
Tacoma, WA 98402
(206) 593-6510

U.S. Department of Agriculture
Natural Resources Conservation
Service
316 Boone Avenue
Suite 456
Spokane, WA 99201
(509) 353-2336

NFIP State Coordinator

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Washington Department of Ecology
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(206) 459-6168

WEST VIRGINIA

West Virginia Office of
Emergency Services
Room EB-80, Capitol Building
Charleston, WV 25305
(304) 348-5380

U.S. Geological Survey
District Chief
Water Resources Division
11 Dunbar Street
Charleston, WV 25301
(304) 347-5130

U.S. Department of Agriculture
Natural Resources Conservation
Service
75 High Street, Rm. 301
Morgantown, WV 26505
(304) 291-4151

Federal Emergency Management Agency Offices and Other Federal and State Agencies

Other Federal and State Agencies

NFIP State Coordinator

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West Virginia Office of Emergency Services
Room EBI-80
Capitol Building
Charleston, WV 25305
(304) 348-5380

WISCONSIN

Department of Natural Resources
Dam Safety/Floodplain Management Section
P.O. Box 7921
Madison, WI 53707
(608) 266-2621

U.S. Geological Survey
District Chief
Water Resources Center
University of Wisconsin/Madison
1975 Willard Drive
Madison, WI 53706-4042
(608) 262-3577

U.S. Department of Agriculture
Natural Resources Conservation Service
6515 Watts Road
Suite 200
Madison, WI 53719
(608) 264-5341

NFIP State Coordinator

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Wisconsin Department of Natural Resources
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Madison, WI 53707
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WYOMING

Wyoming Emergency Management Agency
P.O. Box 1709
Cheyenne, WY 82003-1709
(307) 777-4900

U.S. Geological Survey
District Chief
Water Resources Division
P.O. Box 1125
Cheyenne, WY 82003
(Street Address:
2617 East Lincoln Way
Cheyenne, WY 82001
(307) 772-2153

U.S. Department of Agriculture
Natural Resources Conservation Service
Federal Office Building
100 East "B" Street
Casper, WY 82601
(307) 261-5231

NFIP State Coordinator

Mr. Joe Daly, Coordinator
Wyoming Emergency Management Agency
P.O. Box 1709
Cheyenne, WY 82003
(307) 777-7566

Federal Emergency Management Agency Offices and Other Federal and State Agencies

U.S. Army Corps of Engineers

U.S. Army Corps of Engineers
Headquarters
20 Massachusetts Ave., NW
Washington, D.C. 20314-1000
Attn: CECW-PF
202/272-0169

U.S. Army Corps of Engineers
Lower Miss. Valley Division
P.O. Box 80
Vicksburg, MS 39181-0080
Attn: CELMV-PD-CM
601/634-5827

U.S. Army Corps of Engineers
Memphis District
167 North Main Street, B-202
Memphis, TN 38103-1894
Attn: CELMM-PD-M
901/544-3968

U.S. Army Corps of Engineers
New Orleans District
P.O. Box 60267
New Orleans, LA 70160-0267
Attn: CELMN-PD-FG
504/865-1121

U.S. Army Corps of Engineers
St. Louis District
1222 Spruce Street
St. Louis, MO
63103-2833
Attn: CELMS-PD-M
314/331-8483

U.S. Army Corps of Engineers
Vicksburg District
2101 North Frontage Road
Vicksburg, MS 39180-0060
Attn: CELMK-PD-FS
601/631-5416

U.S. Army Corps of Engineers
Missouri River Division
12565 West Center Road
Omaha, NE 68104-3869
Attn: CEMRD-PD-F
402/221-7273

U.S. Army Corps of Engineers
Kansas City District
700 Federal Building Kansas
City, MO 64106-2896
Attn: CEMRK-PD-P
816/426-3674

U.S. Army Corps of Engineers
Omaha District
215 North 17th Street
Omaha, NE 68102-4978
Attn: CEMRO-PD-F
402/221-4596

U.S. Army Corps of Engineers
North Atlantic Division
90 Church Street
New York, NY 10007-2979
Attn: CENAD-PL-FP
212/264-7482

U.S. Army Corps ot Engineers
Baltimore District
Supervisor of Baltimore Harbor
P.O. Box 1715
Baltimore, MD 21201-1715
Attn: CENAB-PL-B
410/962-7608

U.S. Army Corps of Engineers
New York District, Planning Division,
Floodplain Management Section
26 Federal Plaza
New York, NY 10278
Attn: CENAN-PL-FP
212/264-8870

U.S. Army Corps of Engineers
Norfolk District
Supervisor of Norfolk Harbor
803 Front Street
Norfolk, VA 23510-1096
Attn: CENAO-PL-FP
804/441-7779

U.S. Army Corps of Engineers
Philadelphia District
U.S. Customs House
2nd & Chestnut Streets
Philadelphia, PA 19106-2991
Attn: CENAP-PL-F
215/656-6516

U.S. Army Corps of Engineers
North Central Division
111 North Canal Street, 14th Floor
Chicago, IL 60606
Attn: CENCD-PD-FP
312/353-1279

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

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U.S. Army Corps of Engineers
Buffalo District, Planning Division,
Floodplain Management Section
1776 Niagara Street
Buffalo, NY 14207-3199
Attn: CENCB-PD-FP
716/879-4104

U.S. Army Corps of Engineers
Chicago District
111 North Canal Street
14th Floor
Chicago, IL 60606
Attn: CENCC-PD-R
312/353-6400

U.S. Army Corps of Engineers
Detroit District
477 Michigan Avenue
Detroit, MI 48226
Attn: CENCE-PD-PF
313/226-6773

U.S. Army Corps of Engineers
Rock Island District
P.O. Box 2004
Clock Tower Building
Rock Island, IL 61204-2004
Attn: CENCR-PD-F
309/788-4750

U.S. Army Corps of Engineers
St. Paul District
190 Phipps Street East
St. Paul, MN 55101-1638
Attn: CENCS-PD-FS
612/290-5200

U.S. Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, MA 02254-9149
Attn: CENED-PL-B
617/647-8111

U.S. Army Corps of Engineers
North Pacific Division
333 Southwest 1st Avenue
Portland, OR 97204
Attn: CENPD-PL-FS
5O3/326-6021

U.S. Army Corps of Engineers
Alaska District
P.O. Box 898
Anchorage, AK 99506-0898
Attn: CENPA-EN-PL-FP
907/753-2504

U.S. Army Corps of Engineers
Portland District
P.O. Box 2946
Portland, OR 97208-2946
Attn: CENPP-PL-CF
503/326-6411

U.S. Army Corps of Engineers
Seattle District
P.O. Box 3755
Seattle, WA 98124-2255
Attn: CENPS-EN-HH
206/764-3660

U.S. Army Corps of Engineers
Walla Walla District
Bldg. 602 City-County Airport
Walla Walla, WA 99362-9265
Attn: CENPW-PL-FP
509/522-6589

U.S. Army Corps of Engineers
Ohio River Division
P.O. Box 59
Louisville, KY 40201-0059
Attn: CEORD-PD-J
502/582-5782

U.S. Army Corps of Engineers
Huntington District
502 8th Street
Huntington,WV 25701-2070
Attn: CEORH-PD-S
304/529-5644

U.S. Army Corps of Engineers
Louisville District
P.O. Box 59
Louisville, KY 40201-0059
Attn: CEORL-PD-S
502/582-5742

U.S. Army Corps of Engineers
Nashville District
P.O. Box 1070
Nashville, TN 37202-1070
Attn: CEORN-ED-P
615/736-5055

U.S. Army Corps of Engineers
Pittsburgh District
William S. Moorehead Fed. Bldg.
1000 Liberty Avenue
Pittsburgh, PA 15222-4186
Attn: CEORP-PD-J
412/644-6924

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

U.S. Army Corps of Engineers

U.S. Army Corps of Engineers
Pacific Ocean Division
Ft. Shafter, HI 96858-5440
Attn: CEPOD-ED-PH
808/438-7009

U.S. Army Corps of Engineers
Charleston District, P.O. Box 919
Charleston, SC 29402-0919
Attn: CESAC-EN-PH
803/727-4263

U.S. Army Corps of Engineers
South Atlantic Division
611 South Cobb Drive
Marietta, GA 30060
Attn: CESAD-PD-A
404/421-5296

U.S. Army Corps of Engineers
Jacksonville District
P.O. Box 4970
Jacksonville, FL 32232-0019
Attn: CESAJ-PD-FP
904/232-2234

U.S. Army Corps of Engineers
Mobile District
P.O. Box 2288
Mobile, AL 36628-0001
Attn: CESAM-PD-P
205/694-3879

U.S. Army Corps of Engineers
Savannah District
P.O. Box 889
Savannah, GA 31402-0889
Attn: CESAS-PD-F
912/652-5822

U.S. Army Corps of Engineers
Wilmington District
P.O. Box 1890
Wilmington, NC 28402-1890
Attn: CESAW-PD-F
910/251-4822

U.S. Army Corps of Engineers
South Pacific Division, Room 720
630 Sansome Street
San Francisco, CA 94111-2206
Attn: CESPD-PD-P
415/705-2427

U.S. Army Corps of Engineers
Los Angeles District
P.O. Box 2711
Los Angeles, CA 90053-2325
Attn: CESPL-PD-WF
213/894-5450

U.S. Army Corps of Engineers
Sacramento District
1325 G Street
Sacramento, CA 95814-4794
Attn: CESPK-PD-F
916/557-6700

U.S. Army Corps of Engineers
San Francisco District
211 Main Street
San Francisco, CA 9410S-1905
Attn: CESPN-PE-W
415/744-3029

U.S. Army Corps of Engineers
Southwestern Division
1114 Commerce Street
Dallas, TX 75242-0216
Attn: CESWD-PL-M
214/767-2310

U.S. Army Corps of Engineers
Albuquerque District
P.O. Box 1580
Albuquerque, NM 87103-1580
Attn: CESWA-ED-PH
505/766-2635

U.S. Army Corps of Engineers
Fort Worth District
P.O. Box 17300
Fort Worth, TX 76102-0300
Attn: CESWF-PL-F
817/334-3207

U.S. Army Corps of Engineers
Galveston District
P.O. Box 1229
Galveston, TX 77553-1229
Attn: CESWG-PL-P
409/766-3023

U.S. Army Corps of Engineers
Little Rock District
P.O. Box 867
Little Rock, AR 72203-0867
Attn: CESWL-PL-F
501/378-5611

U.S. Army Corps of Engineers
Tulsa District
P.O. Box 61
Tulsa, OK 74121 0061
Attn: CESWT-PL-GF
918/581-7896

**Federal Emergency Management Agency Offices
and Other Federal and State Agencies**

River Basin Commissions

Delaware River Basin Commission
25 State Police Drive
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West Trenton, NJ 08628
609/883-9500

Susquehanna River Basin Commission
1721 North Front Street
Harrisburg, PA
717/238-0422

Appendix 4

State Hydrology Reports

ALABAMA

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ARIZONA

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CALIFORNIA

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COLORADO

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CONNECTICUT

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DELAWARE

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DISTRICT OF COLUMBIA

None listed

FLORIDA

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GEORGIA

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HAWAII

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IDAHO

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ILLINOIS

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INDIANA

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IOWA

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KANSAS

Clement, R.W., 1987, **Floods in Kansas and techniques for estimating their magnitude and frequency:** U.S. Geological Survey Water-Resources Investigations 87-4008.

Hedman, E.R., Kastner, W.M., and Hejl, H.R., 1974, **Selected streamflow characteristics as related to active-channel geometry of streams in Kansas:** Kansas Water Resources Board Technical Report No. 10.

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KENTUCKY

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LOUISIANA

Lee, F.N., 1985, **Floods in Louisiana, Magnitude and Frequency, Fourth Edition:** Department of Transportation and Development, Water Resources Technical Report No. 36.

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MAINE

Morrill, R.A., 1975, **A technique for estimating the magnitude and frequency of floods in Maine:** U.S. Geological Survey Open-File Report.

MARYLAND

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MASSACHUSETTS

Wandle, S.W., 1983, **Estimating peak discharges and frequencies of small rural streams in Massachusetts:** U.S. Geological Survey Water-Supply Paper 2214.

MICHIGAN

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MINNESOTA

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MISSISSIPPI

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MISSOURI

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MISSOURI continued

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MONTANA

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NEBRASKA

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NEVADA

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NEW JERSEY

Stankowski, S.J., 1974, **Magnitude and frequency of floods in New Jersey with effects of urbanization:** New Jersey Department of Environmental Protection Special Report 38.

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NEW MEXICO

Hejl, H.R., Jr., 1984, **Use of selected basin characteristics to estimate mean annual runoff and peak discharges for ungaged streams in drainage basins containing strippable coal resources, northwestern New Mexico:** U.S. Geological Survey Water-Resources Investigations 84-4264.

Scott, A.G., and Kunkler, J.L., 1976, **Flood discharges of streams in New Mexico as related to channel geometry:** U.S. Geological Survey Open-File Report.

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NEW YORK

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NORTH CAROLINA

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NORTH DAKOTA

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OHIO

Roth, D.K., 1985, **Estimation of flood peaks from channel characteristics in Ohio:** U.S. Geological Survey Water-Resources Investigations Report 85-4175.

Sherwood, J.M., 1986, **Estimating peak discharges, flood volumes, and hydrograph stages of small urban streams in Ohio:** U.S. Geological Survey Water-Resources Investigations Report 86-4197.

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OKLAHOMA

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OREGON

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PENNSYLVANIA

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PUERTO RICO

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Appendix 5

Manning's "n" Values

The value of "n" may be computed by

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5$$

where:

n_0	=	basic "n" value for a straight, uniform, smooth channel
n_1	=	value added to correct for the effect of surface irregularities
n_2	=	value added for variation in the shape and size of the channel cross section
n_3	=	value added for obstructions
n_4	=	value added for vegetation and flow conditions
m_5	=	correction factor for meandering of the channel

Proper values of n_0 to n_4 and m_5 may be selected from the following table according to the given conditions:

Channel Conditions		Values	
Material involved	Earth	n_0	0.020
	Rock cut		0.025
	Fine gravel		0.024
	Coarse gravel		0.028
Degree of irregularity	Smooth	n_1	0.000
	Minor		0.005
	Moderate		0.010
	Severe		0.020
Variations of channel cross section	Gradual	n_2	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010-0.015
Relative effect of obstructions	Negligible	n_3	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030
	Severe		0.040-0.060
Vegetation	Low	n_4	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050
	Very High		0.050-0.100
Degree of meandering	Minor	m_5	1.000
	Appreciable		1.150
	Severe		1.300

REFERENCE

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The computed "n" values should be compared with the typical "n" values from the following pages, or with those in the U.S. Geological Survey Report (Reference 2) or the Federal Highway Administration Report (Reference 3).

Appendix 5 - continued
Manning's "n" Values

Type of channel and description	Minimum	Normal	Maximum
A. Closed Conduits Flowing Partly Full			
A-1. Metal			
a. Brass, smooth	0.009	0.010	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
A-2. Nonmetal			
a. Lucite	0.008	0.009	0.010
b. Glass	0.009	0.010	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
g. Brickwork			
1. Glazed	0.011	0.013	0.015
2. Lined with cement mortar	0.012	0.015	0.017
h. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
i. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
j. Rubble masonry, cemented	0.018	0.025	0.030

Manning's "n" Values

Type of channel and description	Minimum	Normal	Maximum
B. Lined or Built-up Channels			
B-1. Metal			
a. Smooth steel surface			
1. Unpainted	0.011	0.012	0.014
2. Painted	0.012	0.013	0.017
b. Corrugated	0.021	0.025	0.030
B-2. Nonmetal			
a. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
b. Wood			
1. Planed, untreated	0.010	0.012	0.014
2. Planed, creosoted	0.011	0.012	0.015
3. Unplaned	0.011	0.013	0.015
4. Plank with battens	0.012	0.015	0.018
5. Lined with roofing paper	0.010	0.014	0.017
c. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Finished, with gravel on bottom	0.015	0.017	0.020
4. Unfinished	0.014	0.017	0.020
5. Gunite, good section	0.016	0.019	0.023
6. Gunite, wavy section	0.018	0.022	0.025
7. On good excavated rock	0.017	0.020	
8. On irregular excavated rock	0.022	0.027	
d. Concrete bottom float finished with sides of			
1. Dressed stone in mortar	0.015	0.017	0.020
2. Random stone in mortar	0.017	0.020	0.024
3. Cement rubble masonry, plastered	0.016	0.020	0.024
4. Cement rubble masonry	0.020	0.025	0.030
5. Dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of			
1. Formed concrete	0.017	0.020	0.025
2. Random stone in mortar	0.020	0.023	0.026
3. Dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. Glazed	0.011	0.013	0.015
2. In cement mortar	0.012	0.015	0.018
g. Masonry			
1. Cemented rubble	0.017	0.025	0.030
2. Dry rubble	0.023	0.032	0.035
h. Dressed ashlar	0.013	0.015	0.017
i. Asphalt			
1. Smooth	0.013	0.013	
2. Rough	0.016	0.016	
j. Vegetal lining	0.030	. . . . .	0.500

Type of channel and description	Minimum	Normal	Maximum
C. Excavated or Dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. Natural Streams			
D-1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pods	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Type of channel and description	Minimum	Normal	Maximum
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D-2. Floodplains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage below branches	0.100	0.120	0.160
D-3. Major streams (top width at flood stage >100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	. . . . .	0.060
b. Irregular and rough section	0.035	. . . . .	0.100

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3. Department of Transportation, Federal Highway Administration, Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains, Report No. FHWA-TS-84-204, McLean, Virginia, April 1984.

Appendix 6

QUICK-2 Computer Program Manual

Q U I C K - 2
Computer Program

COMPUTATION OF WATER SURFACE
ELEVATIONS IN OPEN
CHANNELS

VERSION 1.0

JANUARY 1995

QUICK-2

Computation of Water Surface Elevations in Open Channels

User's Guide

Federal Emergency Management Agency

1995

TABLE OF CONTENTS

Chapter 1: Introduction

QUICK-2 is a user friendly program that assists in the computation of flood Water Surface Elevations (WSEs) in open channels of all types. It is much easier to use than the United States Army Corps of Engineers (USACE) HEC-2 program. However, a QUICK-2 step-backwater file can also be used, as is, with the HEC-2 program, which is also included in the QUICK-2 package of programs. Therefore a HEC-2 output file can be generated with a QUICK-2 input data file, without ever leaving the QUICK-2 environment; and, without having to know how to set-up and run the HEC-2 program. This version of QUICK-2 (Version 1.0) however, does not perform hydraulic calculations through bridges or culverts.

QUICK-2 was primarily developed to accompany the FEMA technical guidance manual titled, "MANAGING FLOODPLAIN DEVELOPMENT IN ZONE A AREAS - A GUIDE FOR OBTAINING AND DEVELOPING BASE FLOOD ELEVATIONS." That manual is intended to assist local community officials who are responsible for administering and enforcing the floodplain management requirements of the National Flood Insurance Program (NFIP). The purpose of that manual is to provide guidance for obtaining and developing base flood (100-year) elevations (BFEs) where Special Flood Hazard Areas (SFHAs) on a community's Flood Hazard Boundary Map (FHBM) or Flood Insurance Rate Map (FIRM) have been identified and designated as Zone A.

QUICK-2 will also be useful to community engineers, architect/engineer firms, developers, builders and others at the local level who may be required to develop BFEs for use in Special Flood Hazard Areas.

This manual includes four other chapters: **Overview**, **Getting Started**, **Tutorials** and **Formulas**. The Formulas section describes the "complex" equations and methodologies used in the development of the program. An Appendix is also included that contains a list of Definitions of the variables shown on the screen and on the printouts.

> ***To get started as quickly as possible in using QUICK-2 we recommend that the user read the Overview and Getting Started chapters; and then work through the Tutorials.***

MINIMUM SYSTEM REQUIREMENTS

Random Access Memory (RAM)	-	512K
Hard disk storage	-	800K
Monitor	-	Color or Monotone
Printer (prints to LPT1)	-	Dot-matrix to LaserJet
Disk Operating System (DOS)	-	Version 3.0 or higher

Chapter 2: Overview

√ FOUR OPTIONS

This user friendly program computes:

- ***Critical Depth***,
- ***Cross Section Capacity*** (Rating Curves),
- ***Normal Depth***, and
- ***Step-Backwater Analysis*** (similar to the USACE HEC-2 program)

CRITICAL DEPTH: This option should be used to determine a Base Flood Elevation (BFE) if a previous calculation using the Normal Depth option computed a depth that was determined to be SUPERCRITICAL. Super Critical depths are generally not accepted for use as BFEs.

CHANNEL CAPACITY: This option is used to determine a rating curve for a cross section. The program computes a discharge based on the entered depth. Repeating with other depths produces a rating curve. A BFE may be determined by interpolation with the correct discharge.

NORMAL DEPTH: This is the usual option to use in determining BFEs. The user should watch the "Flow Type" message to make sure that the calculation is CRITICAL or SUBCRITICAL. Use Option 1 if SUPERCRITICAL.

STEP-BACKWATER: This option should be used to calculate BFEs if more than one cross-section is warranted to cover the extent of the property. Generally if the property parallels more than 500 feet of a flooding source this option should be used.

√ HANDLES "REGULAR" *AND* "IRREGULAR" SHAPED CROSS SECTIONS

The REGULAR shape cross-sections include:

- ***V-shape***,
- ***Trapezoidal***,
- ***Rectangular***, and
- ***Circular***

For IRREGULAR cross-sections:

- up to 40 points can be input to describe the ground points

- Ground points are easily modified using the Insert or Delete Keys

- Encroachments or other changes in the floodplain are easily modeled

- An unlimited number of cross sections may be modeled

In addition, ground points and other input variables for the irregular shape cross-sections can be saved to a file, for later use.

√ SINGLE SCREEN DATA INPUT, COMPUTATION AND OUTPUT

One of the most user-friendly aspects of this program that sets it apart from many other computational programs is that all of the data input, the computation, and the printing or plotting, is performed from the same screen. You will not get lost in a maze of menus.

√ GRAPHICS

- ***Cross-Section Plots***,
- ***Water Surface Elevation Profiles***, and
- ***Rating Curve Plots***

Cross section plots and water surface elevation profiles from QUICK-2's step-backwater analysis can be viewed on the screen using the USACE PLOT-2 program that comes with the QUICK-2 package of programs. The channel capacity option of QUICK-2 can be used to generate rating curve plots of individual cross sections that can be viewed on screen and printed.

√ AUTOMATIC ERROR CHECKING

This software is designed to virtually eliminate the need for user's manuals. The program incorporates error-checking routines and warning messages to alert the user to incorrect input data or potentially incorrect output data. The program prompts the user for the required input data so that there is no need to worry about which columns to put data in; whether or not it needs to be left-justified, or right- justified, etc.

SPECIAL FEATURES OF QUICK-2

»» Critical Depth, Channel Capacity, and Normal Depth Options ««

EASY VIEW: All of the input data is viewed on the same screen (and changes can be made) before starting the computations

EASY CHANGE: After an initial calculation, the following parameters can be changed, and the above options can be re-calculated in seconds:

Discharge	Channel Slope	Manning's N
Base width or Diameter	Channel Side Slope	Ground Points
Channel Stations		

AUTO-SAVE: For irregular channels the program automatically stores all the input variables to a file designated as "TEMP.XSC", which is stored in the C:\QUICK2\DATA Directory.

RATING CURVES: A special feature of the Channel Capacity Option for irregular channels is the Rating Curve Print Option. A rating curve plot can be automatically generated with 20 computations of water surface elevation versus discharge. The maximum elevation of the rating curve will be just lower than the channel depth specified by the user. The rating curve can be viewed on the screen and/or printed.

»» Step-Backwater Option ««

EASY VIEW: All of the input data is viewed on the same screen (and changes can be made) before starting the computations

PRECISE: Balances the energy equation to within .01 foot.

COMPUTES CRITICAL DEPTH AUTOMATICALLY: After up to 40 energy balance trials (without a balance) the program automatically computes critical depth.

OUTPUT OPTIONS: Detailed and Summary printouts are available

AUTO-SAVE: The program automatically saves the first cross-section into a file designated as T0.XSC, and subsequent cross-sections are saved adding the Channel distance (XLCH) to the previous cross-section's file name. Therefore, if we run 3 cross-sections that are 200 feet apart their filenames will be: T0.XSC, T200.XSC, and T400.XSC. These files are automatically stored in a directory named C:\QUICK2\DATA.

HEC-2 RUNS WITH QUICK-2 FILES: *The backwater option also automatically saves all of the cross-sections into a HEC-2 compatible file called HEC2.DAT, which is stored in the C:\QUICK2 Directory. The QUICK-2 program is linked with the USACE HEC-2 program such that any backwater computation that is run using QUICK-2 can also be run using the HEC-2 program within the QUICK-2 environment. The user does not need to have any previous experience in running the HEC-2 model.*

AUTOMATIC ERROR CHECKS AND WARNING MESSAGES

ERROR CHECKS

Error checks prevent the user from continuing by re-prompting the user for correct input data. The following are error checks performed automatically by the program:

- Ground Point (GR) stations should be increasing

- Stations of the left and right bank should match a GR point

WARNING MESSAGES

Warning messages instruct the user that the program has had to modify the input data in order to complete a calculation, or that the completed calculation may not be valid. The following are warning messages performed by the program:

Extended Cross Section
The computed water surface elevation is higher than one or both ends of the cross-section, and the program automatically extended the end(s) of the cross-section vertically to complete the computation.

Divided Flow
There is a ground point(s) within the cross-section which is higher than the computed water surface elevation which is dividing the flow within the cross-section.

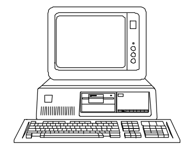
No Energy Balance ... Computing Critical Depth
The program attempted up to 40 trial computations and could not arrive at an energy balance; and therefore, critical depth is assumed to occur at this cross-section.

Computing Critical Depth ... Critical Depth Assumed
Either the initial Starting Water Surface Elevation or an energy balance between two cross sections occurred at an elevation for which the froude number or the index froude number was equal to or greater than 1. Thus, the computed water surface elevation is suspected of being below the critical depth. Therefore the critical depth is computed and compared to the previous calculated water surface elevation. In this case the critical depth elevation was higher, and thus Critical Depth is Assumed.

Computing Critical Depth ... Critical Depth Not Assumed
Same as above except, the critical depth is computed and compared to the previous calculated water surface elevation; and, in this case the critical depth elevation was lower, and thus Critical Depth is **Not** Assumed.

Chapter 3: Getting Started

This section provides you with convenient installation and run procedures that will enable you to run the program from the hard disk drive or the floppy disk drive.



HARD DISK INSTALLATION AND RUN PROCEDURE

To install and run QUICK-2 simply place the floppy disk in either your "A" disk drive or your "B" disk drive.

For "A" Drive users: Type **A:\AQ2** and Press <Enter>

For "B" Drive users: Type **B:\BQ2** and Press <Enter>

Follow the screen message to start the program. That's it!

The program resides in a C:\QUICK2 directory. To run the program in the future, just change to that directory and type Q2 and press <Enter>.

FLOPPY DISK INSTALLATION AND RUN PROCEDURE

To install and run QUICK-2 from the floppy disk drive simply place the floppy disk in either your "A" disk drive or your "B" disk drive.

For "A" Drive users: Type **A:\FAQ2** and Press <Enter>
For "B" Drive users: Type **B:\FBQ2** and Press <Enter>

Follow the screen message to start the program. That's it!

To run the program in the future, just place the disk in your floppy drive, change to that directory and type Q2 and press <Enter>. *Although the program will run from the floppy disk drive it will run much faster if installed and run on the hard disk drive.*

REMINDER:

Entering and editing data, as well as moving around within the input screens is performed using the Function keys, the Backspace Key and the Enter Key. ***DO NOT USE THE CURSOR CONTROL KEYS (ARROW KEYS) FOR ENTERING, DELETING, OR EDITING DATA.***

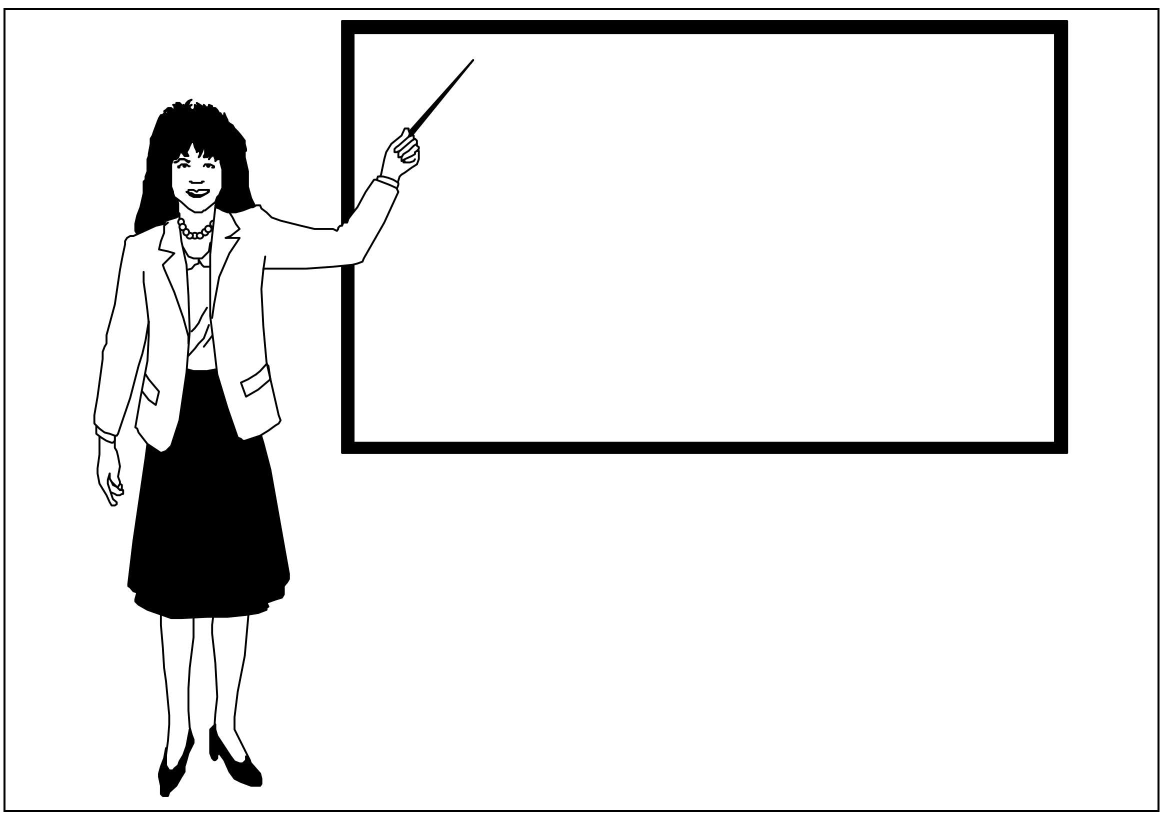
Chapter 4: TUTORIALS

Normal Depth

Step-Backwater

Channel Capacity

PLOT - 2



{TIME REQUIRED TO COMPLETE ALL THE TUTORIALS IS ABOUT ONE HOUR}

NORMAL DEPTH {Tutorial Time: 5 to 10 minutes}

After pressing **Q2** and **<Enter>** to start the program you will come to the Main Menu screen of QUICK-2 as shown below.

```
                  QUICK - 2
              MAIN         MENU
                                         Press
                                         -----
 Critical Depth                            1
 Channel Capacity                          2
 Normal Depth                              3
 Step-Backwater                            4

 QUIT                                    <F10>
```

```
<F1> - Help
```

1. Press **3** and then press **<Enter>** to start the Normal Depth Option.

Next you will see the Shape of Cross Section screen:

```
             SHAPE OF CROSS SECTION
                                         Press
                                         -----
 V - Ditch                                 V
 Rectangular Channel                       R
 Trapezoidal Channel                       T
 Circular    Channel                       C

 Irregular   Channel                       I
```

```
<F7> - Main Menu
```

Let's try the Trapezoidal Channel option.

2. Press **T** and then press **<Enter>** to perform a Normal Depth calculation for a trapezoidal channel.

The next screen you will see is the Input / Output screen:

```
                    NORMAL  DEPTH
                 TRAPEZOIDAL CHANNEL

                   INPUT VARIABLES

 L Side Slope (H:V)    :1   R Side Slope (H:V)    :1
 Bottom Width (ft)          Manning's n
 Discharge (cfs)            Depth (ft)
 Slope (ft/ft)
 ----------------------------------------------------
                  OUTPUT VARIABLES

 Area (sq ft)               Wet Perimeter (ft)
 Velocity (ft/s)            Hyd Radius
 Top Width (ft)             Froude #
                            Flow Type
 ----------------------------------------------------
 Enter Left Side Slope  and Press  <Enter>          :1

 <- Back Tab  <F2>                Main Menu  <F7>
```

The program is currently prompting you to enter the Left Side Slope (in terms of the Number of Horizontal feet (H) to every 1 foot Vertical (H : 1). **Let's say our left side slope is 3 to 1 (3:1).**

3. Enter **3** and then Press **<Enter>.**

The next screen you will see is the Input / Output screen with a new prompt:

```
                    NORMAL  DEPTH

                 TRAPEZOIDAL CHANNEL


                   INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V)    :1
 Bottom Width (ft)          Manning's n
 Discharge (cfs)            Depth (ft)
 Slope (ft/ft)
 ----------------------------------------------------
                  OUTPUT VARIABLES

 Area (sq ft)               Wet Perimeter (ft)
 Velocity (ft/s)            Hyd Radius
 Top Width (ft)             Froude #
                            Flow Type
 ----------------------------------------------------
 Enter Right Side Slope  and Press  <Enter>         :1

 <- Back Tab  <F2>                Main Menu  <F7>
```

Notice that the **3** has been entered to the right of "L Side Slope (H:V)"

The program is currently prompting you to enter the Right Side Slope (in terms of the Number of Horizontal feet (H) to every 1 foot Vertical (H : 1). **Let's say our right side slope is 2 to 1 (2:1).**

4. Enter **2** and then Press **<Enter>.**

```
                 NORMAL  DEPTH
              TRAPEZOIDAL CHANNEL

                INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)          Manning's n
 Discharge (cfs)            Depth (ft)
 Slope (ft/ft)
-------------------------------------------------------
               OUTPUT VARIABLES

 Area (sq ft)               Wet Perimeter (ft)
 Velocity (ft/s)            Hyd Radius
 Top Width (ft)             Froude #
                            Flow Type
-------------------------------------------------------
 Enter ".............."  and Press  <Enter>

 <- Back Tab  <F2>                 Main Menu  <F7>
```

The program will continue to prompt you for input data.

Let's say our channel is **10** feet wide, with a Manning's n value of **0.035**, the discharge is **300** cfs, and the channel slope is **.005** ft/ft.

SCREEN PROMPT - "Enter Bottom Width and Press <Enter>"
5. Enter **10** and then Press **<Enter>.**

SCREEN PROMPT - "Enter Manning's n and Press <Enter>"
6. Enter **.035** and then Press **<Enter>.**

SCREEN PROMPT - "Enter Discharge and Press <Enter>"
7. Enter **300** and then Press **<Enter>.**

SCREEN PROMPT - "Enter Slope and Press <Enter>"
8. Enter **.005** and then Press **<Enter>.**

```
                 NORMAL  DEPTH
              TRAPEZOIDAL CHANNEL

                INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)   10.0   Manning's n       0.0350
 Discharge (cfs)      300   Depth (ft)          0.00
 Slope (ft/ft)     0.0050
-------------------------------------------------------
               OUTPUT VARIABLES

 Area (sq ft)               Wet Perimeter (ft)
 Velocity (ft/s)            Hyd Radius
 Top Width (ft)             Froude #
                            Flow Type
-------------------------------------------------------
 Begin Calculations  <Enter>

 <- Back Tab  <F2>                 Main Menu  <F7>
```

After all the data is input your screen should look like this

To begin the calculation simply ...

9. Press **<Enter>.**

After a split second the screen should look like this:

```
                    NORMAL  DEPTH
                 TRAPEZOIDAL CHANNEL

                   INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)   10.0   Manning's n       0.0350
 Discharge (cfs)      300   Depth (ft)          3.27
 Slope (ft/ft)     0.0050
 -----------------------------------------------------
                  OUTPUT VARIABLES

 Area (sq ft)        59.6   Wet Perimeter (ft)  27.7
 Velocity (ft/s)      5.0   Hyd Radius           2.2
 Top Width (ft)      26.4   Froude #             0.6
                            Flow Type  SUBCRITICAL
 -----------------------------------------------------
 Begin Calculations  <Enter>
 Print               <F5>
 <- Back Tab         <F2>          Main Menu <F7>
```

Notice that the Depth is no longer 0.00, but equals **3.27** feet, which is the Normal Depth for this particular Trapezoidal cross-section. **If 300 cfs represents the 100-year discharge, then the 100-year flood depth would equal 3.27 feet.** All of the output variables have also been computed and listed.

10. To print the output simply **Press** the **<F5>** Function key.

The printed output is shown below.

```
QUICK -  2
NORMAL DEPTH
Trapezoidal Channel


                INPUT  VARIABLES              OUTPUT VARIABLES
  ___
   ^       \                     /            Depth (ft)          3.27
   |     1|  \    n = 0.035    /    |1        Discharge (cfs)  300.0
Depth     |____ \             / ____|         Velocity (ft/s)    5.04
   |        3.0  \           /   2.0          Top Width (ft)    26.4
  _v_             \_____________/             Froude No.          0.59
          Base Width =   10.0                 Flow Type:  SUBCRITICAL
          Slope      = 0.0050
```

CHANGING THE VARIABLES

```
                     NORMAL  DEPTH
                  TRAPEZOIDAL CHANNEL

                    INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)   10.0   Manning's n       0.0350
 Discharge (cfs)      300   Depth (ft)          3.27
 Slope (ft/ft)     0.0050
-------------------------------------------------------
                   OUTPUT VARIABLES

 Area (sq ft)        59.6   Wet Perimeter (ft)  27.7
 Velocity (ft/s)      5.0   Hyd Radius           2.2
 Top Width (ft)      26.4   Froude #             0.6
                            Flow Type  SUBCRITICAL
-------------------------------------------------------
 Begin Calculations  <Enter>
 Print               <F5>
 <- Back Tab         <F2>          Main Menu <F7>
```

Let's say we want to run this calculation again but with a discharge of **<u>500</u>** cfs instead of 300 cfs.

1. Press the Function Key **<F2>**

```
                     NORMAL  DEPTH
                  TRAPEZOIDAL CHANNEL

                    INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)   10.0   Manning's n       0.0350
 Discharge (cfs)      300   Depth (ft)          3.27
 Slope (ft/ft)     0.0050
-------------------------------------------------------
                   OUTPUT VARIABLES

 Area (sq ft)        59.6   Wet Perimeter (ft)  27.7
 Velocity (ft/s)      5.0   Hyd Radius           2.2
 Top Width (ft)      26.4   Froude #             0.6
                            Flow Type  SUBCRITICAL
-------------------------------------------------------
 Enter Slope  and Press  <Enter>

 <- Back Tab  <F2>                 Main Menu  <F7>
```

The above screen is what you should be looking at. The **<F2>** key will move the prompt backwards through all the variables. Note that since we want to change the Discharge (from **300** to **500**), we will need to Press <F2> again to come to the Enter Discharge prompt. **Follow the steps as shown on the following page to rerun this calculation with a new discharge.**

SCREEN PROMPT - "Enter Slope and Press <Enter>"

2. Press **<F2>.**

SCREEN PROMPT - "Enter Discharge and Press <Enter>"

3. Enter **500** and then Press **<Enter>.**

SCREEN PROMPT - "Enter Slope and Press <Enter>"

4. Press **<Enter>.**

After all of the data is input your screen should look like this:

```
                    NORMAL  DEPTH
                 TRAPEZOIDAL CHANNEL

                   INPUT VARIABLES

L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
Bottom Width (ft)   10.0   Manning's n       0.0350
Discharge (cfs)      500   Depth (ft)          3.27
Slope (ft/ft)     0.0050
---------------------------------------------------
                  OUTPUT VARIABLES

Area (sq ft)        59.6   Wet Perimeter (ft)  27.7
Velocity (ft/s)      5.0   Hyd Radius           2.2
Top Width (ft)      26.4   Froude #             0.6
                           Flow Type  SUBCRITICAL
---------------------------------------------------
Begin Calculations  <Enter>

<- Back Tab         <F2>          Main Menu  <F7>
```

5. Press **<Enter>** to begin the calculation.

After a split second the screen should look like this:

```
                    NORMAL  DEPTH
                 TRAPEZOIDAL CHANNEL

                   INPUT VARIABLES

 L Side Slope (H:V) 3.0:1   R Side Slope (H:V) 2.0:1
 Bottom Width (ft)   10.0   Manning's n       0.0350
 Discharge (cfs)      500   Depth (ft)          4.22
 Slope (ft/ft)     0.0050
 ----------------------------------------------------
                  OUTPUT VARIABLES

 Area (sq ft)        86.7   Wet Perimeter (ft)  32.8
 Velocity (ft/s)      5.8   Hyd Radius           2.6
 Top Width (ft)      31.1   Froude #             0.6
                            Flow Type  SUBCRITICAL
 ----------------------------------------------------
 Begin Calculations  <Enter>
 Print               <F5>
 <- Back Tab         <F2>          Main Menu <F7>
```

Let's return to the Main Menu... Just **Press** the **<F7>** Function Key

```
                       QUICK - 2
                   MAIN         MENU
                                                 Press
                                                 -----
 Critical Depth                                    1
 Channel Capacity                                  2
 Normal Depth                                      3
 Step-Backwater                                    4

 ----------------------------------------------------
 QUIT                                            <F10>
```

```
<F1> - Help
```

➢ If you want to continue and to perform the Step-Backwater Tutorial, then *turn to the next page.* ═══════════➢➢➢➢

➢ If you want to exit out of the program for now, **Press <F10>**. ≺

STEP-BACKWATER {Tutorial Time: 20 to 25 minutes}

Let's say that we have a piece of property located in an unnumbered Zone A, and we need to determine if our property is really in or out of the floodplain. We will be referring to Figure 1 on the next page which represents a plan view of our proposed floodplain study (step-backwater analysis). We have field surveyed 3 cross-sections to use in the step-backwater analysis. The next page lists all of the data from the field surveyed cross-sections.

If you have continued from the previous Normal Depth Tutorial you should see the screen below. If you are just starting the program, you will see the screen below after pressing **Q2** and **<Enter>**.

```
                    QUICK - 2
              MAIN         MENU
                                             Press
                                             -----
 Critical Depth                                1
 Channel Capacity                              2
 Normal Depth                                  3
 Step-Backwater                                4

 QUIT                                        <F10>
```

```
<F1> - Help
```

1. Press **4** and then press **<Enter>** to start the Step-Backwater Option.

Next you will see the Starting Water Surface Elevation Method screen:

```
       Starting Water Surface Elevation Method

                                        Input
                                 -----------------

 NORMAL DEPTH (Slope-Area)
  Enter the Slope in Ft/Ft        (for ex.   .0025)

            OR

 KNOWN WATER SURFACE ELEVATION
  Enter the known WS Elevation    (for ex.  656.78)
```

Enter a Slope or an Elevation:

Let's say that we do not have any previous information about flood elevations for our sample stream. Thus we need to start the step-backwater analysis assuming that the flow in our first cross-section is at Normal Depth. (This assumes that the channel slope downstream of our first cross-section will approximate the slope of the energy grade at the first cross-section of our study.) Let's assume that our calculated downstream channel slope is .0029 ft/ft.

2. Type **.0029** and then press **<Enter>**.

CROSS SECTION INFORMATION

	Cross-Section 1		Cross-Section 2		Cross-Section 3

GROUND POINTS

Station	Elevation	Station	Elevation	Station	Elevation
362	505.0	0	510.0	0	515.0
425	499.1	150	504.8	433	510.1
509	498.0	233	502.2	600	506.3
512	496.9	236	500.9	614	504.9
602	496.9	331	500.9	701	504.8
605	498.2	334	501.8	725	506.5
732	500.1	402	505.5	866	511.1
1020	504.7	591	510.1	1240	514.6

CHANNEL BANK STATIONS

Cross-Section 1	Cross-Section 2	Cross-Section 3
Left 509 Right 605	Left 233 Right 334	Left 600 Right 725

MANNING'S N VALUES

Cross-Section 1	Cross-Section 2	Cross-Section 3
Left .065	Left .055	Left .065
Channel .040	Channel .040	Channel .040
Right .060	Right .060	Right .060

CHANNEL REACH LENGTHS

Cross-Section 1	Cross-Section 2	Cross-Section 3
Left ---	Left 450	Left 490
Channel ---	Channel 450	Channel 490
Right ---	Right 450	Right 490

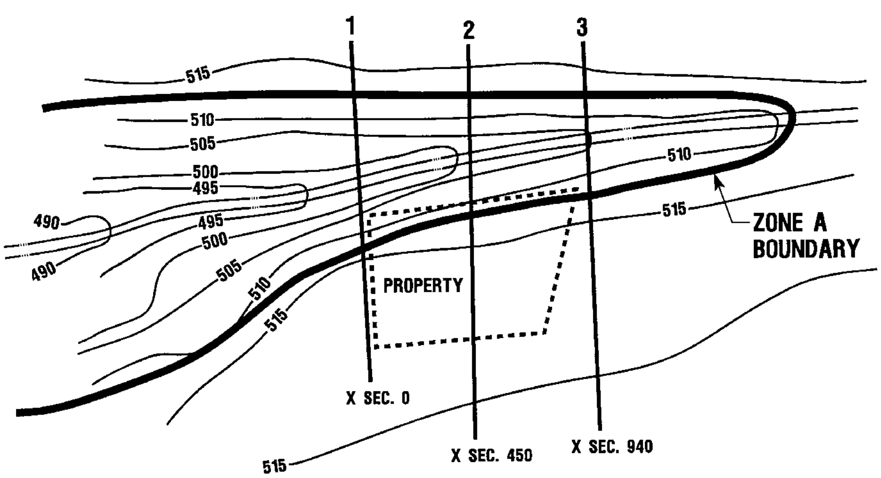
LOSS COEFFICIENTS

Cross-Section 1	Cross-Section 2	Cross-Section 3
Cont --- Expan ---	Cont 0.1 Expan 0.3	Cont 0.1 Expan 0.3

100-YEAR DISCHARGE

Cross-Section 1	Cross-Section 2	Cross-Section 3
3000	3000	3000

FIGURE 1



The next screen you will see is the Input / Output screen as shown:

```
XSEC ID:      0           >> STEP - BACKWATER <<          GROUND  POINTS
STAT      ELEV      STAT      ELEV      STAT      ELEV      STAT      ELEV










 CHANNEL BANK STATIONS:      Left                        Right
 MANNING'S  N   VALUES:      Left         Channel        Right
 CHANNEL REACH LENGTHS:      Left         Channel        Right
 LOSS     COEFFICIENTS: Contractn         Expansn       :Dschrg
 WS ELEV                    Depth         Top Wid        Kratio
 EG ELEV              Flow Regime         ChanVel        Froud#

F2}<-Back Tab F5}List Files F6}Retrieve File F7}Main Menu F10}Ed/Ex GrPt
 F3}Insert GrPt F4}Delete GrPt                           F1 }HELP
```

Before we go on let's read about how data is to be input for this screen.

3. Press **<F1>** to access the Help screen.

4. When you are finished reading the Help screen just **Press <Enter>.**

If you refer to the previous page, you will see a tabulation of the Ground Points for the first field surveyed cross-section listed by Station and Elevation. You will also see the Channel Bank Stations, Manning's N values, and Discharge.

5. Following the method explained in the Help Screen, enter the Ground Points one at a time, by their respective Station and Elevation. Be sure to Press <Enter> after you have typed in each correct number.

Once you have entered all of the Ground Points correctly ...

6. Press **<F10>** to Exit from entering Ground Point data

NOTE: The **<F10> Key** will EXIT you from the top of the screen, or it will RETURN you to the top of the screen if you need to go back to EDIT the Ground Points.

Your screen should now look like this:

```
XSEC ID:      0           >> STEP - BACKWATER <<          GROUND  POINTS
STAT       ELEV      STAT       ELEV      STAT       ELEV      STAT       ELEV
362        505.0     425        499.1     509        498.0     512        496.9
602        496.9     605        498.2     732        500.1     1020       504.7

 CHANNEL BANK STATIONS:      Left                       Right
 MANNING'S  N   VALUES:      Left        Channel        Right
 CHANNEL REACH LENGTHS:      Left        Channel        Right
 LOSS     COEFFICIENTS: Contractn        Expansn        :Dschrg
 WS ELEV                    Depth        Top Wid        Kratio
 EG ELEV              Flow Regime        ChanVel        Froud#

 F2}<- Back Tab F5}PRINT F6}SAVE F7}Main Menu F8}New XSEC F10}Ed/Ex GrPt
 Enter  LEFT  Channel Bank Station  and Press  <Enter>
```

The program is currently prompting you to **enter the Left Channel Bank Station**. Using the information contained on the previous page, we know that our Left Channel Bank Station is **509**. Therefore ...

7. Enter **509** and then Press **<Enter>.** (Notice that the **509** has been entered to the right of "CHANNEL BANK STATIONS: Left".)

Next you will see the Input / Output screen with a new prompt:
SCREEN PROMPT - "Enter RIGHT Channel Bank Station and Press <Enter>"

Using the information for Cross-section 1, simply follow the screen prompts to input the required data, as follows:

SCREEN PROMPT - "Enter RIGHT Channel Bank Station and Press <Enter>"
8. Type **605** and then Press **<Enter>.**

SCREEN PROMPT - "Enter LEFT Manning's n Value and Press <Enter>"
9. Type **.065** and then Press **<Enter>.**

SCREEN PROMPT - "Enter CHANNEL Manning's n Value and Press <Enter>"
10. Type **.040** and then Press **<Enter>.**

SCREEN PROMPT - "Enter RIGHT Manning's n Value and Press <Enter>"
11. Type **.060** and then Press **<Enter>.**

SCREEN PROMPT - "Enter Discharge and Press <Enter>"
12. Type **3000** and then Press **<Enter>.**

Your screen should now look like this:

```
XSEC ID:      0          >> STEP - BACKWATER <<          GROUND  POINTS
STAT      ELEV      STAT      ELEV      STAT      ELEV      STAT      ELEV
362       505.0     425       499.1     509       498.0     512       496.9
602       496.9     605       498.2     732       500.1     1020      504.7

 CHANNEL BANK STATIONS:      Left  509.0                  Right  605.0
 MANNING'S  N   VALUES:      Left 0.0650  Channel 0.0400  Right 0.0600
 CHANNEL REACH LENGTHS:      Left         Channel         Right
 LOSS     COEFFICIENTS: Contractn         Expansn        :Dschrg  3000
 WS ELEV                Depth             Top Wid         Kratio
 EG ELEV               Flow Regime        ChanVel         Froud#

 F2}<- Back Tab F5}PRINT F6}SAVE F7}Main Menu F8}New XSEC F10}Ed/Ex GrPt
 TO BEGIN CALCULATIONS      Press  <Enter>
```

The program is now ready to begin the calculations since all of the required data has been entered for the 1st cross-section of our step-backwater analysis. Note that even at this point, if any of the data on the screen has been typed in incorrectly, the user can simply press the <F2> key to toggle backwards through all of the input data, even back to the Ground Points. Remember that you can instantly go back to the Ground Points by pressing <F10>, also.

13. Press **<Enter>** to Begin the Calculations.

Your screen should now look like this:

```
XSEC ID:      0          >> STEP - BACKWATER <<          GROUND  POINTS
STAT      ELEV      STAT      ELEV      STAT      ELEV      STAT      ELEV
362       505.0     425       499.1     509       498.0     512       496.9
602       496.9     605       498.2     732       500.1     1020      504.7

 CHANNEL BANK STATIONS:      Left  509.0                  Right  605.0
 MANNING'S  N   VALUES:      Left 0.0650  Channel 0.0400  Right 0.0600
 CHANNEL REACH LENGTHS:      Left         Channel         Right
 LOSS     COEFFICIENTS: Contractn         Expansn        :Dschrg  3000
 WS ELEV     501.03         Depth   4.13  Top Wid    385  Kratio  1.00
 EG ELEV     501.32    Flow Regime   M-1  ChanVel   5.10  Froud#  0.50

 F2}<- Back Tab F5}PRINT F6}SAVE F7}Main Menu F8}New XSEC F10}Ed/Ex GrPt
```

As you can see from the screen, the (100-year) Water Surface Elevation (WS ELEV) has been computed (*501.03*), with other variables.

Before we move on to enter the data for the next cross-section let's obtain a printout of this first calculation.

_ Press **<F5>**.

The screen prompt will be ...

PRINT: Summary or Detailed? Press S or D and <Enter>

Let's obtain a Detailed Printout ... Therefore ...

_ Press **D** and then Press **<Enter>**.

Assuming your printer is turned on, the detailed printout will look like this:

```
░ Cross Section:  0
░ XLOB: 0  XLCH: 0  XROB: 0  CC: 0  CE: 0
░
░ NLOB:  .065  STCHL:  509  NCHL:  .04  STCHR:  605  NROB:  .06
░
░ STAT     ELEV     STAT     ELEV     STAT     ELEV     STAT    ELEV
░ 362.00   505.00   425.00   499.10   509.00   498.00   512.00 496.90
░ 602.00   496.90   605.00   498.20   732.00   500.10  1020.00 504.70
░
░ CWSEL           EG      ELMIN       QLOB        QCH         QROB
░ Chan Vel        HV      KRATIO      ALOB        ACH         AROB
░ Depth           HL      Top Width   STAT-L      ST-MIDCH    STAT-R
░ Discharge       OL      Froude #    CH-Slope    EG-Slope  FlowRegim
░  501.03    501.317      496.90         493        2003          505
░    5.10       0.29        1.00         228         392          265
░    4.13       0.00         385       404.4       557.0        789.9
░    3000       0.00        0.50      0.0000      0.0029          ---
```

If any of the above variables are unfamiliar, a description of each is provided in Appendix 1.

If you want to save the cross-section data to a different name and/or directory, ***before pressing*** <F8>, *you can Press* <F6>, (**F6}**SAVE) , *to perform this.*

Now we need to enter the data for the 2nd cross-section. Since we are entering a new cross-section (**New XSEC**), we need to ...

_ Press **<F8>**.

Before the Screen changes you will notice that at the bottom of the screen a message will briefly appear ...

SAVING TEMPORARY FILE C:\QUICK2\DATA\T0.XSC

This alerts you that your cross-section data has been saved to a file called T0.XSC, which is located in your C:\QUICK2\DATA directory.

Your screen should be blank again as shown below:

```
XSEC ID:      0          >> STEP - BACKWATER <<          GROUND  POINTS
STAT      ELEV      STAT      ELEV      STAT      ELEV      STAT      ELEV











 CHANNEL BANK STATIONS:      Left                        Right
 MANNING'S  N   VALUES:      Left         Channel        Right
 CHANNEL REACH LENGTHS:      Left         Channel        Right
 LOSS     COEFFICIENTS: Contractn         Expansn       :Dschrg
 WS ELEV                    Depth         Top Wid        Kratio
 EG ELEV              Flow Regime         ChanVel        Froud#

F2}<-Back Tab F5}List Files F6}Retrieve File F7}Main Menu F10}Ed/Ex GrPt
 F3}Insert GrPt F4}Delete GrPt                           F1 }HELP
```

_ Following the method used before, for the 1st cross-section, enter the Ground Points one at a time, by their respective Station and Elevation for the 2nd cross-section using the data provided. Be sure to Press <Enter> after you have typed in each correct number.

_ Once you have entered all of the Ground Points correctly, remember to Press **<F10>** to Exit from entering Ground Point data .

_ Follow the on screen prompts to enter all of the other data.

Remember that if any of the data on the screen has been typed in incorrectly, the user can simply press the <F2> key to toggle backwards through all of the input data, even back to the Ground Points. (You can also Press <F10> to go back to the Ground Points immediately for editing).

After entering all the data your screen should now look like this:

```
XSEC ID:    450          >> STEP - BACKWATER <<          GROUND  POINTS
STAT      ELEV      STAT      ELEV      STAT      ELEV      STAT      ELEV
  0       510.0     150       504.8     233       502.2     236       500.9
331       500.9     334       501.8     402       505.5     591       510.1









 CHANNEL BANK STATIONS:      Left  233.0                 Right  334.0
 MANNING'S  N   VALUES:      Left 0.0550  Channel 0.0400  Right 0.0600
 CHANNEL REACH LENGTHS:      Left    450  Channel     450  Right    450
 LOSS     COEFFICIENTS: Contractn    0.1  Expansn     0.3 :Dschrg  3000
 WS ELEV                    Depth         Top Wid        Kratio
 EG ELEV              Flow Regime         ChanVel        Froud#

 F2}<- Back Tab F5}PRINT F6}SAVE F7}Main Menu F8}New XSEC F10}Ed/Ex GrPt
 TO BEGIN CALCULATIONS     Press  <Enter>
```

The program is now ready to begin the calculations since all of the required data has been entered for the 2nd cross-section of our step-backwater analysis.

_ Press **<Enter>** to Begin the Calculations.

Once the calculation is finished you may ...

_ Press **<F5>** to obtain a printout

_ Press **<F6>** to save the data to another name and/or directory

---

Finally, to finish our analysis we need to enter in the data for the 3rd cross-section.

_ Press **<F8>**

Before the Screen changes you will notice that at the bottom of the screen a message will briefly appear ...

SAVING TEMPORARY FILE C:QUICK2\DATA\T450.XSC

This alerts you that your 2nd cross-section data has been saved to a file called T450.XSC, which is located in your C:\QUICK2\DATA directory. Notice that the **450**, represents the channel distance between the 1st and 2nd cross-sections.

_ Following the method used before for the other cross-sections, enter the Ground Points one at a time, by their respective Station and Elevation for the 3rd cross-section using the data provided. Be sure to Press <Enter> after you have typed in each correct number.

_ Once you have entered all of the Ground Points correctly, remember to Press **<F10>** to Exit from entering Ground Point data .

_ Follow the on screen prompts to enter all of the other data.

After entering all the data for the 3rd cross-section ...

_ Press **<Enter>** to Begin the Calculations.

Once the calculation is finished you may ...

_ Press **<F5>** to obtain a printout

_ Press **<F6>** to save the data to another name and/or directory

---

TO EXIT OUT OF THIS SCREEN NOW THAT OUR ANALYSIS IS COMPLETED ...

_ Press **<F7>**

You will see a screen prompt at the bottom ...

SUMMARY PRINTOUT: Press <F5>, otherwise Press <Enter>

To print a summary of the output for all 3 cross-sections then ...

_ Press **<F5>**, otherwise just Press **<Enter>**

The on screen Summary or the printed summary will look like this:

SECNO	Q	XLCH	CWSEL	FR#	ELMIN	AVG.VEL.	AREA	TOPWID
0	3000.0	0	501.03	0.50	496.90	3.39	885.0	385.5
450	3000.0	450	503.96	1.06	500.90	7.54	398.1	196.9
940	3000.0	490	508.54	0.71	504.80	4.95	606.5	286.2

If we carefully compare the Computed Water Surface Elevations (CWSELs) at each cross-section, to the topographic contours on Figure 1, we will see that the property is clearly higher than the CWSEL at every cross-section. Therefore this analysis with more detailed cross-section data has proven that the property has been inadvertently included in an unnumbered Zone A Special Flood Hazard Area.

Turn to the next page to continue ══════➢➢➢➢

RUNNING HEC-2 USING QUICK-2 FILES {Tutorial Time: 5 minutes}

_ You will be prompted one more time to Press <Enter>. The next prompt will ask you a question concerning running the HEC-2 or PLOT-2 programs.

Press Y and <Enter> to rerun w/HEC-2 or PLOT-2: If NO Press <Enter>

_ For purposes of this tutorial let's answer "**Y**" , (and Press **<Enter>**) to run the HEC-2 program. The next screen that will appear will include the following:

To Run	Type
QUICK-2	Q2
HEC-2	H2
AUTOHEC-2	AH2
PLOT-2	P2
VIEW/PRINT	LIST

_ Type **AH2** and Press **<Enter>**.

Once the HEC-2 run is complete it will return you to the above-mentioned screen.

NOTE: Typing **AH2** runs the HEC-2 program automatically using the QUICK-2 generated HEC2.DAT, HEC-2 data file.

*If you are using a HEC-2 data file other than HEC2.DAT, then Type **H2** and Press **<Enter>**. Follow the directions on the screen for naming the Input, Output and Tape95 files; pressing <Enter> after each filename is typed in.*

_ Type **LIST** and Press **<Enter>**, and then enter your output filename, (Default is HEC2.OUT), to view the results. *Note that you move up, down and across the screen using the <Page UP>,<Page Down>, the cursor keys, etc.*

_ To **Print** the data that appears on the screen simply **Press P**.

_ To **Exit** from the screen simply **Press X** or the **Escape** key.

If you would like to complete the next tutorial example, then

Type Q2 and **Press <Enter>**; and, *turn to the next page*.══════➢➢➢➢

RERUNNING USING SAVED CROSS-SECTION FILES

{Tutorial Time: 5 minutes}

Let's say that in the analysis that was performed in the previous tutorial, we want to change the discharge from 3000 to 5000, and run the step-backwater option again with the same cross-sections. This is quite easily done. Just follow the steps as shown below.

1. At the Main Menu Screen **Type 4 and Press <Enter>**

2. At the Starting Water Surface Elevation Method Screen
Type .0029 and Press <Enter>

3. At the Input/Output Screen **Press <F6>** to retrieve a saved cross-section file

Assuming your 1st cross-section file is stored as C:\QUICK2\DATA\T0.XSC

Type C and Press <Enter> when prompted for the directory
Type QUICK2\DATA & Press <Enter> when prompted for the subdirectory
Type T0 and Press <Enter> when prompted for the filename

4. **Press <F2>** to toggle back to the "Enter Discharge" prompt

5. **Type 5000 and Press <Enter>** to enter the new discharge

6. **Press <Enter>** to Begin the Calculations

7. **Press <F8>** to input another cross-section
Press <F6> to retrieve a saved cross-section file

Assuming your 2nd cross-section file is stored as C:\QUICK2\DATA\T450.XSC

Type C and Press <Enter> when prompted for the directory
Type QUICK2\DATA & Press <Enter> when prompted for the subdirectory
Type T450 and Press <Enter> when prompted for the filename

8. **Press <F2>** to toggle back to the "Enter Discharge" prompt

9. **Type 5000 and Press <Enter>** to enter the new discharge

10. **Press <Enter>** to Begin the Calculations

11. **Press <F8>** to input another cross-section

Press <F6> to retrieve a saved cross-section file

Assuming your 3rd cross-section file is stored as
C:\QUICK2\DATA\T940.XSC
Type C and Press <Enter> when prompted for the directory
Type QUICK2\DATA & Press <Enter> when prompted for the subdirectory
Type T940 and Press <Enter> when prompted for the filename

12. **Press <F2>** to toggle back to the "Enter Discharge" prompt

13. **Type 5000 and Press <Enter>** to enter the new discharge

14. **Press <Enter>** to Begin the Calculations

_ **Press <F7>** to Exit out of the screen

_ **Press <F5>** to obtain a summary printout

_ **Press <Enter>** twice to get back to the main menu

_ **Press <F10>** to leave the program

Q.E.D.

CHANNEL CAPACITY OPTION WITH THE RATING CURVE PLOT

{Tutorial Time: 5 to 10 minutes}

Let's say that we need to determine a Base Flood Elevation (BFE) for the property shown in Figure 1. We do not want to exempt the entire property from the flood plain, only a structure which is located in the middle of the property. Therefore, we can use one cross-section (the 2nd cross-section (T450.XSC) from our previous tutorial and shown on Figure 1), to compute a BFE.

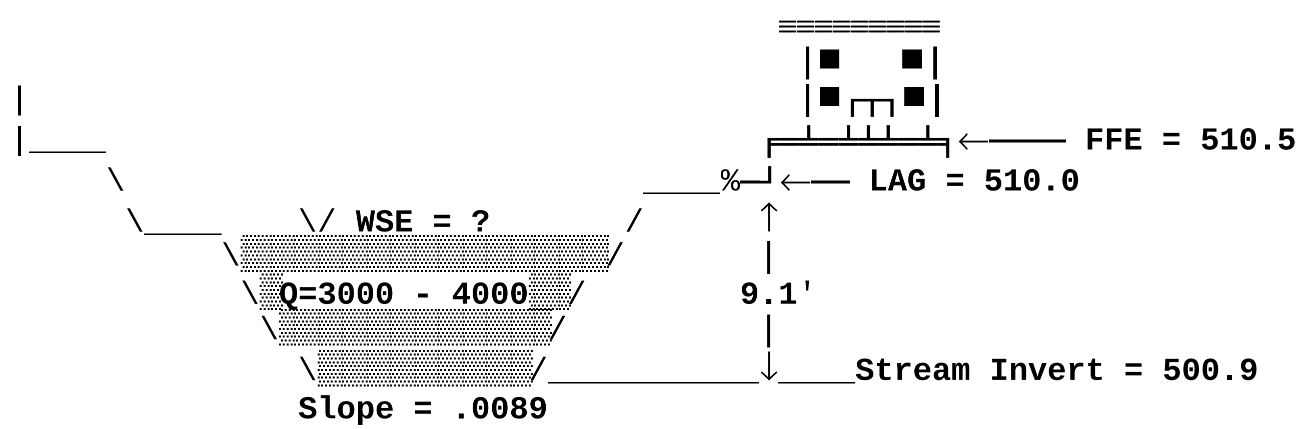
Let's assume that we know the discharge is between 3000 cfs and 4000 cfs based on our best estimates.

Let's assume our structure does not have a basement; the lowest adjacent grade (LAG) to the house is at elevation 510 NGVD; and the first floor elevation (FFE) is 510.5 NGVD.

Let's determine the maximum carrying capacity of the floodplain using a depth equal to the lowest adjacent grade (510.0) minus the minimum stream elevation (500.9). For purposes of this example we'll use a depth of 9 feet (510-501).

To perform a channel capacity calculation we also need to know the downstream slope, which in this case is easy to compute from the information on page 15. Slope = 500.9 - 496.9 / 450 = .0089.

The graphic below sums up our situation so far:



Follow the steps as shown on the next page to compute the rating curve ...

1. At the Main Menu Screen **Type 2 and Press <Enter>**

2. At the Shape of Cross Section Screen
Type I and Press <Enter>

3. At the Input/Output Screen **Press <F6>**

We are using the 2nd cross-section file stored as C:\QUICK2\DATA\T450.XSC

Type C and Press <Enter> when prompted for the directory
Type QUICK2\DATA & Press <Enter> when prompted for the subdirectory
Type T450 and Press <Enter> when prompted for the filename

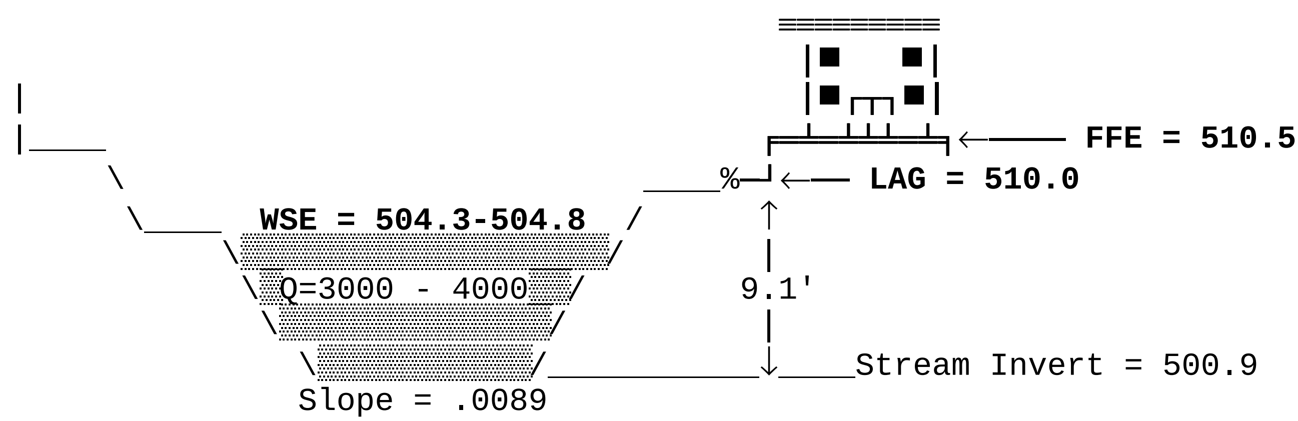
4. **Type .0089 and Press <Enter>** to enter the slope

5. **Type 9 and Press <Enter>** to enter the depth

6. **Press <Enter>** to Begin the Calculations

7. **Press <F4>** to Plot to screen .... **Press <F5>** to Print

Looking at the rating curve plot we can see that for a discharge range of between 3000cfs - 4000cfs the BFE ranges from about 504.3 to 504.8. Since our lowest adjacent grade and first floor elevation are at or above 510, it is clear that this structure is above the BFE.



8. **Press <Enter>** to continue

9. **Press <F7>** to go back to the Main Menu

10. **Press <F10>** to Exit the program

PLOT-2

In general PLOT-2 will only work on QUICK-2 files that have been converted into HEC-2 format using QUICK-2's Step-Backwater option.

Profile plots from PLOT-2 will work only if the QUICK-2 generated data file (HEC2.DAT) is also run using the HEC-2 program (see Running HEC-2 Using QUICK-2 Files, page 4-18), since a HEC2.T95 file needs to be generated by the HEC-2 program for use by PLOT-2.

PLOT-2 Cross-section plots can be generated using the QUICK-2 generated data file (HEC2.DAT) even if it is not run with HEC-2. However, the Cross-section plot will not show the computed water surface elevation (CWSEL) unless the QUICK-2 HEC2.DAT file is run with HEC-2, since the CWSEL is found on the HEC2.T95 file.

Note that the user can compute a normal depth elevation for only one cross-section and have that cross-section plotted by choosing the Step-Backwater option and the Normal Depth starting water surface elevation method. Once the computation is finished, the user simply exits (Presses <F7>), and the QUICK-2 program automatically creates the HEC2.DAT file for that one cross-section, which can be used by the PLOT-2 program.

Let's say that we want to view the water surface elevation profile and the cross-section plots from our previous tutorial on the Step-Backwater option.

_ From the QUICK-2 Title screen **Press P2**

_ You are now into the PLOT-2 program, **Press <Enter> to continue**

PROFILE PLOT {Tutorial Time: 5 to 10 minutes}

1. Let's view the profile first. **Press 1** from the PLOT-2 main menu selection

2. Cursor to the HEC2 Tape95 file name entry and **Type ?**

This will list all of the data files in the QUICK-2 directory. T95 files are designated with the 3 letter extension .T95 . Therefore cursor over to highlight that file (HEC2.T95) and **Press <Enter>.**

3. Move up to highlight the Plot profiles entry and **Press <Enter>.**

4. Your profile is now plotted. **Pressing <Enter>** moves you back to the Profile plots main menu screen. You can explore the different Profile and Plotting options and replot the profile if you wish.

5. When you are finished plotting, highlight the Return to main menu message and **Press <Enter>**

CROSS-SECTION PLOT {Tutorial Time: 5 to 10 minutes}

1. From the PLOT-2 main menu **Press 2** from the menu selection.

2. Cursor down to the HEC2 input file name entry and **Type ?**

This will list all of the data files in the QUICK-2 directory. Input files are designated with the 3 letter extension .DAT . Therefore cursor over to highlight that file (HEC2.DAT) and **Press <Enter>**. If we want to view a different data file than that of the profile we previously viewed, we would have to specify a different file here before proceeding.

3. Cursor down to the HEC2 Tape95 file name entry

Note that we do not have to re-enter this file since we have already entered it previously. If we want to view a different Tape95 file than that of the profile we previously viewed, we would have to **Type ?**, and then specify a different file here before proceeding.

4. Move up to highlight the Plot cross sections entry and **Press <Enter>.**

5. You now have the option of printing all or selected cross sections from your data file. Press Y for plotting all, or N for plotting selected cross sections.

Your first cross-section is now plotted. Pressing <Enter> moves you back to the Cross-section plots main menu screen or plots additional cross-sections depending on how many cross-section plots you have. You can explore the different Cross-section and Plotting options if you wish.

6. Highlight the Return to main menu message and **Press <Enter>**

Pressing 4 at the PLOT-2 main menu exits you from PLOT-2 and back to the QUICK-2 title screen.

Note: To use PLOT-2 and to access data files that are in another directory (i.e., they are not in the C:\QUICK2 directory), just change to that data directory (i.e., CD\dirname) and access PLOT-2 by typing C:\QUICK2\PLOT2 (or A:\PLOT2 if using the program from the floppy drive) from that data directory.

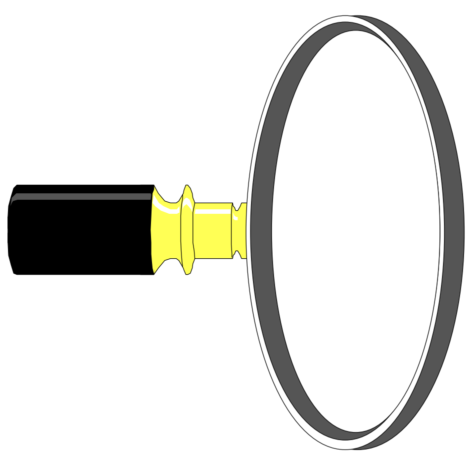
Chapter 5: FORMULAS

Critical Depth

Channel Capacity

Normal Depth

Step-Backwater



1. *CRITICAL DEPTH*

In every cross-section for a given discharge there exists a critical depth, where the energy grade (depth of water plus velocity head - $V^2/2G$) is at a minimum. Increasing the discharge above this given discharge will force the flow into the super-critical regime. Discharges below the given discharge will remain in the sub-critical regime. Super-critical depths will be lower than the critical depth, and sub-critical depths will be above the critical depth. Super-critical flow is characterized by small water depths with large velocity heads; while, sub-critical flow is characterized by large water depths with small velocity heads. A rule of thumb used to determine critical depth is that when the Velocity Head equals 1/2 the hydraulic depth (Area/Topwidth) critical flow is probable.

A formula which can be used to approximate critical depth (D_c) is given below.

$$\mathbf{Qc^2 / g = A^3 / T}$$

Where Qc is the discharge (in cfs) based on critical depth, g is the gravitational constant (32.15 feet/second squared), A is the cross-section area (in square feet), and T is the top width of the water surface (in feet). Note: for rectangular channels the above equation can be reduced so that

$$D_c = (Qc/5.67\ T)^{.667}.$$

The more exact way to compute critical depth (minimum specific energy) is to find a specific depth of water within a cross-section for a given discharge which produces the lowest energy grade. The following represents the process that the Critical Depth option of QUICK-2 goes through to calculate critical depth.

After the cross-section information (ground points, channel stations, etc.) has been input the program starts computing the water surface elevation (WSE) and corresponding energy grade elevation (EG) at a depth of 0.1 foot above the lowest elevation in the cross-section. It continues to calculate WSE and EG at intervals of 0.5 foot. As the depth of water in the cross-section increases the EG will decrease. At one point the EG will begin to increase. This means that between the last 0.5 foot interval there exists a minimum energy grade. Once this has occurred the program decreases the WSE in intervals of .02 foot. As the depth of water decreases in the cross-section the EG will also decrease as it approaches the minimum specific energy. At one point the EG will begin to increase again.

This means that between the last .02 foot interval critical depth exists. At this point the screen will display the actual critical water surface elevation (along with other variables) by assuming that the next to the last iteration was the critical depth.

The calculations performed by the program for a given cross-section are listed on the next page. The calculations include the iterations that the program goes through to arrive at critical depth.

ELMIN = 92.5

WSE = 92.6	Qc= 6.026845E-02	Q= 260	EG=466080.8	EG Decreasing
WSE= 93.1	Qc= 5.314738	Q= 260	EG=452.6406	-
WSE= 93.6	Qc= 24.18726	Q= 260	EG=125.4259	-
WSE= 94.1	Qc= 61.71717	Q= 260	EG=101.21	-
WSE= 94.6	Qc= 121.451	Q= 260	EG=96.99928	-
WSE= 95.1	Qc= 204.4488	Q= 260	EG=96.14474	-
WSE= 95.6	Qc= 311.15	Q= 260	EG=96.14897	+ EG Increasing

Therefore Minimum Specific Energy is between WSE's of 95.1 and 95.6. Note also that the Discharge (Q = 260) is also within the computed Critical Discharge (Qc) range of 204 - 311.

WSE= 95.58	Qc= 306.5006	Q= 260	EG=96.14179	- EG Decreasing
WSE= 95.56	Qc= 301.8821	Q= 260	EG=96.13499	-
WSE= 95.54	Qc= 297.2962	Q= 260	EG=96.12863	-
WSE= 95.52	Qc= 292.7447	Q= 260	EG=96.12271	-
WSE= 95.50	Qc= 288.2256	Q= 260	EG=96.11724	-
WSE= 95.48	Qc= 283.737	Q= 260	EG=96.11225	-
WSE= 95.46	Qc= 279.2825	Q= 260	EG=96.10776	-
WSE= 95.44	Qc= 274.8583	Q= 260	EG=96.1038	-
WSE= 95.42	Qc= 270.4678	Q= 260	EG=96.10038	-
WSE= 95.40	Qc= 266.1075	Q= 260	EG=96.09752	-
WSE= 95.38	Qc= 261.7806	Q= 260	EG=96.09525	-
WSE= 95.36	Qc= 257.4854	Q= 260	EG=96.09361	-
WSE= 95.34	Qc= 253.22	Q= 260	EG=96.09262	-
WSE= 95.32	**Qc= 248.986**	**Q= 260**	**EG=96.09199**	**minimum**
WSE= 95.30	Qc= 244.76	Q= 260	EG=96.09271	+ EG Increasing

We assume that ... Critical Depth = 95.32', Minimum Specific Energy = 96.09199'

The Froude number would be, Q / Qc, or 260 / 248.986 = 1.04.

It is not unusual for the Froude number to not equal exactly 1.0, since the calculation of critical discharge using the formula $Qc^2 / g = A^3 / T$, does not always yield a WSE that is exactly at the True minimum specific energy.

You should notice from the above tabulation, that as you approach critical depth (minimum specific energy), for very small changes in EG there are large jumps in the water surface elevation. The EG is only changing by .001' to .003' while the WSE changes by .02'. A 0.01' difference in EG can cause a 0.10' change in WSE.

2. *CHANNEL CAPACITY*

In this option, a Normal Depth elevation (see 3. *NORMAL DEPTH*) is input and the program computes the corresponding discharge. (In the Normal Depth option, the discharge is input and the program computes a normal depth elevation). The Manning's equation is used as the formula for determining the (normal) discharge.

$$Q = 1.486\ A\ (R^{.667})\ S^{.5}\ /\ N$$

Where Q is the discharge (in cfs), A is the cross-section area (in square feet), R is the hydraulic radius (in feet), S is the energy slope (in feet/feet), and N is the Manning's roughness value.

After the cross-section information (ground points, channel stations, streambed slope, normal depth elevation(s), etc.) has been input, the program simply solves for the area (A) and hydraulic radius (R) below the normal depth elevation (specified by the user) and computes the (normal) discharge directly using the Manning's equation. This is not an iterative process. The screen will display the (normal) discharge (which represents the channel capacity) along with other variables.

3. *NORMAL DEPTH*

The standard formula for determining normal depth in a cross-section is the Manning's formula. Water is flowing at normal depth when the energy grade and the hydraulic grade (water surface) slopes are the same as the stream bed slope. Normal depth profiles occur, in general, when the flow is uniform, steady, one-dimensional, and is not affected by downstream obstructions or flow changes. The standard Manning's equation is:

$$Q = 1.486\ A\ (R^{.667})\ S^{.5}\ /N$$

Where Q is the discharge (in cfs), A is the cross-section area (in square feet), R is the hydraulic radius (in feet), S is the energy slope (in feet/feet), and N is the Manning's roughness value.

The exact method for computing normal depth for a given discharge at a particular cross-section, is to assume that S is equal to the downstream streambed slope and to solve iteratively for the depth (this obviously assumes N is known). The following represents the process that the Normal Depth option of QUICK-2 goes through to calculate normal depth.

After the cross-section information (ground points, channel stations, discharge, streambed slope, etc.) has been input, the program starts computing discharge using the Manning's equation at an initial depth of 0.1 foot above the lowest point in the cross-section, and from that point in 0.5 foot intervals. At some point, the computed discharge will exceed the given target discharge. The program then uses a converging technique to compute a discharge (with a corresponding normal depth) that is within 1% of the given discharge. At this point the screen will display the actual normal depth water surface elevation (along with other variables).

The calculations performed by the program for a given cross-section are listed below. The calculations include the iterations that the program goes through to arrive at normal depth.

```
ELMIN= 92.5
WSE  = 92.6       Q=  260      Computed Q=  .023579   below target Q

WSE=  93.1        Q=  260      Computed Q=  2.803083  below
WSE=  93.6        Q=  260      Computed Q=  14.11313  below
WSE=  94.1        Q=  260      Computed Q=  38.33264  below
WSE=  94.6        Q=  260      Computed Q=  80.01045  below
WSE=  95.1        Q=  260      Computed Q=  146.9773  below
WSE=  95.6        Q=  260      Computed Q=  245.9516  below

WSE=  96.1        Q=  260      Computed Q=  369.2461  above target Q

WSE=  95.65697    Q=  260      Computed Q=  258.7531  within 1%
```

We assume that ... Normal depth = 95.66 for a Discharge (Q) of 260 cfs

4. *STEP-BACKWATER*

The **Energy Equation** which represents one-dimensional, uniform, and steady flow in open channels is shown below.

$$(1) \quad WSE_d + HV_d = WSE_u + HV_u + HL + OL$$

Where WSE_d is the water surface elevation at the downstream cross-section, HV_d is the velocity head at the downstream cross-section, WSE_u is the water surface elevation at the upstream cross-section, HV_u is the velocity head at the upstream cross-section, HL is the friction loss between the two cross-sections, and OL is the eddy (contraction or expansion) loss between the two cross-sections.

Velocity Head, HV, is calculated as follows:

$$HV = (\alpha) V^2 / 2g$$

Where (α) is alpha the velocity coefficient, V is velocity (Q/A), and g is the gravitational constant. Alpha (α) is calculated as follows:

$$(\alpha) = \frac{(A^2)}{(K^3)} \left| \frac{Kl^3}{Al^2} + \frac{Kc^3}{Ac^2} + \frac{Kr^3}{Ar^2} \right|$$

Where A and K are the total area and conveyance below the water surface, respectively; and Kl, Kc, Kr and Al, Ac, Ar, are the conveyance and area in the left overbank, channel, and right overbank, respectively.

Friction Loss, HL, is calculated as follows:

$$HL = Lw \, (Q_d + Q_u)^2 / (K_d + K_u)^2$$

Where Lw is the discharge weighted reach length between cross- sections, Q_d is the discharge at the downstream cross-section, Q_u is the discharge at the upstream cross section, K_d is the conveyance at the downstream cross-section, and K_u is the conveyance at the upstream cross-section. This is derived from the Average Conveyance Friction slope equation.

The Discharge Weighted Reach Length, Lw, is calculated as follows:

$$Lw = \{(Ll * Ql) + (Lc * Qc) + (Lr * Qr)\} / Qa$$

Where Qa is the average total discharge between cross-sections; and, Ll, Lc, Lr, and Ql, Qc, Qr, represent the reach length and average discharge between cross-sections for the left overbank, channel, and right overbank, respectively.

Eddy Loss, OL, is calculated as follows:

$$OL = (Ce \text{ or } Cc) * ABS\, |HV_d - HV_u|$$

Where Ce is the expansion coefficient, Cc is the contraction coefficient, HV_d is the velocity head at the downstream cross-section, and HV_u is the velocity head at the upstream cross-section. When HV_u is greater than HV_d Ce is utilized. When HV_u is greater than or equal to HV_d Cc is utilized.

After the cross-section information for the first cross-section has been input, either a known water surface elevation is input to start the calculations or the water surface elevation could have been determined by the Normal or Critical Depth options or by another source or method. The program then computes all pertinent variables for the first cross-section that will be needed for an energy balance with the next upstream cross-section. After this the user must put in the appropriate information for the next cross-section (i.e., ground points, channel stations, reach lengths, contraction and expansion coefficients, etc.). Once this is done the program performs a series of trial iterations to make sure that the Energy Equation (1) listed previously will balance to within .014 foot. The sequence of trial elevations is listed below.

1ST TRIAL:

Uses the depth of water (DP) of the previous cross-section added to the lowest elevation (ELMIN) within the current cross-section. If DP + ELMIN is less than the previous WSE (i.e., adverse slope condition) then the program uses the previous WSE for the 1st trial at the current cross-section.

2ND TRIAL:

Uses the average of the computed WSE and the WSE assumed in Trial number 1.

3RD TRIAL AND ON ...:

Uses a formula designed to help converge quickly to balance the energy equation as shown below:

Trial WSE = WSE-(WSE+HV-DG-HL-OL)/(1-((Q/QC)^2)+((1.5*HL)/(A/W)))

Where WSE, HV, HL, OL, QC, A, and W are the latest computations of water surface elevation, velocity head, friction loss, eddy loss, critical discharge, total area, and total wetted perimeter, respectively; and, DG is the computed energy grade elevation from the previous cross-section; and, Q is the discharge at the current cross-section.

For most energy balances between cross-sections that are not at or near critical flow, the program will balance the energy equation within 5 trials.

The calculations performed by the program for an energy balance between two cross-sections are listed below. The calculations include the iterations that the program goes through to arrive at the energy balance.

WSE Assumed	WSE Calculated	Difference	Trial #
98.75	98.32489	+.4251099	1
98.53744	98.32472	+.2127228	2
98.32476	98.32513	-.00037	3

We assume that the correct WSE = 98.32

Note: Energy balance in this case was accurate to .00037 foot.

Appendix 1: Definition of Variables

ACH - Area within the specified channel below the water surface elevation

ALOB - Area within the specified left overbank below the water surface elevation

AROB - Area within the specified right overbank below the water surface elevation

ALPHA - Velocity head coefficient

AREA or **Area** - Total area within the cross-section below the water surface elevation

AVG.VEL or **Velocity** - Average Velocity within the entire cross-section

Base Width - Channel bottom width of a trapezoidal or rectangular cross-section

Bottom Width - Channel bottom width of a trapezoidal or rectangular cross-section

CC - Contraction Coefficient

CE - Expansion Coefficient

CH-SLOPE - Slope of the streambed, Channel Slope

CHAN-VEL or **ChanVel** - Velocity within the main channel of cross-section

Critical Slope - Slope of the Energy Grade line at Critical Flow

CWSEL - Computed water surface elevation within a cross-section

Depth - Max depth of water in the cross-sect as measured below the water surface elevation

Diameter - Width or Height of a circular pipe

Discharge - The rate of the flow of a volume of water within a cross-section, usually expressed in cubic feet per second (cfs)

EG or **EG ELEV** - Energy grade elevation, expressed as, WSE + HV

EG-Slope - Energy grade slope

ELEV - Elev of a ground pt of a cross-sect, as ref to some datum (i.e., NGVD, NAVD, etc.)

ELMIN - Lowest elevation in a cross section

Flow Regime - Type of water surface profile (Supercritical regimes are not computed)
M1: EG-Slope <= Ch-Slope and FR# < .8 **M2**: EG-Slope > Ch-Slope and FR# < .8
C1: EG-Slope <= Ch-Slope and FR# >= .8 **C3**: EG-Slope > Ch-Slope and FR# >= .8

Flow Type - either, Supercritical, Critical or Subcritical

Froude#, **Froude No.**, **Froud#** or **FR#** - Froude number, used to determine the flow type (i.e., **sub-** (FR# < 1), **critical** (FR# = 1) or **super-critical** (FR# > 1) flow)

HL - Friction loss between cross sections

HV - Velocity head

Hyd Radius or **Hyd R** - Hydraulic Radius: equal to (Area / Wet Perimeter)

KRATIO - Ratio of upstream total conveyance to downstream total conveyance

L Side Slope - Ratio of the slope of the left side of a channel in terms of Horizontal distance in feet to 1 foot Vertical.

Manning's n - Coefficient used to account for the friction caused by earthen, vegetative, and/or man-made surfaces within a floodplain cross-section.

Max Discharge - The maximum flow possible within a circular pipe, (usually occurring at .94 * Diameter).

NCHL, NLOB, NROB - Manning's "N" value for the specified channel, left overbank, and right overbank, respectively.

OL - Expansion/contraction loss

Q - Total discharge in the cross-section

QC - Critical discharge within entire cross-section for a specific water surface elevation

QCH - Discharge within the specified channel of a cross-section

QIC - Critical discharge within the entire cross-section for a specific water surface elevation, assuming that critical flow is limited to the channel, even if flow is occurring in the overbanks

QLOB, QROB - Discharge within the specified left overbank, and right overbank, respectively, of a cross-section

R Side Slope - Ratio of the slope of the right side of a channel in terms of Horizontal distance in feet to 1 foot Vertical.

SECNO - Cross section number or identifier

Slope or **EG-Slope** - Energy grade slope

STAT-L, STAT-R - Station, within a cross-section, of the left edge, and right edge, respectively, of the water surface

STAT - Station of a ground point of a cross-section

STCHL, STCHR, ST-MIDCH - Station of the left bank, right bank, and mid-point, respectively, of a cross-section

Top Width or **Top Wid** - Top width of the water surface within a cross-section

Velocity - Average Velocity within the entire cross-section

Wet Perimeter or **Wet Per** - actual width of ground within a cross-section below the water surface elevation.

WS ELEV or **CWSEL** - Water surface elevation within a cross-section

XLCH, XLOB, XROB - Distance between cross-sections as measured along the channel, left overbank, and right overbank, respectively.

NOTES

Appendix 7

Hydraulic Computer Manuals

HEC-2

U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), "Water Surface Profiles, HEC-2, User's Manual," Davis, California, 1991.

HEC-RAS

U.S. Army Corps of Engineers, Hydraulic Engineering Center (HEC), "HEC-RAS, River Analysis System, User's Manual - Draft," BETA 2 Test Version, Davis, California, February 1995.

PSUPRO

Federal Emergency Management Agency, "PSUPRO Encroachment Analysis User's Manual", Washington, D.C., 1989.

SFD

Federal Emergency Management Agency, "Simplified Floodway Determination Computer Program User's Manual", Washington, D.C., 1989.

WSPRO

U.S. Geological Survey, "Water Surface PROfiles, WSPRO, User's Manual, Reston, Virginia, 1990.

WSP2

U.S. Department of Agriculture, Natural Resources Conservation Service, "WSP2 Computer Program User's Manual", Technical Release No. 61, Washington, D.C., 1976.

Appendix 8

Normal Depth Hand Calculation

Appendix 8 - continued

Normal Depth Hand Calculation

Appendix 8 - continued

Normal Depth Hand Calculation

Appendix 9

Weir Flow Hand Calculations

Appendix 9 - continued

Weir Flow Hand Calculations

Appendix 9 - continued

Weir Flow Hand Calculations

Appendix 9 - continued

Weir Flow Hand Calculations

Base Flood Elevations in Zone A Areas

Community Name:_______________________________________ State:__________

Community ID# :__________________Panel #:_________ FIRM Date:_________________

Project Identifier :____

This request is for: Existing [ ] Proposed [ ] <5 acres [ ] >5 acres [ ]
Single Lot [ ] Multi-Lot [ ] <50 lots [ ] >50 lots [ ]

Other ____

APPROACH USED TO DEVELOP THE BASE FLOOD ELEVATION (BFE)

EXISTING DATA

	Available	Not Available	Did Not Check
FEMA	[ ]	[ ]	[ ]
Federal	[ ]	[ ]	[ ]
Other	[ ]	[ ]	[ ]

SIMPLIFIED Contour Interpolation [ ] Data Extrapolation [ ]

DETAILED

Hydraulics Normal Depth [ ] Weir Flow [ ] Culvert Flow [ ]

Other____

Hydrology Regression Equations [ ] Rational Formula [ ]
Discharge-Drainage [ ] TR-55 [ ]

Other____

Topography Topographic Map [ ] or Field Survey [ ]

Map Scale: 1" = ________' Contour Interval: _______'

Field Survey tied to Datum? YES NO N/A

Datum: NGVD 1929 [ ] Other___________________________

Cross-Sections [ ] Length of Stream _______________ ft.

RESULTS

BFE or Depth of 100-year Flood __________

First Floor Elevation or Depth __________

Lowest Adjacent Grade to Structure __________

Lowest Grade on entire Property __________ N/A

<u>A Unofficial Reproduction of the</u>

WETLANDS RESEARCH PROGRAM's

Technical Report Y-87-1

CORPS OF ENGINEERS WETLANDS DELINEATION MANUAL

by

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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ABSTRACT

This document presents approaches and methods for identifying and delineating wetlands for purposes of Section 404 of the Clean Water Act. It is designed to assist users in making wetland determinations using a multiparameter approach. Except where noted in the manual, this approach requires positive evidence of hydrophytic vegetation, hydric soils, and wetland hydrology for a determination that an area is a wetland. The multiparameter approach provides a logical, easily defensible, and technical basis for wetland determinations. Technical guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands (uplands).

Hydrophytic vegetation, hydric soils, and wetland hydrology are also characterized, and wetland indicators of each parameter are listed.

Methods for applying the multiparameter approach are described. Separate sections are devoted to preliminary data gathering and analysis, method selection, routine determinations, comprehensive determinations, atypical situations, and problem areas. Three levels of routine determinations are described, thereby affording significant flexibility in method selection.

Four appendices provide supporting information. Appendix A is a glossary of technical terms used in the manual. Appendix B contains data forms for use with the various methods. Appendix C, developed by a Federal interagency panel, contains a list of all plant species known to occur in wetlands of the-region. Each species has been assigned an indicator status that describes its estimated probability of occurring in wetlands. A second list contains plant species that commonly occur in wetlands of the region. Morphological, physiological, and reproductive adaptations that enable a plant species to occur in wetlands are also described, along with a listing of some species having such adaptations. Appendix D describes the procedure for examining the soil for indicators of hydric soil conditions, and includes a national list of hydric soils developed by the National Technical Committee for Hydric Soils.

PREFACE

This manual is a product of the Wetlands Research Program (WRP) of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The work was sponsored by the Office, Chief of Engineers (OCE), US Army. OCE Technical Monitors for the WRP were Drs. John R. Hall and Robert J. Pierce, and Mr. Phillip C. Pierce.

The manual has been reviewed and concurred in by the Office of the Chief of Engineers and the Office of the Assistant Secretary of the Army (Civil Works) as a method approved for voluntary use in the field for a trial period of 1 year.

This manual is not intended to change appreciably the jurisdiction of the Clean Water Act (CWA) as it is currently implemented. Should any District find that use of this method appreciably contracts or expands jurisdiction in their District as the District currently interprets

CWA authority, the District should immediately discontinue use of this method and furnish a full report of the circumstances to the Office of the Chief of Engineers.

This manual describes technical guidelines and methods using a multiparameter approach to identify and delineate wetlands for purposes of Section 404 of the Clean Water Act. Appendices of supporting technical information are also provided.

The manual is presented in four parts. Part II was prepared by Dr. Robert T. Huffman, formerly of the Environmental Laboratory (EL), WES, and Dr. Dana R. Sanders, Sr., of the Wetland and Terrestrial Habitat Group (WTHG), Environmental Resources Division (ERD), EL. Dr. Huffman prepared the original version of Part II in 1980, entitled “Multiple Parameter Approach to the Field Identification and Delineation of Wetlands.” The original version was distributed to all Corps field elements, as well as other Federal resource and environmental regulatory agencies, for review and comments. Dr. Sanders revised the original version in 1982, incorporating review comments. Parts I, III, and IV were prepared by Dr. Sanders, Mr. William B. Parker (formerly detailed to WES by the US Department of Agriculture (USDA), Soil Conservation Service (SCS)) and Mr. Stephen W. Forsythe (formerly detailed to WES by the US Department of the Interior, Fish and Wildlife Service (FWS)). Dr. Sanders also served as overall technical editor of the manual. The manual was edited by Ms. Jamie W. Leach of the WES Information Products Division.

The authors acknowledge technical assistance provided by: Mr. Russell F. Theriot, Mr. Ellis J. Clairain, Jr., and Mr. Charles J. Newling, all of WTHG, ERD; Mr. Phillip Jones, former SCS detail to WES; Mr. Porter B. Reed, FWS, National Wetland Inventory, St. Petersburg, Fla.; Dr. Dan K. Evans, Marshall University, Huntington, W. Va.; and the USDA-SCS. The authors also express gratitude to Corps personnel who assisted in developing the regional lists of species that commonly occur in wetlands, including Mr. Richard Macomber, Bureau of Rivers and Harbors; Ms. Kathy Mulder, Kansas City District; Mr. Michael Gilbert, Omaha District; Ms. Vicki Goodnight, Southwestern Division; Dr. Fred Weinmann, Seattle District; and Mr. Michael Lee, Pacific Ocean Division. Special thanks are offered to the CE personnel who reviewed and commented on the draft manual, and to those who participated in a workshop that consolidated the field comments.

The work was monitored at WES under the direct supervision of Dr. Hanley K. Smith, Chief, WTHG, and under the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD. Dr. Smith, Dr. Sanders, and Mr. Theriot were Managers of the WRP. Dr. John Harrison was Chief, EL.

Director of WES during the preparation of this report was COL Allen F. Grum, USA. During publication, COL Dwayne G. Lee, CE, was Commander and Director. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

CORPS OF ENGINEERS WETLANDS DELINEATION MANUAL

PART I: INTRODUCTION

Background

1. Recognizing the potential for continued or accelerated degradation of the Nation's waters, the US Congress enacted the Clean Water Act (hereafter referred to as the Act), formerly known as the Federal Water Pollution Control Act (33 U.S.C. 1344). The objective of the Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Section 404 of the Act authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into the waters of the United States, including wetlands.

Purpose and Objectives

Purpose

2. The purpose of this manual is to provide users with guidelines and methods to determine whether an area is a wetland for purposes of Section 404 of the Act.

Objectives

3. Specific objectives of the manual are to:

a. Present technical guidelines for identifying wetlands and distinguishing them from aquatic habitats and other nonwetlands. *Definitions of terms used in this manual are presented in the Glossary Appendix A.*
b. Provide methods for applying the technical guidelines.
c. Provide supporting information useful in applying the technical guidelines.

Scope

4. This manual is limited in scope to wetlands that are a subset of "waters of the United States" and thus subject to Section 404. The term "waters of the United States" has broad meaning and incorporates both deep-water aquatic habitats and special aquatic sites, including wetlands (Federal Register 1982), as follows:

a. The territorial seas with respect to the discharge of fill material.

b, Coastal and inland waters, lakes, rivers, and streams that are navigable waters of the United States, including their adjacent wetlands.
c. Tributaries to navigable waters of the United States, including adjacent wetlands.
d. Interstate waters and their tributaries, including adjacent wetlands.
e. All others waters of the United States not identified above, such as isolated wetlands and lakes, intermittent streams, prairie potholes, and other waters that are not a part of a tributary system to interstate waters or navigable waters of the United States, the degradation or destruction of which could affect interstate commerce.

Determination that a water body or wetland is subject to interstate commerce and therefore is a “water of the United States” shall be made independently of procedures described in this manual.

Special aquatic sites

5. The Environmental Protection Agency (EPA) identifies six categories of special aquatic sites in their Section 404 b.(1) guidelines (Federal Register 1980), including:

a. Sanctuaries and refuges.
b. Wetlands.
c. Mudflats.
d. Vegetated shallows.
e. Coral reefs.
f. Riffle and pool complexes.

Although all of these special aquatic sites are subject to provisions of the Clean Water Act, this manual considers only wetlands. By definition (see paragraph 26a), wetlands are vegetated. Thus, unvegetated special aquatic sites (e.g. mudflats lacking macrophytic vegetation) are not covered in this manual.

Relationship to wetland classification systems

6. The technical guideline for wetlands does not constitute a classification system. It only provides a basis for determining whether a given area is a wetland for purposes of Section 404, without attempting to classify it by wetland type.

7. Consideration should be given to the relationship between the technical guideline for wetlands and the classification system developed for the Fish and Wildlife Service (FWS), US Department of the Interior, by Cowardin et al. (1979). The FWS classification system was developed as a basis for identifying, classifying, and mapping wetlands, other special aquatic sites, and deepwater aquatic habitats. Using this classification system, the National Wetland Inventory (NWI) is mapping the wetlands, other special aquatic sites, and deepwater aquatic habitats of the United States, and is also developing both a list of plant species that occur in wetlands and an associated plant database. These products should contribute significantly to

application of the technical guideline for wetlands. The technical guideline for wetlands as presented in the manual includes most, but not all, wetlands identified in the FWS system. The difference is due to two principal factors:

a. The FWS system includes all categories of special aquatic sites identified in the EPA Section 404 b.(I) guidelines. All other special aquatic sites are clearly within the purview of Section 404; thus, special methods for their delineation are unnecessary.
b. The FWS system requires that a positive indicator of wetlands be present for any one of the three parameters, while the technical guideline for wetlands requires that a positive wetland indicator be present for each parameter (vegetation, soils, and hydrology), except in limited instances identified in the manual.

Organization

8. This manual consists of four parts and four appendices. PART I presents the background, purpose and objectives, scope, organization, and use of the manual.

9. PART II focuses on the technical guideline for wetlands, and stresses the need for considering all three parameters (vegetation, soils, and hydrology) when making wetland determinations. Since wetlands occur in an intermediate position along the hydrologic gradient, comparative technical guidelines are also presented for deepwater aquatic sites and nonwetlands.

10. PART III contains general information on hydrophytic vegetation, hydric soils, and wetland hydrology. Positive wetland indicators of each parameter are included.

11. PART IV, which presents methods for applying the technical guideline for wetlands, is arranged in a format that leads to a logical determination of whether a given area is a wetlands Section A contains general information related to application of methods. Section B outlines preliminary data-gathering efforts. Section C discusses two approaches (routine and comprehensive) for making wetland determinations and presents criteria for deciding the correct approach to use. Sections D and E describe detailed procedures for making routine and comprehensive determinations, respectively. The basic procedures are described in a series of steps that lead to a wetland determination.

12. The manual also describes (PART IV, Section F) methods for delineating wetlands in which the vegetation, soils, and/or hydrology have been altered by recent human activities or natural events, as discussed below:

a. The definition of wetlands (paragraph 26a) contains the phrase plunder normal circumstances, which was included because there are instances in which the vegetation in a wetland has been inadvertently or purposely removed or altered as a result of recent natural events or human activities. Other examples of human alterations that may affect wetlands are

draining, ditching, levees, deposition of fill, irrigation, and impoundments. When such activities occur, an area may fail to meet the diagnostic criteria for a wetlands Likewise, positive hydric soil indicators may be absent in some recently created wetlands. In such cases, an alternative method must be employed in making wetland determinations.
b. Natural events may also result in sufficient modification of an area that indicators of one or more wetland parameters are absent. For example, changes in river course may significantly alter hydrology, or beaver dams may create new wetland areas that lack hydric soil conditions. Catastrophic events (e.g. fires, avalanches, mudslides, and volcanic activities) may also alter or destroy wetland indicators on a site.

Such atypical situations occur throughout the United States, and all of these cannot be identified in this manual.

13. Certain wetland types, under the extremes of normal circumstances, may not always meet all the wetland criteria defined in the manual. Examples include prairie potholes during drought years and seasonal wetlands that may lack hydrophytic vegetation during the dry season. Such areas are discussed in PART IV, Section G, and guidance is provided for making wetland determinations in these areas. However, such wetland areas may warrant additional research to refine methods for their delineation.

14. Appendix A is a glossary of technical terms used in the manual. Definitions of some terms were taken from other technical sources, but most terms are defined according to the manner in which they are used in the manual.

15. Data forms for methods presented in PART IV are included in Appendix B. Examples of completed data forms are also provided.

16. Supporting information is presented in Appendices C and D. Appendix C contains lists of plant species that occur in wetlands. Section 1 consists of regional lists developed by a Federal interagency panel. Section 2 consists of shorter lists of plant species that commonly occur in wetlands of each region. Section 3 describes morphological, physiological, and reproductive adaptations associated with hydrophytic species, as well as a list of some species exhibiting such adaptations. Appendix D discusses procedures for examining soils for hydric soil indicators, and also contains a list of hydric soils of the United States.

Use

17. Although this manual was prepared primarily for use by Corps of Engineers (CE) field inspectors, it should be useful to anyone who makes wetland determinations for purposes of Section 404 of the Clean Water Act. The user is directed through a series of steps that involve gathering of information and decisionmaking, ultimately leading to a wetland determination. A general flow diagram of activities leading to a determination is presented in Figure 1.

However, not all activities identified in Figure 1 will be required for each wetland determination. For example, if a decision is made to use a routine determination procedure, comprehensive determination procedures will not be employed.

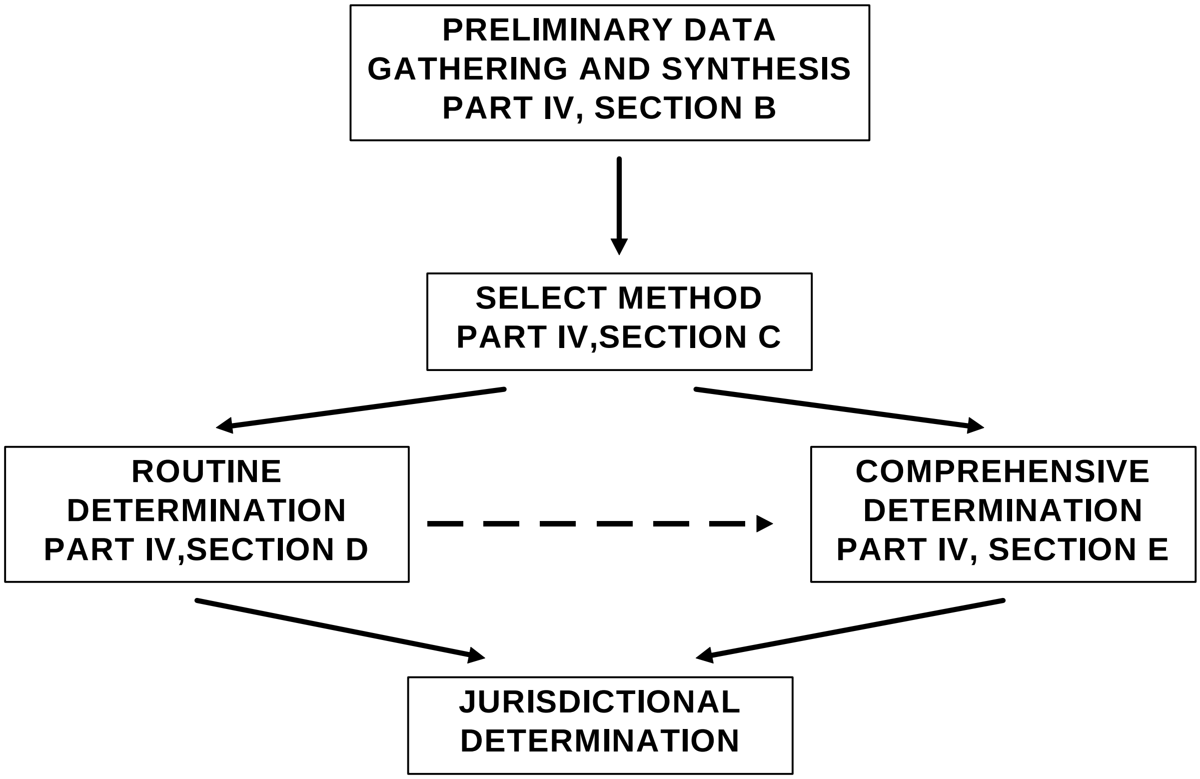

Figure 1. General schematic diagram of activities leading to a wetland/nonwetland determination

<u>Premise for use of the manual</u>

18. Three key provisions of the CE/EPA definition of wetlands (see paragraph <u>26a)</u> include:

<u>a</u>. Inundated or saturated soil conditions resulting from permanent or periodic inundation by ground water or surface water.
<u>b</u>. A prevalence of vegetation typically adapted for life in saturated soil conditions (hydrophytic vegetation).
<u>c</u>. The presence of "normal circumstances."

19. Explicit in the definition is the consideration of three environmental parameters: hydrology, soil, and vegetation. Positive wetland indicators of all three parameters are normally present in wetlands. Although vegetation is often the most readily observed parameter, sole reliance on vegetation or either of the other parameters as the determinant of wetlands can sometimes be misleading. Many plant species can grow successfully in both wetlands and nonwetlands, and hydrophytic vegetation and hydric soils may persist for decades following alteration of hydrology that will render an area a nonwetland. The presence of hydric soils and wetland hydrology indicators in addition to vegetation indicators will provide a logical, easily defensible, and technical basis for the presence of wetlands. The combined use of indicators for all three parameters will enhance the technical accuracy, consistency, and credibility of wetland determinations. Therefore, all three parameters were used in developing the technical guideline for wetlands and all approaches for applying the technical guideline embody the multiparameter concept.

Approaches

20. The approach used for wetland delineations will vary, based primarily on t;he complexity of the area in question. Two basic approaches described in the manual are (a) routine and (b) comprehensive.

21. Routine approach. The routine approach normally will be used in the vast majority of determinations. The routine approach requires minimal level of effort, using primarily qualitative procedures. This approach can be further subdivided into three levels of required effort, depending on the complexity of the area and the amount and quality of preliminary data available. The following levels of effort may be used for routine determinations:

a. Level 1 - Onsite inspection unnecessary. (PART IV, Section D, Subsection 1).
b. Level 2 - Onsite inspection necessary. (PART IV, Section D, Subsection 2).
c. Level 3 - Combination of Levels 1 and 2. (PART IV, Section D, Subsection 3).

22. Comprehensive approach. The comprehensive approach requires application of quantitative procedures for making wetland determinations. It should seldom be necessary, and its use should be restricted to situations in which the wetland is very complex and/or is the subject of likely or pending litigation. Application of the comprehensive approach (PART IV, Section E) requires a greater level of expertise than application of the routine approach, and only experienced field personnel with sufficient training should use this approach.

Flexibility

23. Procedures described for both routine and comprehensive wetland determinations have been tested and found to be reliable. However, site-specific conditions may require modification of field procedures. For example, slope configuration in a complex area may necessitate modification of the baseline and transect positions. Since specific characteristics (e.g. plant density) of a given plant community may necessitate the use of alternate methods

for determining the dominant species, the user has the flexibility to employ sampling procedures other than those described. However, the basic approach for making wetland determinations should not be altered (i.e. the determination should be based on the dominant plant species, soil characteristics, and hydrologic characteristics of the area in question). The user should document reasons for using a different characterization procedure than described in the manual. *CAUTION: Application of methods described in the manual or the modified sampling procedures requires that the user be familiar with wetlands of the area and use his training, experience, and good judgment in making wetland determinations.*

PART II: TECHNICAL GUIDELINES

24. The interaction of hydrology, vegetation, and soil results in the development of characteristics unique to wetlands. Therefore, the following technical guideline for wetlands is based on these three parameters, and diagnostic environmental characteristics used in applying the technical guideline are represented by various indicators of these parameters.

25. Because wetlands may be bordered by both wetter areas (aquatic habitats) and by drier areas (nonwetlands), guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands. However, procedures for applying the technical guidelines for deepwater aquatic habitats and nonwetlands are not included in the manual.

Wetlands

26. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and delineation of wetlands:

a. Definition. The CE (Federal Register 1982) and the EPA (Federal Register 1980) jointly define wetlands as: Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.
b. Diagnostic environmental characteristics. Wetlands have the following general diagnostic environmental characteristics:
(1) Vegetation. The prevalent vegetation consists of macrophytes that are typically adapted to areas having hydrologic and soil conditions described in a above. Hydrophytic species, due to morphological, physiological, and/or reproductive adaptations), have the ability to grow, effectively compete, reproduce, and/or persist in anaerobic soil conditions. *Footnote: Species (e.g. Acer rubrum) having broad ecological tolerances occur in both wetlands and nonwetlands*. Indicators of vegetation associated with wetlands are listed in paragraph 35.
(2) Soil. Soils are present and have been classified as hydric, or they possess characteristics that are associated with reducing soil conditions. Indicators of soils developed under reducing conditions are listed in paragraphs 44 and 45.
(3) Hydrology. The area is inundated either permanently or periodically at mean water depths $\leq$6.6 ft, or the soil is saturated to the surface at some time during the growing season of the prevalent vegetation. *The period of inundation or soil saturation varies according to the hydrologic/soil moisture regime and occurs in both tidal and nontidal situations*. Indicators of hydrologic conditions that occur in wetlands are listed in paragraph 49.
c. Technical approach for the identification and delineation of wetlands. Except in certain situations defined in this manual, evidence of a minimum of one positive wetland indicator from each parameter (hydrology, soil, and vegetation) must be found in order to make a positive wetland determination.

Deepwater Aquatic Habitats

27. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for deepwater aquatic habitats:

a. Definition. Deepwater aquatic habitats are areas that are permanently inundated at mean annual water depths >6.6 ft or permanently inundated areas ≤6.6 ft in depth that do not support rooted-emergent or woody plant species. *Areas ≤6.6 ft mean annual depth that support only submergent aquatic plants are vegetated shallows, not wetlands.*
b. Diagnostic environmental characteristics. Deepwater aquatic habitats have the following diagnostic environmental characteristics:
(1) Vegetation. No rooted-emergent or woody plant species are present in-these permanently inundated areas.
(2) Soil. The substrate technically is not defined as a soil if the mean water depth is >6.6 ft or if it will not support rooted emergent or woody plants.
(3) Hydrology. The area is permanently inundated at mean water depths >6.6 ft.
c. Technical approach for the identification and delineation of deepwater aquatic habitats. When any one of the diagnostic characteristics identified in b above is present, the area is a deepwater aquatic habitat.

Nonwetlands

28. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and del4.neation of nonwetlands:

a. Definition. Nonwetlands include uplands and lowland areas that are neither deepwater aquatic habitats, wetlands, nor other special aquatic sites. They are seldom or never inundated, or if frequently inundated, they have saturated soils for only brief periods during the growing season, and, if vegetated, they normally support a prevalence of vegetation typically adapted for life only in aerobic soil conditions.
b. Diagnostic environmental characteristics. Nonwetlands have the following general diagnostic environmental characteristics:
(1) Vegetation. The prevalent vegetation consists of plant species that are typically adapted for life only in aerobic soils. These mesophytic and/or xerophytic macrophytes cannot persist in predominantly anaerobic soil conditions. *Some species, due to their broad ecological tolerances, occur in both wetlands and nonwetlands (e.g. Acer rubrum).*
(2) Soil. Soils, when present, are not classified as hydric, and possess characteristics associated with aerobic conditions.
(3) Hydrology. Although the soil may be inundated or saturated by surface water or ground water periodically during the growing season of the prevalent vegetation, the average annual duration of inundation or soil saturation does not preclude the occurrence of plant species typically adapted for life in aerobic soil conditions.
c. Technical approach for the identification and delineation of nonwetlands. When any one of the diagnostic characteristics identified in b above is present, the area is a nonwetland.

PART III: CHARACTERISTICS AND INDICATORS OF HYDROPHYTIC VEGETATION, HYDRIC SOILS, AND WETLAND HYDROLOGY

Hydrophytic Vegetation

Definition

29. Hydrophytic vegetation. Hydrophytic vegetation is defined herein as the sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. The vegetation occurring in a wetland may consist of more than one plant community (species association). The plant community concept is followed throughout the manual. Emphasis is placed on the assemblage of plant species that exert a controlling influence on the character of the plant community, rather than on indicator species. Thus, the presence of scattered individuals of an upland plant species in a community dominated by hydrophytic species is not a sufficient basis for concluding that the area is an upland community. Likewise, the presence of a few individuals of a hydrophytic species in a community dominated by upland species is not a sufficient basis for concluding that the area has hydrophytic vegetation.
CAUTION: In determining whether an area is "vegetated" for the purpose of Section 404 jurisdiction, users must consider the density of vegetation at the site being evaluated. While it is not possible to develope a numerical method to determine how many plants or how much biomass is needed to establish an area as being vegetated or unvegetated, it is intended that the predominant condition of the site be used to make that characterization. This concept applies to areas grading from wetland to upland, and from wetland to other waters. This limitation would not necessarily apply to areas which have been disturbed by man or recent natural events.

30. Prevalence of vegetation. The definition of wetlands (paragraph 26a) includes the phrase "prevalence of vegetation." Prevalence, as applied to vegetation, is an imprecise, seldom-used ecological term. As used in the wetlands definition, prevalence refers to the plant community or communities that occur in an area at some point in time. Prevalent vegetation is characterized by the dominant species comprising the plant community or communities. Dominant plant species are those that contribute more to the character of a plant community than other species present, as estimated or measured in terms of some ecological parameter or parameters. The two most commonly used estimates of dominance are basal area (trees) and percent areal cover (herbs). Hydrophytic vegetation is prevalent in an area when the dominant species comprising the plant community or communities are typically adapted for life in saturated soil conditions.

31. Typically adapted. The term "typically adapted" refers to a species being normally or commonly suited to a given set of environmental conditions, due to some morphological,

physiological, or reproductive adaptation (Appendix C, Section 3). As used in the CE wetlands definition, the governing environmental conditions for hydrophytic vegetation are saturated soils resulting from periodic inundation or saturation by surface or ground water. These periodic events must occur for sufficient duration to result in anaerobic soil conditions. When the dominant species in a plant community are typically adapted for life in anaerobic soil conditions, hydrophytic vegetation is present. Species listed in Appendix C, Section 1 or 2. that have an indicator status of OBL, FACW, or FAC (Table 1) are considered to be typically adapted for life in anaerobic soil conditions (see paragraph 35a). *Species having a FAC- indicator status are not considered to be typically adapted for life in anaerobic soil conditions*.

Influencing factors

32. Many factors (e.g. light, temperature, soil texture and permeability, man-induced disturbance, etc.) influence the character of hydrophytic vegetation. However, hydrologic factors exert an overriding influence on species that can occur in wetlands. Plants lacking morphological, physiological, and/or reproductive adaptations cannot grow, effectively compete, reproduce, and/or persist in areas that are subject to prolonged inundation or saturated soil conditions.

Geographic diversity

33. Many hydrophytic vegetation types occur in the United States due to the diversity of interactions among various factors that influence the distribution of hydrophytic species. General climate and flora contribute greatly to regional variations in hydrophytic vegetation. Consequently, the same associations of hydrophytic species occurring in the southeastern United States are not found in the Pacific Northwest. In addition, local environmental conditions (e.g. local climate, hydrologic regimes, soil series, salinity, etc.) may result in broad variations in hydrophytic associations within a given region. For example, a coastal saltwater marsh will consist of different species than an inland freshwater marsh in the same region. An overview of hydrophytic vegetation occurring in each region of the Nation has been published by the CE in a series of eight preliminary wetland guides (Table 2), and a group of wetland and estuarine ecological profiles (Table 3) has been published by FWS.

Classification

34. Numerous efforts have been made to classify hydrophytic vegetation. Most systems are based on general characteristics of the dominant species occurring in each vegetation type. These range from the use of general physiognomic categories (e.g. overstory, subcanopy, ground cover, vines) to specific vegetation types (e.g. forest type numbers as developed by the Society of American Foresters). In other cases, vegetational characteristics are combined with hydrologic features to produce more elaborate systems. The most recent example of such a system was developed for the FWS by Cowardin et al. (1979).

Table 1
Plant Indicator Status Categories*

Indicator Category	Indicator Symbol	Definition
OBLIGATE WETLAND PLANTS	OBL	Plants that occur almost always (estimated probability >99%) in wetlands under natural conditions, but which may also occur rarely (estimated probability <1%) in nonwetlands. Examples: *Spartina alterniflora*, *Taxodium distichum.*
FACULTATIVE WETLAND PLANTS	FACW	Plants that occur usually (estimated probability >67% to 99%) inwetlands, but may also occur (estimated probability 1% to 33% in nonwetlands). Examples: *Fraxinus pennsylvanica*, *Cornus stolonifera.*
FACULTATIVE UPLAND PLANTS	FACU	Plants that occur sometimes (estimated probability 1% to <33%) in wetlands, but occur more often (estimated probability >67% to 99%) in nonwetlands. Examples: *Quercus rubra*, *Potentilla arguta*.
OBLIGATE UPLAND PLANTS	OBL	Plants that occur rarely (estimated probability <1%) in wetlands, but occur almost always (estimated probability >99%) in nonwetlands under natural conditions. Examples: *Pinus echinata*, *Bromus mollis*.

* Categories were originally developed and defined by the USFWS National Wetlands Inventory and subsequently modified by the National Plant List Panel. The three facultative categories are subdivided by (+) and (-) modifiers (See Appendix C, Section 1).

<u>Indicators of hydrophytic vegetation</u>

35. Several indicators may be used to determine whether hydrophytic vegetation is present on a site. However, the presence of a single individual of a hydrophytic species does not mean that hydrophytic vegetation is present. The strongest case for the presence of hydrophytic vegetation can be made when several indicators, such as those in the following list, are present. However, any one of the following is indicative that hydrophytic vegetation is present: *Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.*

<u>a</u>. <u>More than 50 percent of the dominant species are OBL, FACW, or FAC-** (Table 1) on lists of plant species that occur in wetlands.</u> A national interagency panel has prepared a National List of Plant Species that occur in wetlands. This list categorizes species according to their affinity for occurrence in wetlands. Regional subset lists of the national list, including only species having an indicator status of OBL, FACW, or FAC, are presented in Appendix C, Section 1. The CE has also developed regional lists of plant species that commonly occur in wetlands (Appendix C, Section 2). Either list may be used. Note: A District that, on a subregional basis, questions the indicator status of FAC species may use the following option: When FAC species occur as dominants along with other dominants that are not FAC (either wetter or drier than FAC), the FAC species can be considered as neutral, and the vegetation decision can be based on the number of dominant species wetter than FAC as compared to the number of dominant species drier than FAC. When a tie occurs or all dominant species are FAC, the nondominant species must be considered. The area has hydrophytic vegetation when more than 50 percent of all considered species are wetter than FAC. When either all considered species are FAC or the number of species wetter than FAC equals the number of species drier than FAC, the wetland determination will be based on the soil and hydrology parameters. Districts adopting this option should provide documented support to the Corps representative on the regional plant list panel, so that a change in indicator status of FAC species of concern can be pursued. Corps representatives on the regional and national plant list panels will continually strive to ensure that plant species are properly designated on both a regional and subregional basis.
***FAC+ species are considered to be wetter (i.e., have a greater estimated probability of occurring in wetlands) than FAC species, while FAC- species are considered to be drier (i.e., have a lesser estimated probability of occurring in wetlands) than FAC species.*

<u>b</u>. <u>Other indicators</u>. Although there are several other indicators of hydrophytic vegetation, it will seldom be necessary to use them. However, they may provide additional useful information to strengthen a case for the presence of hydrophytic vegetation. Additional training and/or experience may be required to employ these indicators.

(1) <u>Visual observation of plant species growing in areas of prolonged inundation and/or soil saturation.</u> This indicator can only be applied by experienced personnel who have accumulated information through several years of field experience and written documentation

(field notes) that certain species commonly occur in areas of prolonged (>10 percent) inundation and/or soil saturation during the growing season. Species such as *Taxodiun distichum*, *Typha latifolia*, and *Spartina alterniflora* normally occur in such areas. Thus, occurrence of species commonly observed in other wetland areas provides a strong indication that hydrophytic vegetation is present. *CAUTION: The presence of standing water or saturated soil on a site is insufficient evidence that the species present are able to tozerate long periods of inundation. The user must rezate the observed species to other simizar situations and determine whether they are normally found in wet areas, taking into consideration the season and immediatezy preceding weather conditions.*

(2) Morphological adaptations. Some hydrophytic species have easily recognized physical characteristics that indicate their ability to occur in wetlands. A given species may exhibit several of these characteristics, but not all hydrophytic species have evident morphological adaptations. A list of such morphological adaptations and a partial list of plant species with known morphological adaptations for occurrence in wetlands are provided in Appendix C, Section 3.

(3) Technical literature. The technical literature may provide a strong indication that plant species comprising the prevalent vegetation are commonly found in areas where soils are periodically saturated for long periods. Sources of available literature include:

(a) Taxonomic references. Such references usually contain at least a general description of the habitat in which a species occurs. A habitat description such as, "Occurs in water of streams and lakes and in alluvial floodplains subject to periodic flooding," supports a conclusion that the species typically occurs in wetlands. Examples of some useful taxonomic references are provided in Table 4.

(b) Botanical journals. Some botanical journals contain studies that define species occurrence in various hydrologic regimes. Examples of such journals include: Ecology, Ecological Monographs, American Journal of Botany, Journal of American Forestry, and Wetlands: The Journal of the Society of Wetland Scientists.

(c) Technical reports. Governmental agencies periodically publish reports (e.g. literature reviews) that contain information on plant species occurrence in relation to hydrologic regimes. Examples of such publications include the CE preliminary regional wetland guides (Table 2) published by the US Army Engineer Waterways Experiment Station (WES) and the wetland community and estuarine profiles of various habitat types (Table 3) published by the FWS.

(d) Technical workshops, conferences, and symposia. Publications resulting from periodic scientific meetings contain valuable information that can be used to support a decision regarding the presence of hydrophytic vegetation. These usually address specific regions or wetland types. For example, distribution of bottomland hardwood forest species in relation to hydrologic regimes was examined at a workshop on bottomland hardwood forest wetlands of the Southeastern United States (Clark and Benforado 1981).

(e) Wetland plant database. The NWI is producing a Plant Database that contains habitat information on approximately 5,200 plant species that occur at some estimated probability in wetlands, as compiled from the technical literature. When completed, this computerized database will be available to all governmental agencies.

(4) Physiological adaptations. Physiological adaptations include any features of the metabolic processes of plants that make them particularly fitted for life in saturated soil conditions. *NOTE: It is impossible to detect the presence of physiological adaptations in plant species during onsite visits.* Physiological adaptations known for hydrophytic species and species known to exhibit these adaptations are listed and discussed in Appendix C, Section 3.
(5) Reproductive adaptations. Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. Reproductive adaptations known for hydrophytic species are presented in Appendix C, Section 3.

Hydric Soils

Definition

36. A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (US Department of Agriculture (USDA) Soil Conservation Service (SCS) 1985, as amended by the National Technical Committee for Hydric Soils (NTCHS) in December 1986).

Criteria for hydric soils

37. Based on the above definition, the NTCHS developed the following criteria for hydric soils:
a. All Histosols except Folists; Soil nomenclature follows USDA-SCS (1975).
b. Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:
(1) Somewhat poorly drained and have a water table less than 0.5 ft from the surface for a significant period (usually a week or more) during the growing season, or
(2) Poorly drained or very poorly drained and have either:
(a) A water table at less than 1.0 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 in/hr in all layers within 20 inches; or
(b) A water table at less than 1.5 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/hr in any layer within 20 inches; or
c. Soils that are ponded for long or very long duration during the growing season; or
d. Soils that are frequently flooded for long duration or very long duration during the growing season."

A hydric soil may be either drained or undrained, and a drained hydric soil may not continue to support hydrophytic vegetation. Therefore, not all areas having hydric soils will qualify as wetlands. Only when a hydric soil supports hydrophytic vegetation and the area has indicators of wetland hydrology may the soil be referred to as a “wetland” soil.

38. A drained hydric soil is one in which sufficient ground or surface water has been removed by artificial means such that the area will no longer support hydrophyte vegetation. Onsite evidence of drained soils includes:

a. Presence of ditches or canals of sufficient depth to lower the water table below the major portion of the root zone of the prevalent vegetation.
b. Presence of dikes, levees, or similar structures that obstruct normal inundation of an area.
c. Presence of a tile system to promote subsurface drainage.
d. Diversion of upland surface runoff from an area.

Although it is important to record such evidence of drainage of an area, a hydric soil that has been drained or partially drained still allows the soil parameter to be met. However, the area will not qualify as a wetland if the degree of drainage has been sufficient to preclude the presence of either hydrophytic vegetation or a hydrologic regime that occurs in wetlands. *NOTE: the mere presence of drainage structures in an area is not sufficient basis .for concluding that a hydric soil has been drained; such areas may continue to have wetland hydrology.*

General information

39. Soils consist of unconsolidated, natural material that supports, or is capable of supporting, plant life. The upper limit is air and the lower limit is either bedrock or the limit of biological activity. Some soils have very little organic matter (mineral soils), while others are composed primarily of organic matter (Histosols). The relative proportions of particles (sand, silt, clay, and organic matter) in a soil are influenced by many interacting environmental factors. As normally defined, a soil must support plant life. The concept is expanded to include substrates that could support plant life. For various reasons, plants may be absent from areas that have well-defined soils.

40. A soil profile (Figure 2) consists of various soil layers described from the surface downward. Most soils have two or more identifiable horizons. A soil horizon is a layer oriented approximately parallel to the soil surface, and usually is differentiated from contiguous horizons by characteristics that can be seen or measured in the field (e.g., color, structure, texture, etc.). Most mineral soils have A-, B-, and C-horizons, and many have surficial organic layers (0-horizon). The A-horizon, the surface soil or topsoil, is a zone in which organic matter is usually being added to the mineral. soil. It is also the zone from which both mineral and organic matter are being moved slowly downward. The next major horizon is the B-horizon, often referred to as the subsoil. The B-horizon is the zone of maximum accumulation of materials. It is usually characterized by higher clay content and/or more pronounced soil structure development and lower organic matter than the A-horizon. The next

major horizon is usually the C-horizon, which consists of unconsolidated parent material that has not been sufficiently weathered to exhibit characteristics of the B-horizon. Clay content and degree of soil structure development in the C-horizon are usually less than in the B-horizon. The lowest major horizon, the R-horizon, consists of consolidated bedrock. In many situations, this horizon occurs at such depths that it has no significant influence on soil characteristics.

Influencing factors

41. Although all soil-forming factors (climate, parent material, relief, organisms, and time) affect the characteristics of a hydric soil, the overriding influence is the hydrologic regime. The unique characteristics of hydric soils result from the influence of periodic or permanent inundation or soil saturation for sufficient duration to effect anaerobic conditions. Prolonged anaerobic soil conditions lead to a reducing environment, thereby lowering the soil redox potential. This results in chemical reduction of some soil components (e.g. iron and manganese oxides), which leads to development of soil colors and other physical characteristics that usually are indicative of hydric soils.

Classification

42. Hydric soils occur in several categories of the current soil classification system, which is published in Soil Taxonomy (USDA-SCS 1975). This classification system is based on physical and chemical properties of soils that can be seen, felt, or measured. Lower taxonomic categories of the system (e.g. soil series and soil phases) remain relatively unchanged from earlier classification systems.

43. Hydric soils may be classified into two broad categories: organic and mineral. Organic soils (Histosols) develop under conditions of nearly continuous saturation and/or inundation. All organic soils are hydric soils except Folists, which are freely drained soils occurring on dry slopes where excess litter accumulates over bedrock. Organic hydric soils are commonly known as peats and mucks. All other hydric soils are mineral soils. Mineral soils have a wide range of textures (sandy to clayey) and colors (red to gray). Mineral hydric soils are those periodically saturated for sufficient duration to produce chemical and physical soil properties associated with a reducing environment. They are usually gray and/or mottled immediately below the surface horizon (see paragraph 44d), or they have thick, dark-colored surface layers overlying gray or mottled subsurface horizons.

Wetland indicators (nonsandy soils)

44. Several indicators are available for determining whether a given soil meets the definition and criteria for hydric soils. Any one of the following indicates that hydric soils are present: *Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.*

a. Organic soils (Histosols). A soil. is an organic soil when:
(1) more than 50 percent (by volume) of the upper 32 inches of soil is composed of organic soil material; *A detailed definition of organic soil material is available in USDA-SCS (1975)*, or
(2) organic soil material of any thickness rests on bedrock. Organic soils (Figure 3) are saturated for long periods and are commonly called peats or mucks.

b. Histic epipedons. A histic epipedon is an 8- to 16-inch layer at or near the surface of a mineral hydric soil that is saturated with water for 30 consecutive days or more in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when clay content is 60 percent or greater. Soils with histic epipedons are inundated or saturated for sufficient periods to greatly retard aerobic decomposition of the organic surface, and are considered to be hydric soils.

c. Sulfidic material. When mineral soils emit an odor of rotten eggs, hydrogen sulfide is present. Such odors are only detected in waterlogged soils that are permanently saturated and have sulfidic material within a few centimetres of the soil surface. Sulfides are produced only in a reducing environment.

d. Aquic or peraquic moisture regime. An aquic moisture regime is a reducing one; i.e., it is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe (USDA-SCS 1975). Because dissolved oxygen is removed from ground water by respiration of microorganisms, roots, and soil fauna, it is also implicit that the soil temperature is above biologic zero (5º C) at some time while the soil is saturated. Soils with peraquic moisture regimes are characterized by the presence of ground water always at or near the soil surface. Examples include soils of tidal marshes and soils of closed, landlocked depressions that are fed by permanent streams.

e. Reducing soil conditions. Soils saturated for long or very long duration will usually exhibit reducing conditions. Under such conditions, ions of iron are transformed from a ferric valence state to a ferrous valence state. This condition can often be detected in the field by a ferrous iron test. A simple calorimetric field test kit has been developed for this purpose. When a soil extract changes to a pink color upon addition of a-a-dipyridil, ferrous iron is present, which indicates a reducing soil environment. *NOTE: This test cannot be used in mineral hydric soils having low iron content, organic soils, and soils that have been desaturated for significant periods of the growing season.*

f. Soil colors. The colors of various soil components are often the most diagnostic indicator of hydric soils. Colors of these components are strongly influenced by the frequency and duration of soil saturation, which leads to reducing soil conditions. Mineral hydric soils will be either gleyed or will have bright mottles and/or low matrix chroma. These are discussed below:

(1) Gleyed soils (gray colors). Gleyed soils develop when anaerobic soil conditions result in pronounced chemical reduction of iron, manganese, and other elements, thereby producing gray soil colors. Anaerobic conditions that occur in waterlogged soils result in the predominance of reduction processes, and such soils are greatly reduced. Iron is one of the most abundant elements in soils. Under anaerobic conditions, iron in converted from the oxidized (ferric) state to the reduced (ferrous) state, which results in the bluish, greenish, or grayish colors associated with the gleying effect (Figure 4). Gleying immediately below the A-horizon or 10 inches (whichever is shallower) is an indication of a markedly reduced soil, and gleyed soils are hydric soils. Gleyed soil conditions can be determined by using the gley page of the Munsell Color Book (Munsell Color 1975).

(2) Soils with bright mottles and/or low matrix chroma. Mineral hydric soils that are saturated for substantial periods of the growing season (but not long enough to produce gleyed soils) will either have bright mottles and a low matrix chroma or will lack mottles but have a low matrix chroma (see Appendix D, Section 1, for a definition and discussion of “chroma” and other components of soil color). Mottled means “marked with spots of contrasting color.” Soils that have brightlv colored mottles and a low matrix chroma are indicative of a fluctuating water table. The soil matrix is the portion (usually more than 50 percent) of a given soil layer that has the predominant color (Figure 5). Mineral hydric soils usually have one of the following color features in the horizon immediately below the A-horizon or 10 inches (whichever is shallower):

(a) Matrix chroma of 2 or less* in mottled soils.
(b) Matrix chroma of 1 or less* in unmottled soils.

**FOOTNOTE: Colors should be determined in soils that have been moistened; otherwise, state that colors are for dry soils.*

NOTE: The matrix chroma of some dark (black) mineral hydric soils will not conform to the criteria described in (a) and (b) above; in such soils, gray mottles occurring at 10 inches or less are indicative of hydric conditions.

CAUTION: Soils with significant coloration due to the nature of the parent material (e.g. red soils of the Red River Valley) may not exhibit the above characteristics. in such cases, this indicator cannot be used.

g. Soil appearing on hydric soils list. Using the criteria for hydric soils (paragraph 37), the NTCHS has developed a list of hydric soils. Listed soils have reducing conditions for a significant portion of the growing season in a major portion of the root zone and are frequently saturated within 12 inches of the soil surface. The NTCHS list of hydric soils is presented in Appendix D, Section 2. *CAUTION: Be sure that the profile description of the mapping unit conforms to that of the sampled soil.*

h. Iron and manganese concretions. During the oxidation-reduction process, iron and manganese in suspension are sometimes segregated as oxides into concretions or soft masses (Figure 6). These accumulations are usually black or dark brown. Concretions >2 mm in diameter occurring within 7.5 cm of the surface are evidence that the soil is saturated for long periods near the surface.

Wetland indicators (sandy soils)

45. Not all indicators listed in paragraph 44 can be applied to sandy soils. In particular, soil color should not be used as an indicator in most sandy soils. However, three additional soil features may be used as indicators of sandy hydric soils, including:

a. High organic matter content in the surface horizon. Organic matter tends to accumulate above or in the surface horizon of sandy soils that are inundated or saturated to the surface for a significant portion of the growing season. Prolonged inundation or saturation creates anaerobic conditions that greatly reduce oxidation of organic matter.

b. Streaking of subsurface horizons by organic matter. Organic matter is moved downward through sand as the water table fluctuates. This often occurs more rapidly and to a greater degree in some vertical sections of a sandy soil containing high content of organic matter than in others. Thus, the sandy soil appears vertically streaked with darker areas. When soil from a darker area is rubbed between the fingers, the organic matter stains the fingers.

c. Organic pans. As organic matter is moved downward through ,;andy soils, it tends to accumulate at the point representing the most commonly occurring depth to the water table. This organic matter tends to become slightly cemented with aluminum, forming a thin layer of hardened soil (spodic horizon). These horizons often occur at depths of 12 to 30 inches below the mineral surface. Wet spodic soils usually have thick dark surface horizons that are high in organic matter with dull, gray horizons above the spodic horizon.

CAUTION: In recently deposited sandy material (e.g. accreting sandbars), it may be impossible to find any of these indicators. in such cases., consider this as a natural atypical situation.

Wetland Hydrology

Definition

46. The term “wetland hydrology” encompasses all hydrologic characteristics of areas that are periodically inundated or have soils saturated to the surface at some time during the growing season. Areas with evident characteristics of wetland hydrology are those where the presence of water has an overriding influence on characteristics of vegetation and soils due to anaerobic

and reducing conditions, respectively. Such characteristics are usually present in areas that are inundated or have soils that are saturated to the surface for sufficient duration to develop hydrl.c soils and support vegetation typically adapted for life in periodically anaerobic soil conditions. Hydrolpgy is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field. However, it is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season.

Influencing factors

47. Numerous factors (e.g., precipitation, stratigraphy, topography,t' soil permeability, and plant cover) influence the wetness of an area. Regardless, the characteristic common to all wetlands is the presence of an abundant supply of water. The water source may be runoff from direct precipitation, headwater or backwater flooding, tidal influence, ground water, or some combination of these sources. The frequency and duration of inundation or soil saturation varies from nearly permanently inundated or saturated to irregularly inundated or saturated. Topographic position, stratigraphy, and soil permeability influence both the frequency and duration of inundation and soil saturation. Areas of lower elevation in a floodplain or marsh have more frequent periods of inundation and/or greater duration than most areas at higher elevations. Floodplain configuration may significantly affect duration of inundation. When the floodplain configuration is conducive to rapid runoff, the influence of frequent periods of inundation on vegetation and soils maylbe reduced. Soil permeability also influences duration of inundation and soil saturation. For example, clayey soils absorb water more slowly than sandy or loamy soils, and therefore have slower permeability and remain saturated much longer. Type and amount of plant cover affect both degree of inundation and duration of saturated soil conditions. Excess water drains more slowly in areas of abundant plant cover, thereby increasing frequency and duration of inundation and/or soil saturation. On the other hand, transpiration rates are higher in areas of abundant plant cover, which may reduce the duration of soil saturation.

Classification

48. Although the interactive effects of all hydrologic factors produce a continuum of wetland hydrologic regimes, efforts have been made to classify wetland hydrologic regimes into functional categories. These efforts have focused on the use of frequency, timing, and duration of inundation or soil saturation as a basis for classification. A classification system developed for nontidal areas is presented in Table 5. This classification system was slightly modified from the system developed by the Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States (Clark and Benforado 1981). Recent research indicates that duration of inundation and/or soil saturation during the growing season is more influential on the plant community than frequency of inundation/saturation during the growing season (Theriot, in press). Thus, frequency of inundation and soil saturation are not included in Table 5. The WES has developed a computer program that can be used to transform stream gage data to mean sea level elevations representing the upper limit of each hydrologic zone shown in Table 5.

Wetland indicators

49. Indicators of wetland hydrology may include, but are not necessarily limited to: drainage patterns, drift lines, sediment deposition, watermarks, stream gage data and flood predictions, historic records, visual observation of saturated soils, and visual observation of inundation. Any of these indicators may be evidence of wetland hydrologic characteristics. Methods for determining hydrologic indicators can be categorized according to the type of indicator. Recorded data include stream gage data, lake gage data, tidal gage data, flood predictions, and historical records. Use of these data is commonly limited to areas adjacent to streams or other similar areas. Recorded data usually provide both short- and long-term information about frequency and duration of inundation, but contain little or no information about soil saturation, which must be gained from soil surveys or other similar sources. The remaining indicators require field observations. Field indicators are evidence of present or past hydrologic events (e.g. location and height of flooding). Indicators for recorded data and field observations include: *(Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.)*

a. Recorded data. Stream gage data, lake gage data, tidal gage data, flood predictions, and historical data may be available from the following sources:

(1) CE District Offices. Most CE Districts maintain stream, lake, and tidal gage records for major water bodies in their area. In addition, CE planning and design documents often contain valuable hydrologic information. For example, a General Design Memorandum (GDM) usually describes flooding frequencies and durations for a project area. Furthermore, the extent of flooding within a project area is sometimes indicated in the GDM according to elevation (height) of certain flood frequencies (1-, 2-, 5-, 10-year, etc.).

(2) US Geological Survey (USGS). Stream and tidal gage data are available from the USGS offices throughout the Nation, and the latter are also available from the National Oceanic and Atmospheric Administration. CE Districts often have such records.

(3) State, county, and local agencies. These agencies often have responsibility for flood control/relief and flood insurance.

(4) Soil Conservation Service Small Watershed Projects. Planning documents from this agency are often helpful, and can be obtained from the SCS district office in the county.

(5) Planning documents of developers.

b. Field data. The following field hydrologic indicators can be assessed quickly, and although some of them are not necessarily indicative of hydrologic events that occur only during the growing season, they do provide evidence that inundation and/or soil saturation has occurred:

(1) Visual observation of inundation. The most obvious and revealing hydrologic indicator may be simply observing the areal extent of inundation. However, because seasonal conditions and recent weather conditions can contribute to surface water being present on a nonwetland site, both should be considered when applying this indicator.

(2) Visual observation of soil saturation. Examination of this indicator requires digging a soil pit (Appendix D, Section 1) to a depth of 16 inches and observing the level at which water stands in the hole after sufficient time has been allowed for water to drain into the hole. The required time will varv depending on soil texture. In some cases, the upper level at which water is flowing into the pit can be observed by examining the wall of the hole. This level represents the depth to the water table. The depth to saturated soils will always be nearer the surface due to the capillary fringe. For soil saturation to impact vegetation, it must occur within a major portion of the root zone (usually within 12 inches of the surface) of the prevalent vegetation. The major portion of the root zone is that portion of the soil profile in which more than one half of the plant roots occur. *CAUTION: In some heavy clay soils, water may not rapidly accumulate in the hole even when the soil is saturated. If water is observed at the bottom of the hole but has not fiLLed to the 12-inch depth, examine the sides of the hole and determine the shallowest depth at which water is entering the hole. When applying this indicator, both the season of the year and preceding weather conditions must be considered.*

(3) Watermarks. Watermarks are most common on woody vegetation. They occur as stains on bark (Figure 7) or other fixed objects (e.g. bridge pillars, buildings, fences, etc.). When several watermarks are present, the highest reflects the maximum extent of recent inundation.

(4) Drift lines. This indicator is most likely to be found adjacent to streams or other sources of water flow in wetlands, but also often occurs in tidal marshes. Evidence consists of deposition of debris in a line on the surface (Figure 8) or debris entangled in aboveground vegetation or other fixed objects. Debris usually consists of remnants of vegetation (branches, stems, and leaves), sediment, litter, and other waterborne materials deposited parallel to the direction of water flow. Drift lines provide an indication of the minimum portion of the area inundated during a flooding event; the maximum level of inundation is generally at a higher elevation than that indicated by a drift line.

(5) Sediment deposits. Plants and other vertical objects often have thin layers, coatings, or depositions of mineral or organic matter on them after inundation (Figure 9). This evidence may remain for a considerable period before it is removed by precipitation or subsequent inundation. Sediment deposition on vegetation and other objects provides an. indication of the minimum inundation level. When sediments are primarily organic (e.g. fine organic material, algae), the detritus may become encrusted on or slightly above the soil surface after dewatering occurs (Figure 10).

(6) Drainage patterns within wetlands. This indicator, which occurs primarily in wetlands adjacent to streams, consists of surface evidence of drainage flow into or through an area (Figure 11). In some wetlands, this evidence may exist as a drainage pattern eroded into the

soil, vegetative matter (debris) piled against thick vegetation or woody stems oriented perpendicular to the direction of water flow, or the absence of leaf litter (Figure 8). Scouring is often evident around roots of persistent vegetation. Debris may be deposited in or along the drainage pattern (Figure 12). *CAUTION: Drainage patterns also occur in upland areas after periods of considerable precipitation; therefore, topographic position must also be considered when applying this indicator.*

PART IV: METHODS

Section A. Introduction

50. PART IV contains sections on preliminary data gathering, method selection, routine determination procedures, comprehensive determination procedures, methods for determinations in atypical situations, and guidance for wetland determinations in natural situations where the three-parameter approach may not always apply.

51. Significant flexibility has been incorporated into PART IV. The user is presented in Section B with various potential sources of information that may be helpful in making a determination, but not all identified sources of information may be applicable to a given situation. *The user is not required to obtain information from all identified sources.* Flexibility is also provided in method selection (Section C). Three levels of routine determinations are available, depending on the complexity of the required determination and the quantity and quality of existing information. Application of methods presented in both Section D (routine determinations) and Section E (comprehensive determinations) may be tailored to meet site-specific requirements, especially with respect to sampling design.

52. Methods presented in Sections D and E vary with respect to the required level of technical knowledge and experience of the user. Application of the qualitative methods presented in Section D (routine determinations) requires considerably less technical knowledge and experience than does application of the quantitative methods presented in Section E (comprehensive determinations). The user must at least be able to identify the dominant ,plant species in the project area when making a routine determination (Section D), and should have some basic knowledge of hydric soils when employing routine methods that require soils examination. Comprehensive determinations require a basic understanding of sampling principles and the ability to identify all commonly occurring plant species in a project area, as well as a good understanding of indicators of hydric soils and wetland hydrology. The comprehensive method should only be employed by experienced field inspectors.

Section B. Preliminary Data Gathering and Synthesis

53. This section discusses potential sources of information that may be helpful in making a wetland determination. When the routine approach is used, it may often be possible to make a wetland determination based on available vegetation, soils, and hydrology data for the area. However, this section deals only with identifying potential information sources, extracting pertinent data, and synthesizing the data for use in making a determination. Based on the quantity and quality of available information and the approach selected for use (Section C), the user is referred to either Section D or Section E for the actual determination. Completion of Section B is not required, but is recommended because the available information may reduce or eliminate the need for field effort and decrease the time and cost of making a determination.

However, there are instances in small project areas in which the time required to obtain the information may be prohibitive. In such cases PROCEED to paragraph 55, complete STEPS 1 through 3, and PROCEED to Section D or E.

Data sources

54. Obtain the following information, when available and applicable:

a. USGS quadrangle maps. USGS quadrangle maps are available at different scales. When possible, obtain maps at a scale of 1:24,000; otherwise, use maps at a scale of 1:62,500. Such maps are available from USGS in Reston, Va., and Menlo Park, Calif., but they may already be available in the CE District Office. These maps provide several types of information:

(1) Assistance in locating field sites. Towns, minor roads, bridges, streams, and other landmark features (e.g. buildings, cemeteries, water bodies, etc.) not commonly found on road maps are shown on these maps.

(2) Topographic details, including contour lines (usually at 5- or 10-ft contour intervals).

(3) General delineation of wet areas (swamps and marshes). *The actual wet area may be greater than that shown on the map because USGS generally maps these areas based on the driest season of the year.*

(4) Latitude, longitude, townships, ranges, and sections. These provide legal descriptions of the area.

(5) Directions, including both true and magnetic north.

(6) Drainage patterns.

(7) General land uses, such as cleared (agriculture or pasture), forested, or urban.

CAUTION: Obtain the most recent USGS maps. Older maps may show features that no longer exist and will not show new features that have developed since the map was constructed. Also, USGS is currently changing the mapping scale from 1:24,000 to 1:25,000.

b. National Wetlands Inventory products.

(1) Wetland maps. The standard NWI maps are at a scale of 1:24,000 or, where USGS base maps at this scale are not available, they are at 1:62,500 (1:63,350 in Alaska). Smaller scale maps ranging from 1:100,000 to 1:500,000 are also available for certain areas. Wetlands on NWI maps are classified in accordance with Cowardin et al. (1979). *CAUTION: Since not all delineated areas on NWI maps are wetlands under Department of Army jurisdiction, NWI maps should not be used as the sole basis for determining whether wetland vegetation is*

present. NWI "User Notes" are available that correlate the classification system with local wetland community types. An important feature of this classification system is the water regime modifier, which describes the flooding or soil saturation characteristics. Wetlands classified as having a temporarily flooded or intermittently flooded water regime should be viewed with particular caution since this designation is indicative of plant communities that are transitional between wetland and nonwetland. These are among the most difficult plant communities to map accurately from aerial photography. For wetlands "wetter" than temporarily flooded and intermittently flooded, the probability of a designated map unit on recent NWI maps being a wetland (according to Cowardin et al. 1979) at the time of the photography is in excess of 90 percent. *CAUTION: Due to the scale of aerial photography used and other factors, all NWI map boundaries are approximate.* The optimum use of NWI maps is to plan field review (i.e. how wet, big, or diverse is the area?) and to assist during field review, particularly by showing the approximate areal extent of the wetland and its association with other communities. NWI maps are available either as a composite with, or an overlay for, USGS base maps and may be obtained from the NWI Central Office in St. Petersburg, Fla., the Wetland Coordinator at each FWS regional office, or the USGS.

(2) Plant database. This database of approximately 5,200 plant species that occur in wetlands provides information (e.g., ranges, habitat, etc.) about each plant species from the technical literature. The database served as a focal point for development of a national list of plants that occur in wetlands (Appendix C, Section 1).

c. Soil surveys. Soil surveys are prepared by the SCS for political units (county, parish, etc.) in a state. Soil surveys contain several types of information:

(1) General information (e.g. climate, settlement, natural resources, farming, geology, general vegetation types).

(2) Soil maps for general and detailed planning purposes. These maps are usually generated from fairly recent aerial photography. *CAUTION: The smallest mapping unit is 3 acres, and a given soil series as mapped may contain small inclusions of other series.*

(3) Uses and management of soils. Any wetness characteristics of soils will be mentioned here.

(4) Soil properties. Soil and water features are provided that may be very helpful for wetland investigations. Frequency, duration, and timing of inundation (when present) are described for each soil type. Water table characteristics that provide valuable information about soil saturation are also described. Soil permeability coefficients may also be available.

(5) Soil classification. Soil series and phases are usually provided. Published soil surveys will not always be available for the area. If not, contact the county SCS office and determine whether the soils have been mapped.

d. Stream and tidal gage data. These documents provide records of tidal and stream flow events. They are available from either the USGS or CE District office.

e. Environmental impact assessments (EIAs), environmental impact statements (EISs), general design memora da (GDM), and other similar publications. These documents may be available from Federal agencies for an area that includes the project area. They may contain some indication of the location and characteristics of wetlands consistent with the required criteria (vegetation, soils, and hydrology), and often contain flood frequency and duration data.

f. Documents and maps from State, county, or local governments. Regional maps that characterize certain areas (e.g., potholes, coastal areas, or basins) may be helpful because they indicate the type and character of wetlands.

g. Remote sensing. Remote sensing is one of the most useful information sources available for wetland identification and delineation. Recent aerial photography, particularly color infrared, provides a detailed view of an area; thus, recent land use and other features (e.g. general type and areal extent of plant communities and degree of inundation of the area when the photography was taken) can be determined. The multiagency cooperative National High Altitude Aerial Photography Program (HAP) has 1:59,000-scale color infrared photography for approximately 85 percent (December 1985) of the coterminous United States from 1980 to 1985. This photography has excellent resolution and can be ordered enlarged to 1:24,000 scale from USGS. Satellite images provide similar information as aerial photography, although the much smaller scale makes observation of detail more difficult without sophisticated equipment and extensive training. Satellite images provide more recent coverage than aerial photography (usually at 18-day intervals). Individual satellite images are more expensive than aerial photography, but are not as expensive as having an area flown and photographed at low altitudes. However, better resolution imagery is now available with remote sensing equipment mounted on fixed-wing aircraft.

h. Local individuals and experts. Individuals having personal knowledge of an area may sometimes provide a reliable and readily available source of information about the area, particularly information on the wetness of the area.

i. USGS land use and land cover maps. Maps created by USGS using remotely sensed data and a geographical information system provide a systematic and comprehensive collection and analysis of land use and land cover on a national basis. Maps at a scale of 1:250,000 are available as overlays that show land use and land cover according to nine basic levels. One level is wetlands (as determined by the FWS), which is further subdivided into forested and nonforested areas. Five other sets of maps show political units, hydrologic units, census subdivisions of counties, Federal land ownership, and State land ownership. These maps can be obtained from any USGS mapping center.

j. Applicant's survey plans and engineering designs. In many cases, the permit applicant will already have had the area surveyed (often at 1-ft contours or less) and will also have engineering designs for the proposed activity.

Data synthesis

55. When employing Section B procedures, use the above sources of information to complete the following steps:

• STEP 1 - Identify the Project Area on a Map. Obtain a USGS quadrangle map (1:24,000) or other appropriate map, and locate the area identified in the permit application. PROCEED TO STEP 2.

• STEP 2 - Prepare a Base Map. Mark the project area boundaries on the map. Either use the selected map as the base map or trace the area on a mylar overlay, including prominent landscape features (e.g., roads, buildings, drainage patterns, etc.). If possible, obtain diazo copies of the resulting base map. PROCEED TO STEP 3.

• STEP 3 - Determine Size of the Project Area. Measure the area boundaries and calculate the size of the area. PROCEED TO STEP 4 OR TO SECTION D OR E IF SECTION B IS NOT USED.

• STEP 4 - Summarize Available Information on Vegetation. Examine available sources that contain information about the area vegetation. Consider the following:

a. USGS quadrangle maps. Is the area shown as a marsh or swamp? *CAUTION: Do not use this as the sole basis for determining that hydrophytic vegetation is present.*

b. NWI overlays or maps. Do the overlays or maps indicate that hydrophytic vegetation occurs in the area? If so, identify the vegetation type(s).

c. EIAs, ElSs, or GDMs that include the project area. Extract any vegetation data that pertain to the area.

d. Federal, State, or local government documents that contain information about the area vegetation. Extract appropriate data.

e. Recent (within last 5 years) aerial photography of the area. Can the area plant community type(s) be determined from the photography? Extract appropriate data.

f. Individuals or experts having knowledge of the area vegetation. Contact them and obtain any appropriate information. *CAUTION: Ensure that the individual providing the information has firsthand knowledge of the area.*

g. Any published scientific studies of the area plant communities. Extract any appropriate data.

h. Previous wetland determinations made for the area. Extract any pertinent vegetation data.

When the above have been considered, PROCEED TO STEP 5.

• STEP 5 - Determine Whether the Vegetation in the Project Area Is Adequately Characterized. Examine the summarized data (STEP 4) and determine whether the area plant communities are adequately characterized. For routine determinations, the plant community type(s) and the dominant species in each vegetation layer of each community type must be known. Dominant species are those that have the largest relative basal area (overstory) *(This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present),* height (woody understory), number of stems (woody vines), or greatest areal cover (herbaceous understory). For comprehensive determinations, each plant community type present in the project area area must have been quantitatively described within the past 5 years using accepted sampling and analytical procedures, and boundaries between community types must be known. Record information on DATA FORM 1. *A separate DATA FORM 1 must be used for each plant community type.* In either case, PROCEED TO Section F if there is evidence of recent significant vegetation alteration due to human activities or natural events. Otherwise, PROCEED TO STEP 6.

• STEP 6. - Summarize Available Information on Area Soils. Examine available information and describe the area soils. Consider the following:

a. County soil surveys. Determine the soil series present and extract characteristics for each. *CAUTION: Soil mapping units sometimes include more than one soil series.*

b. Unpublished county soil maps. Contact the local SCS office and determine whether soil maps are available for the area. Determine the soil series of the area, and obtain any available information about possible hydric soil indicators (paragraph 44 or 45) for each soil series.

c. Published EIAs, EISs, or GDMs that include soils information. Extract any pertinent information.

d. Federal, State, and/or local government documents that contain descriptions of the area soils. Summarize these data.

e. Published scientific studies that include area soils data. Summarize these data.

f. Previous wetland determinations for the area. Extract any pertinent soils data.

When the above have been considered, PROCEED TO STEP 7.

• STEP 7 - Determine Whether Soils of the Project Area Have Been Adequately Characterized. Examine the summarized soils data and determine whether the soils have been adequately characterized. For routine determinations, the soil series must be known. For comprehensive determinations, both the soil series and the boundary of each soil series must be known. Record information on DATA FORM 1. In either case, if there is evidence of recent significant soils alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO STEP 8.

• STEP 8 - Summarize Available Hydrology Data. Examine available information and describe the area hydrology. Consider the following:

a. USGS quadrangle maps. Is there a significant, well-defined drainage through the area? Is the area within a maior floodplain or tidal area? What range of elevations occur in the area, especially in relation to the elevation of the nearest perennial watercourse?

b. NWI overlays or maps. Is the area shown as a wetland or deepwater aquatic habitat? What is the water regime modifier?

c. EIAs, EISs, or GDMs that describe the project area. Extract any pertinent hydrologic data.

d. Floodplain management maps. These maps may be used to extrapolate elevations that can be expected to be inundated on a 1-, 2-, 3-year, etc., basis. Compare the elevations of these features with the elevation range of the project area to determine the frequency of inundation.

e. Federal, State, and local government documents (e.g. CE floodplain management maps and profiles) that contain hydrologic data. Summarize these data.

f. Recent (within past 5 years) aerial photography that shows the area to be inundated. Record the date of the photographic mission.

1. Newspaper accounts of flooding events that indicate periodic inundation of the area.

h. SCS County Soil Surveys that indicate the frequency and duration of inundation and soil saturation for area soils. *CAUTION: Data provided only represent average conditions for a particular soil series in its natural undrained state, and cannot be used as a positive hydrologic indicator in areas that have significantly altered hydrology.*

i. Tidal or stream gage data for a nearby water body that apparently influences the area. Obtain the gage data and complete (1) below if the routine approach is used, or (2) below if the comprehensive approach is used (OMIT IF GAGING STATION DATA ARE UNAVAILABLE):

(1) Routine approach. Determine the highest water level elevation reached during the growing season for each of the most recent 10 years of gage data. Rank these elevations in descending order and select the fifth highest elevation. Combine this elevation with the mean sea level elevation of the gaging station to produce a mean sea level elevation for the highest water level reached every other year. *Stream gage data are often presented as flow rates in cubic feet per second. In these cases, ask the CE District's Hydrology Branch to convert flow rates to corresponding mean sea level elevations and adjust gage data to the site.* Compare the resulting elevations reached biennially with the project area elevations. If the water level elevation exceeds the area elevation, the area is inundated during the growing season on average at least biennially.

(2) Comprehensive approach. Complete the following:

(a) Decide whether hydrologic data reflect the apparent hydrology. Data available from the gaging station may or may not accurately reflect the area hydrology. Answer the following questions:

• Does the water level of the area appear to fluctuate in a manner that differs from that of the water body on which the gaging station is located? (In ponded situations, the water level of the area is usually higher than the water level at the gaging station.)

• Are less than 10 years of daily readings available for the gaging station?

• Do other water sources that would not be reflected by readings at the gaging station appear to significantly affect the area? For example, do major tributaries enter the stream or tidal area between the area and gaging station?

If the answer to any of the above questions is YES, the area hydrology cannot be determined from the gaging station data. If the answer to all of the above questions is NO, PROCEED TO (b).

(b) Analyze hydrologic data. Subject the hydrologic data to appropriate analytical procedures. Either use duration curves or a computer program developed by WES (available from the Environmental Laboratory upon request) for determining the mean sea level elevation representing the upper limits of wetland hydrology. In the latter case, when the site elevation is lower than the mean sea level elevation representing a 5-percent duration of inundation and saturation during the growing season, the area has a hydrologic regime that may occur in wetlands. *NOTE: Duration curves do not reflect the period of soil saturation following dewatering.*

When all of the above have been considered, PROCEED TO STEP 9.

• STEP 9 - Determine Whether Hydrology Is Adequately Characterized. Examine the summarized data and determine whether the hydrology of the project area is adequately characterized. For routine determinations, there must be documented evidence of frequent inundation or soil saturation during the growing season. For comprehensive determinations, there must be documented quantitative evidence of frequent inundation or soil saturation during the growing season, based on at least 10 years of stream or tidal gage data. Record information on DATA FORM 1. In either case, if there is evidence of recent significant hydrologic alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO Section C.

Section C. Selection of Method

56. All wetland delineation methods described in this manual can be grouped into two general types: routine and comprehensive. Routine determinations (Section D) involve simple, rapidly applied methods that result in sufficient qualitative data for making a determination. Comprehensive methods (Section E) usually require significant time and effort to obtain the needed quantitative data. The primary factor influencing method selection will usually be the complexity of the required determination. However, comprehensive methods may sometimes be selected for use in relatively simple determinations when rigorous documentation is required.

57. Three levels of routine wetland determinations are described below. Complexity of the project area and the quality and quantity of available information will influence the level selected for use.

a. Level 1 - Onsite Inspection Unnecessary. This level may be employed when the information already obtained (Section B) is sufficient for making a determination for the entire project area (see Section D., Subsection 1).

b. Level 2 - Onsite Inspection Necessary. This level must be employed when there is insufficient information already available to characterize the vegetation, soils, and hydrologyof the entire project area (see Section D, Subsection 2).

c. Level 3 - Combination of Levels 1 and 2. This level should be used when there is sufficient information already available to characterize the vegetation, soils, and hydrology of a portion, but not all, of the project area. Methods described for Level 1 may be applied to portions of the area for which adequate information already exists, and onsite methods (Level 2) must be applied to the remainder of the area (see Section D, Subsection 3).

58. After considering all available information, select a tentative method (see above) for use, and PROCEED TO EITHER Section D or E, as appropriate. *NOTE: Sometimes it may be necessary to change to another method described in the manuaz, depending on the quality of available information and/or recent changes in the prospect area.*

Section D. Routine Determinations

59. This section describes general procedures for making routine wetland determinations. It is assumed that the user has already completed all applicable steps in Section B, *(If it has been determined that it is more expedient to conduct an onsite inspection than to search for available information, complete STEPS 1 through 3 of Section B, and PROCEED TO Subsection 2.)* and a routine method has been tentatively selected for use (Section C). Subsections 1-3 describe steps to be followed when making a routine determination using one of the three levels described in Section C. Each subsection contains a flowchart that defines the

relationship of steps to be used for that level of routine determinations. *The selected method must be considered tentative because the user may be required to change methods during the determination.*

Subsection 1 - Onsite Inspection Unnecessary

60. This subsection describes procedures for making wetland determinations when sufficient information is already available (Section B) on which to base the determination. A flowchart of required steps to be completed is presented in Figure 13, and each step is described below.

Equipment and materials

61. No special equipment is needed for applying this method. The following materials will be needed:
a. Map of project area (Section B, STEP 2).

b. Copies of DATA FORM 1 (Appendix B).

c. Appendices C and D to this manual.

Procedure

62. Complete the following steps, as necessary:

• STEP 1 - Determine Whether Available Data Are Sufficient for Entire Project Area. Examine the summarized data (Section B, STEPS 5, 7, and 9) and determine whether the vegetation, soils, and hydrology of the entire project area are adequately characterized. If so, PROCEED TO STEP 2. If all three parameters are adequately characterized for a portion, but not all, of the project area, PROCEED TO Subsection 3. If the vegetation, soils, and hydrology are not adequately characterized for any portion of the area, PROCEED TO Subsection 2. & STEP 2 - Determine Whether Hydrophytic Vegetation Is Present. Examine the vegetation data and list on DATA FORM 1 the dominant plant species found in each vegetation layer of each community type. *NOTE: A separate DATA FORM 1 will be required for each* community type. Record the indicator status for each dominant species (Appendix C, Section 1 or 2). When more than 50 percent of the dominant species in a plant community have an indicator status of OBL, FACW, and/or FAC, hydrophytic vegetation is present *(For the FAC-neutral option, see paragraph 35a)*. If one or more plant communities comprise of hydrophytic vegetation, PROCEED TO STEP 3. If none of the plant communities comprise hydrophytic vegetation, none of the area is a wetlands Complete the vegetation section for each DATA FORM 1.

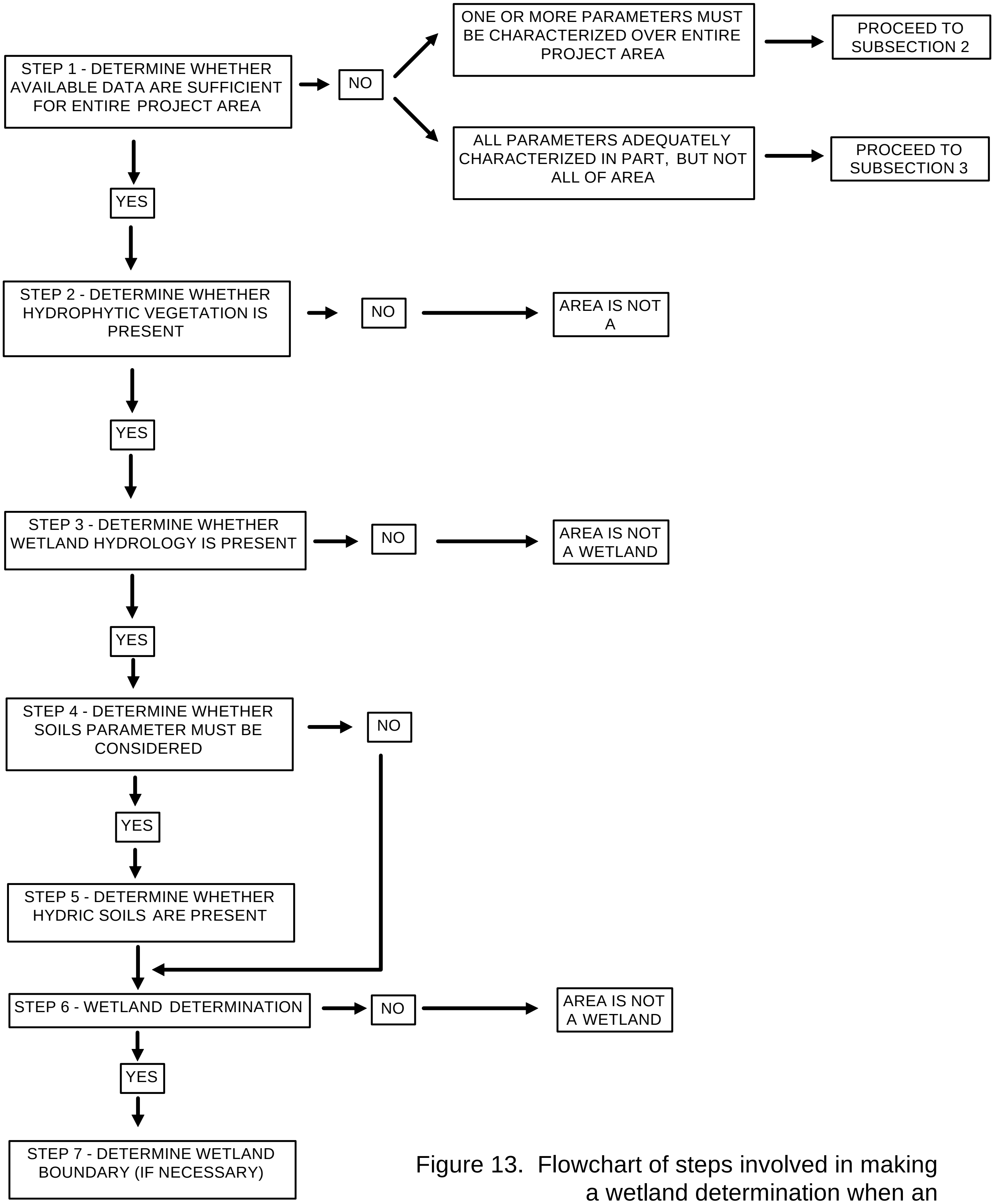

Figure 13. Flowchart of steps involved in making a wetland determination when an onsite inspection is unnecessary

• STEP 3 - Determine Whether Wetland Hydrology Is Present. When one of the following conditions applies (STEP 2), it is only necessary to confirm that there has been no recent hydrologic alteration of the area:

a. The entire project area is occupied by a plant community or communities in which all dominant species are OBL (Appendix C, Section 1 or 2).
b. The project area contains two or more plant communities, all of which are dominated by OBL and/or FACW species, and the wetland-nonwetland boundary is abrupt (e.g. a *Spartina* alternifzora marsh bordered by a road embankment). * *There must be documented evidence of periodic inundation or saturated soils when the project area:*
a. Has plant communities dominated by one or more FAC species;
b. Has vegetation dominated by FACW species but no adjacent community dominated by OBL species;
c. Has a gradual, nondistinct boundary between wetlands and nonwetlands; and/or
d. Is known to have or is suspected of having significantly altered hydrology.

If either a or b applies, look for recorded evidence of recently constructed dikes, levees, impoundments, and drainage systems, or recent avalanches, mudslides, beaver dams, etc., that have significantly altered the area hydrology. If any significant hydrologic alteration is found, determine whether the area is still periodically inundated or has saturated soils for sufficient duration to support the documented vegetation (a or b above). When a or b applies and there is no evidence of recent hydrologic alteration, or when a or b do not applv and there is documented evidence that the area is periodically inundated or has saturated soils, wetland hydrology is present. Otherwise, wetland hydrology does not occur on the area. Complete the hydrology section of DATA FORM 1 and PROCEED TO STEP 4.

• STEP 4 - Determine Whether the Soils Parameter Must Be Considered. When either a or b of STEP 3 applies and there is either no evidence of recent hydrologic alteration of the project area or if wetland hydrology presently occurs on the area, hydric soils can be assumed to be present. If so, PROCEED TO STEP 6. Otherwise PROCEED TO STEP 5. o STEP 5 - Determine Whether Hydric Soils Are Present. Examine the soils data (Section B, STEP 7) and record the soil series or soil phase on DATA FORM 1 for each community type. Determine whether the soil is listed as a hydric soil (Appendix D, Section 2). If all community types have hydric soils, the entire project area has hydric soils. *(CAUTION: If the soil series description makes reference to inclusions of other soil types, data must be field verified).* Any portion of the area that lacks hydric soils is a nonwetland. Complete the soils section of each DATA FORM 1 and PROCEED TO STEP 6.

• STEP 6 - Wetland Determination. Examine the DATA FORM 1 for each community type. Any portion of the project area is a wetland that has:
a. Hydrophytic vegetation that conforms to one of the conditions identified in STEP 3a or 3b and has either no evidence of altered hydrology or confirmed wetland hydrology.

b. Hydrophytic vegetation that does not conform to STEP 3a or 3b, has hydric soils, and has confirmed wetland hydrology.

If STEP 6a or 6b applies to the entire project area, the entire area is a wetlands Complete a DATA FORM 1 for all plant community types. Portions of the area not qualifying as a wetland based on an office determination might or might not be wetlands. If the data used for the determination are considered to be highly reliable, portions of the area not qualifying as wetlands may properly be considered nonwetlands. PROCEED TO STEP 7. If the available data are incomplete or questionable, an onsite inspection (Subsection 2) will be required.

• STEP 7 - Determine Wetland Boundary. Mark on the base map all community types determined to be wetlands with a W and those determined to be nonwetlands with an N. Combine all wetland community types into a single mapping unit. The boundary of these community types is the interface between wetlands and nonwetlands.

Subsection 2 - Onsite Inspection Necessary

63. This subsection describes procedures for routine determinations in which the available information (Section B) is insufficient for one or more parameters. If only one or two parameters must be characterized, apply the appropriate steps and return to Subsection 1 and complete the determination. A flowchart of steps required for using this method is presented in Figure 14, and each step is described below.

Equipment and materials

64. The following equipment and materials will be needed:

a. Base map (Section B, STEP 2).
b. Copies of DATA FORM 1 (one for each community type and additional copies for boundary determinations).
c. Appendices C and D.
d. Compass.
e. Soil auger or spade (soils only).
f. Tape (300 ft).
g. Munsell Color Charts (Munsell Color 1975) (soils only).

Procedure

65. Complete the following steps, as necessary:

• STEP 1 - Locate the Project Area. Determine the spatial boundaries of the project area using information from a USGS quadrangle map or other appropriate map, aerial photography, and/or the project survey plan (when available). PROCEED TO STEP 2.

• STEP 2 - Determine Whether an Atypical Situation Exists. Examine the area and determine whether there is evidence of sufficient natural or human-induced alteration to significantly alter the area vegetation, soils, and/or hydrology. *NOTE: Include possible offsite modifications that may affect the area hydrology*. If not, PROCEED TO STEP 3.
If one or more parameters have been significantly altered by an activity that would normally require a permit, PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present prior to this alteration. Then, return to this subsection and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3.

• STEP 3 - Determine the Field Characterization Approach to be Used. Considering the size and complexity of the area, determine the field characterization approach to be used. When the area is equal to or less than 5 acres in size (Section B,-STEP 3) and the area is thought to be relatively homogeneous with respect to vegetation, soils, and/or hydrologic regime, PROCEED TO STEP 4. When the area is greater than 5 acres in size (Section B, STEP 3) or appears to be highly diverse with respect to vegetation, PROCEED TO STEP 18.

Areas Equal to or Less Than 5 Acres in Size

• STEP 4 - Identify the Plant Community Type(s). Traverse the area and determine the number and locations of plant community types. Sketch the location of each on the base map (Section B, STEP 2), and give each community type a name. PROCEED TO STEP 5.

• STEP 5 - Determine UThether Normal Environmental Conditions Are Present. Determine whether normal environmental conditions are present by considering the following:

a. Is the area presently lacking hydrophytic vegetation or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?

b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 6.

• STEP 6 - Select Representative Observation Points. Select a representative observation point in each community type. A representative observation point is one in which the apparent characteristics (determine visually) best represent characteristics of the entire community. Mark on the base map the approximate location of the observation point. PROCEED TO STEP 7.
• STEP 7 - Characterize Each Plant Community Type. Visually determine the dominant plant species in each vegetation layer of each community type and record them on DATA FORM 1 (use a separate DATA FORM 1 for each community type). Dominant species are those having the greatest relative basal area (woody overstory) *(This term is used because species having the largest individuals may not be dominant when only a few are present. To determine*

relative basal area, consider both the size and number of individuals of a species and subjectly compare with other species present.) ,greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). PROCEED TO STEP 8.

• STEP 8 - Record Indicator Status of Dominant Species. Record on DATA FORM 1 the indicator status (Appendix C, Section 1 or 2) of each dominant species in each community type. PROCEED TO STEP 9.

• STEP 9 - Determine Whether Hydrophytic Vegetation Is Present. Examine each DATA FORM 1. When more than 50 percent of the dominant species in a community type have an indicator status (STEP 8) of OBL, FACW, and/or FAC *(for the FAC-neutral option, see paragraph 35a.)*, hydrophytic vegetation is present. Complete the vegetation section of each DATA FORM 1. Portions of the area failing this test are not wetlands. PROCEED TO STEP 10.

• STEP 10 - Apply Wetland Hydrologic Indicators. Examine the portion of the area occupied by each plant community type for positive indicators of wetland hydrology (PART III, paragraph 49). Record findings on the appropriate DATA FORM 1. PROCEED TO STEP 11.

• STEP 11 - Determine Whether Wetland Hydrology Is Present. Examine the hydrologic information on DATA FORM 1 for each plant community type. Any portion of the area having a positive wetland hydrology indicator has wetland hydrology. If positive wetland hydrology indicators are present in all community types, the entire area has wetland hydrology. If no plant community type has a wetland hydrology indicator, none of the area has wetland hydrology. Complete the hydrology portion of each DATA FORM 1. PROCEED TO STEP 12.

This term is used because species having the largest individuals may not be dominant when only a few are present. To determine relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present. For the FAC-neutral option, see paragraph 35a.

• STEP 12 - Determine Whether Soils Must Be Characterized. Examine the vegetation section of each DATA FORM 1. Hydric soils are assumed to be present in any plant community type in which:
a. All dominant species have an indicator status of OBL.
b. All dominant species have an indicator status of OBL or FACW, and the wetland boundary (when present) is abrupt. *The soils parameter must be considered in any plant community in which:*
a. The community is dominated by one or more FAC species.
b. No community type dominated by OBL species is present.
c. The boundary between wetlands and nonwetlands is gradual or nondistinct.
d. The area is known to or is suspected of having significantly altered hydrology.

When either a or b occurs and wetland hydrology is present, check the hydric soils blank as positive on DATA FORM 1 and PROCEED TO STEP 16. If neither a nor b applies, PROCEED TO STEP 13.

• STEP 13 - Dig a Soil Pit. Using a soil auger or spade, dig a soil pit at the representative location in each community type. The procedure for digging a soil pit is described in Appendix D, Section 1. When completed, approximately 16 inches of the soil profile will be available for examination. PROCEED TO STEP 14.

• STEP 14 - Apply Hydric Soil Indicators. Examine the soil at each location and compare its characteristics immediately below the A-horizon or 10 inches (whichever is shallower) with the hydric soil indicators described in PART III, paragraphs 44 and/or 45. Record findings on the appropriate DATA FORM l's. PROCEED TO STEP 15.

• STEP 15 - Determine Whether Hydric Soils Are Present. Examine each DATA FORM 1 and determine whether a positive hydric soil indicator was found. If so, the area at that location has hydric soil. If soils at all sampling locations have positive hydric soil indicators, the entire area has hydric soils. If soils at all sampling locations lack positive hydric soil indicators, none of the area is a wetlands Complete the soil section of each DATA FORM 1. PROCEED TO STEP 16.

• STEP 16 - Make Wetland Determination. Examine DATA FORM 1. If the entire area presently or normally has wetland indicators of all three parameters (STEPS 9, 11, and 15), the entire area is a wetlands If the entire area presently or normallv lacks wetland indicators of one or more parameters, the entire area is a nonwetland. If only a portion of the area presently or normally has wetland indicators for all three parameters, PROCEED TO STEP 17.

• STEP 17 - Determine Wetland-Nonwetland Boundary. Mark each plant community type on the base map with a W if wetland or an N if nonwetland. Combine all wetland plant communities into one mapping unit and all nonwetland plant communities into another mapping unit. The wetland-nonwetland boundary will be represented by the interface of these two mapping units.

Areas Greater Than 5 Acres in Size

• STEP 18 - Establish a Baseline. Select one project boundary as a baseline. The baseline should parallel the major watercourse through the area or should be perpendicular to the hydrologic gradient (Figure 15). Determine the approximate baseline length. PROCEED TO STEP 19.

• STEP 19 - Determine the Required Number and Position of Transects. Use the following to determine the required number and position of transacts (specific site conditions may necessitate changes in intervals):

Baseline length, miles	Number of Required Transects
≤0.25	3
>0.25-0.50	3
>0.50-0.75	3
>0.75-1.00	3
>1.00-2.00	3-5
>2.00-4.00	5-8
>4.00	8 or more*

*Transect intervals should not exceed 0.5 mile.

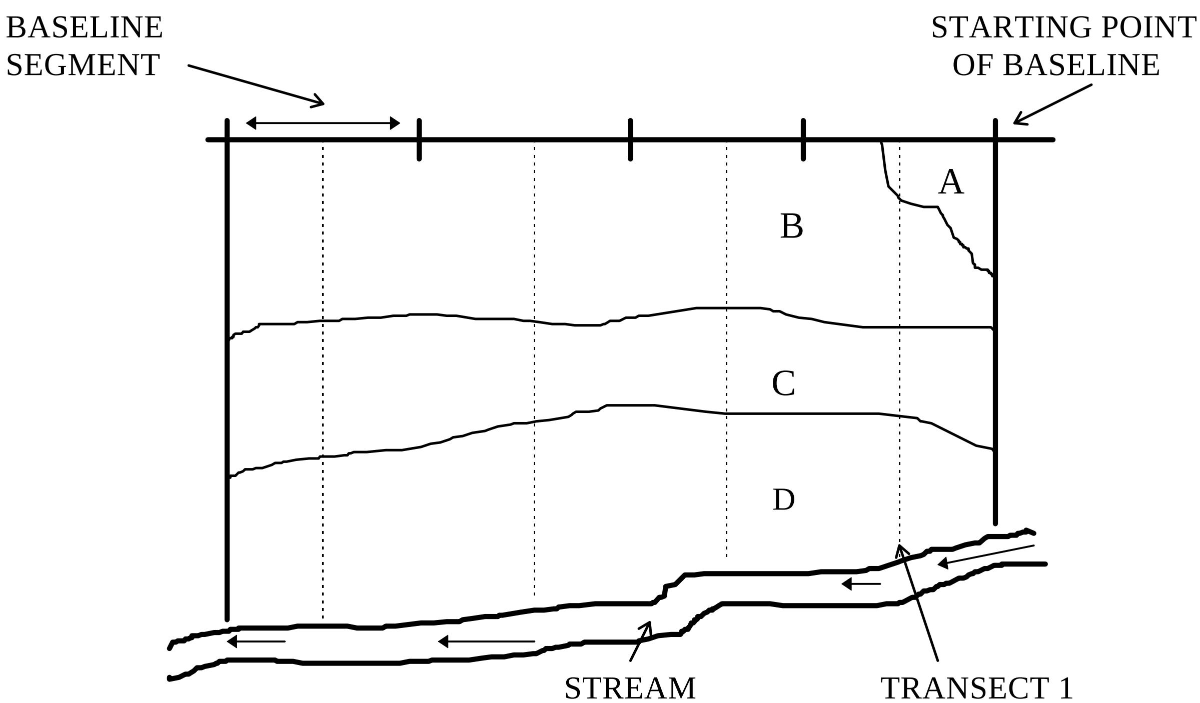

Figure 15. General Orientation of baseline and transects (dotted lines) in a hypothetical project area. Alpha characters represent different plant communities. All transects start at the midpoint of a basline segment except the first, which may be repositioned to include community type A.

Divide the baseline length by the number of required transacts. Establish one transect in each resulting baseline increment. Use the midpoint of each baseline increment as a transect starting point. For example, if the baseline is 1,200 ft in length, three transacts would be established--one at 200 ft, one at 600 ft, and one at 1,000 ft from the baseline starting point. *CAUTION: All plant community types must be included. This may necessitate relocation of one or more transect* lines. PROCEED TO STEP 20.

• STEP 20 - Sample Observation Points Along the First Transect. Beginning at the starting point of the first transect, extend the transect at a 90-deg angle to the baseline. Use the following procedure as appropriate to simultaneously characterize the parameters at each observation point. Combine field-collected data with information already available and make a wetland determination at each observation point. A DATA FORM 1 must be completed for each observation point.

a. Determine whether normal environmental conditions are present. Determine whether normal environmental conditions are present by considering the following:

(1) Is the area presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?
(2) Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 20b.

b. Establish an observation point in the first plant community type encountered. Select a representative location along the transect in the first plant community type encountered. When the first plant community type is large and covers a significant distance along the transect, select an area that is no closer than 300 ft to a perceptible change in plant community type. PROCEED TO STEP 20c.

c. Characterize parameters. Characterize the parameters at the observation point by completing (1), (2), and (3) below:

(1) Vegetation. Record on DATA FORM 1 the dominant plant species in each vegetation layer occurring in the immediate vicinity of the observation point. Use a 5-ft radius for herbs and saplings/shrubs, and a 30-ft radius for trees and woody vines (when present). Subjectively determine the dominant species by estimating those having the largest relative basal area (woody overstory) *This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.*, greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). *NOTE: Plot size may be estimated, and plot size may also be varied when site conditions warrant*. Record on DATA FORM 1 any dominant species observed to have morphological adaptations (Appendix C, Section 3) for occurrence in wetlands, and determine and record dominant species that have known physiological adaptations for occurrence in wetlands (Appendix C, Section 3). Record on DATA FORM 1 the indicator status (Appendix C, Section 1 or 2) of each dominant species.

Hydrophytic vegetation is present at the observation point when more than 50 percent of the dominant species have an indicator status of OBL, FACW, and/or FAC *(For the FAC-neutral option, see paragraph 35a)*; when two or more dominant species have observed morphological or known physiological adaptations for occurrence in wetlands; or when other indicators of hydrophytic vegetation (PART III, paragraph 35) are present. Complete the vegetation section of DATA FORM 1. PROCEED TO (2).

(2) Soils. In some cases, it is not necessary to characterize the soils. Examine the vegetation of DATA FORM 1. Hydric soils can be assumed to be present when:

(a) All dominant plant species have an indicator status of OBL.
(b) All dominant plant species have an indicator status of OBL and/or FACW (at least one dominant species must be OBL). *Soils must be characterized when any dominant species has an indicator status of FAC.*

When either (a) or (b) applies, check the hydric soils blank as positive and PROCEED TO (3). If neither (a) nor (b) applies but the vegetation qualifies as hydrophytic, dig a soil pit at the observation point using the procedure described in Appendix D, Section 1. Examine the soil immediately below the A-horizon or 10-inches (whichever is shallower) and compare its characteristics (Appendix D, Section 1) with the hydric soil indicators described in PART III, paragraphs 44 and/or 45. Record findings on DATA FORM 1. If a positive hydric soil indicator is present, the soil at the observation point is a hydric soil. If no positive hydric soil indicator is found, the area at the observation point does not have hvdric soils and the area at the observation point is not a wetland. Complete the soils section of DATA FORM 1 for the observation point. PROCEED TO (3) if hydrophytic vegetation (1) and hydric soils (2) are present. Otherwise, PROCEED TO STEP 20d.

(3) Hydrology. Examine the observation point for indicators of wetland hydrology (PART III, paragraph 49), and record observations on DATA FORM 1. Consider the indicators in the same sequence as presented in PART III, paragraph 49. If a positive wetland hydrology indicator is present, the area at the observation point has wetland hydrology. If no positive wetland hydrologic indicator is present, the area at the observation point is not a wetland. Complete the hydrology section of DATA FORM 1 for the observation point. PROCEED TO STEP 20d.

d. Wetland determination. Examine DATA FORM 1 for the observation point. Determine whether wetland indicators of all three parameters are or would normally be present during a slgnificant portion of the growing season. If so, the area at the observation point is a wetland. If no evidence can be found that the area at the observation point normally has wetland indicators for all three parameters, the area is a nonwetland. PROCEED TO STEP 20e.

e. Sample other observation points along the first transect. Continue along the first transect until a different community type is encountered. Establish a representative observation point within this community type and repeat STEP 20c - 20d. If the areas at both observation points are either wetfands -or nonwetlands, continue along the transect and repeat STEP 20c - 20d for the next community type encountered. Repeat for all other community types along the first transect. If the area at one observation point is wetlands and the next observation point is nonwetlands (or vice versa), PROCEED TO STEP 20f.

f. Determine wetland-nonwetland boundary. Proceed along the transect from the wetland observation point toward the nonwetland observation point. Look for subtle changes in the plant community (e.g. the first appearance of upland species, disappearance of apparent hydrology indicators, or slight changes in topography). When such features are noted, establish an observation point and repeat the procedures described in STEP 20c - 20d. *NOTE: A new DATA FORM 1 must be completed for this observation point, and all three parameters must be characterized by field observation.* If the area at this observation point is a wetlands proceed along the transect toward the nonwetland observation point until upland indicators are more apparent. Repeat the procedures described in STEP 20c - 20d. If the area at this observation point is a nonwetland, move lialfway back along the transect toward the last documented wetland observation point and repeat the procedure described in STEP 20c - 20d. Continue this procedure until the wetland-nonwetland boundary is found. It is not necessary to complete a DATA FORM 1 for all intermediate points, but a DATA FORM 1 should be completed for the wetland-nonwetland boundary. Mark the position of the wetland boundary on the base map, and continue along the first transect until all community types have been sampled and all wetland boundaries located. *CAUTION: In areas where wetlands are interspersed among nonwetlands (or vice versa), several boundary determinations will be required.* When all necessary wetland determinations have been completed for the first transect, PROCEED TO STEP 21.

• STEP 21 - Sample Other Transects. Repeat procedures described in STEP 21 for all other transacts. When completed, a wetland determination will have been made for one observation point in each community type along each transect, and all wetland-nonwetland boundaries along each transect will have been determined. PROCEED TO STEP 22.

• STEP 22 - Synthesize Data. Examine all completed copies of DATA FORM 1, and mark each plant community type on the base map. Identify each plant community type as either a wetland (W) or nonwetland (N). If all plant community types are identified as wetlands, the entire area is wetlands. If all plant community types are identified as nonwetlands, the entire area is nonwetlands. If both wetlands and nonwetlands are present, identify observation points that represent wetland boundaries on the base map. Connect these points on the map by generally following contour lines to separate wetlands from nonwetlands. Walk the contour line between transects to confirm the wetland boundary. Should anomalies be encountered, it will be necessary to establish short transects in these areas, apply the procedures described in STEP 20f, and make any necessary adjustments on the base map.

Subsection 3 - Combination of Levels 1 and 2

66. In some cases, especially for large projects, adequate information may already be available (Section B) to enable a wetland determination for a portion of the project area, while an onsite visit will be required for the remainder of the area. Since procedures for each situation have already been described in Subsections 1 and 2, they will not be repeated. Apply the following steps:

• STEP 1 - Make Wetland Determination for Portions of the Project Area That Are Already Adequately Characterized. Apply procedures described in Subsection 1. When completed, a DATA FORM 1 will have been completed for each community type, and a map will have been prepared identifying each community type as wetland or nonwetland and showing any wetland boundary occurring in this portion of the project area. PROCEED TO STEP 2.

• STEP 2 - Make Wetland Determination for Portions of the Project Area That Require an Onsite Visit. Apply procedures described in Subsection 2. When completed, a DATA FORM 1 will have been completed for each plant community type or for a number of observation points (including wetland boundary determinations). A map of the wetland (if present) will also be available. PROCEED TO STEP 3.

• STEP 3 - Synthesize Data. Using the maps resulting from STEPS 1 and 2, prepare a summary map that shows the wetlands of the entire project area. *CAUTION: Wetland boundaries for the two maps will not always match exactly. When this occurs, an additional site visit will be required to refine the wetland boundaries. Since the degree of resolution of wetland boundaries will be greater when determined onsite, it may be necessary to employ procedures described in Subsection 2 in the vicinity of the boundaries determined from Subsection 1 to refine these boundaries.*

Section E. Comprehensive Determinations

67. This section describes procedures for making comprehensive wetland determinations. Unlike procedures for making routine determinations (Section D), application of procedures described in this section will result in maximum information for use in making determinations, and the information usually will be quantitatively expressed. Comprehensive determinations should only be used when the project area is very complex and/or when the determination requires rigorous documentation. This type of determination may be required in areas of any size, but will be especially useful in large areas. There may be instances in which only one parameter (vegetation, soil, or hydrology) is disputed. In such cases, only procedures described in this section that pertain to the disputed parameter need be completed. It is assumed that the user has already completed all applicable steps in Section B. *NOTE: Depending on site characteristics, it may be necessary to alter the sampling design and/or data collection procedures.*

68. This section is divided into five basic types of activities. The first consists of preliminary field activities that must be completed prior to making a determination (STEPS 1-5). The second outlines procedures for determining the number and locations of required determinations (STEPS 6-8). The third describes the basic procedure for making a comprehensive wetland determination at any given point (STEPS 9-17). The fourth describes a procedure for determining wetland boundaries (STEP 18). The fifth describes a procedure for synthesizing the collected data to determine the extent of wetlands in the area (STEPS 20-21). A flowchart showing the relationship of various steps required for making a comprehensive determination is presented in Figure 16.

Equipment and material

69. Equipment and materials needed for making a comprehensive determination include:
a. Base map (Section B, STEP 2).
b. Copies of DATA FORMS 1 and 2.
c. Appendices C and D.
d. Compass.
e. Tape (300 ft).
f. Soil auger or spade.
g. Munsell Color Charts (Munsell Color 1975).
h. Quadrat (3.28 ft by 3.28 ft).
i. Diameter or basal area tape (for woody overstory).

Field procedures

70. Complete the following steps:
• STEP I - Identify the Project Area. Using information from the USGS quadrangle or other appropriate map (Section B), locate and measure the spatial boundaries of the project area. Determine the compass heading of each boundary and record on the base map (Section B,

STEP 2). The applicant's survey plan may be helpful in locating the project boundaries. PROCEED TO STEP 2.

• STEP 2 - Determine Whether an Atypical Situation Exists. Examine the area and determine whether there is sufficient natural or human-induced alteration to significantly change the area vegetation, soils, and/or hydrology. If not, PROCEED TO STEP 3. If one or more parameters have been recently altered significantly.- PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present on the area prior to alteration. Then return to this section and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3. o STEP 3 - Determine Homogeneity of Vegetation. While completing STEP 2, determine the number of plant community types present. Mark the approximate location of each community type on the base map. The number and locations of required wetland determinations will be strongly influenced by both the size of the area and the number and distribution of plant community types; the larger the area and greater the number of plant community types, the greater the number of required wetland determinations. It is imperative that all plant community types occurring in all portions of the area be included in the investigation. PROCEED TO STEP 4.

• STEP 4 - Determine the Type and Number of Layers in Each Plant Community. Examine each identified plant community type and determine the type(s) and number of layers in each community. Potential layers include trees (woody overstory), saplings/shrubs (woody understory), herbs (herbaceous understory), and/or woody vines. PROCEED TO STEP 5. o

• STEP 5 - Determine Whether Normal Environmental Conditions Are Present. Determine whether normal environmental conditions are present
at the observation point by considering the following:

a. Is the area at the observation point presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or groundwater levels?

b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

If the answer to either of these questions is thought to be YES,

PROCEED TO Section G. If the answer to both questions is NO, PROCEEDTO STEP 6.

• STEP 6 - Establish a Baseline. Select one project boundary area as a baseline. The baseline should extend parallel to any major watercourse and/or perpendicular to a topographic gradient (see Figure 17). Determine the baseline length and record on the base map both the baseline length and its compass heading. PROCEED TO STEP 7.

• STEP 7. Establish Transect Locations. Divide the baseline into a number of equal segments (Figure 17). Use the following as a guide to determine the appropriate number of baseline segments:

Baseline Length, ft	Number of Segments	Length of Baseline Segment, ft
>50 - 500	3	18 - 167
>500 - 1,000	3	167 - 333
>1,000 - 5,000	5	200 - 1,000
>5,000 - 10,000	7	700 - 1,400
>10,000*	variable	- 2,000

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*If the baseline exceeds 5 miles, baseline segments should be 0.5 mile in length.

Use a random numbers table or a calculator with a random numbers generation feature to determine the position of a transect starting point within each baseline segment. For example, when the baseline is 4,000 ft, the number of baseline segments will be five, and the baseline segment length will be 4,000/5 = 800 ft. Locate the first transect within the first 800 ft of the baseline. If the random numbers table yields 264 as the distance from the baseline starting point, measure 264 ft from the baseline starting point and establish the starting point of the first transect. If the second random number selected is 530, the starting point of the second transect will be located at a distance of 1,330 ft (800 + 530 ft) from the baseline starting point.

CAUTION: Make sure that each plant community type is included in at least one transect. If not, modify the sampling design accordingly. When the starting point locations for all required transacts have been determined, PROCEED TO STEP 8.

• STEP 8 - Determine the Number of Required Observation Points Along Transects. The number of required observation points along each transect will be largely dependent on transect length. Establish observation points along each transect using the following as a guide:

Transect Length, ft	Number of Observation Points	Interval Between Observation Points, ft
<1,000	2-10	100
1,000 - <5,000	10	100 - 500
5,000 - <10,000	10	500 - 1,000
>10,000	>10	1,000

Establish the first observation point at a distance of 50 ft from the baseline (Figure 17). When obvious nonwetlands occupy a long portion of the transect from the baseline starting point, establish the first observation point in the obvious nonwetland at a distance of approximately 300 ft from the point that the obvious nonwetland begins to intergrade into a potential wetland community type. Additional observation points must also be established to determine the wetland boundary between successive regular observation points when one of the points is a wetland and the other is a nonwetland. *CAUTION: In large areas having a mosaic of plant community types, several wetland boundaries may occur along the same transect.* PROCEED TO STEP 9 and apply the comprehensive wetland determination procedure at each required observation point. Use the described procedure to simultaneously characterize the vegetation, soil, and hydrology at each required observation point along each transect, and use the resulting characterization **to** make a wetland determination at each point. *NOTE: All required wetland boundary determinations should be made while proceeding along a transect.*

• STEP 9 - Characterize the Vegetation at the First Observation Point Along the First Transect. *There is no single best procedure for characterizing vegetation. Methods described in STEP 9 afford standardization of the procedure. However, plot size and descriptors for determining dominance may vary*. Record on DATA FORM 2 the vegetation occurring at the first observation point along the first transect by completing the following (as appropriate):

a. Trees. Identify each tree occurring within a 30-ft radius *(A larger sampling plot may be necessary when trees are large and widely spaced.)* of the observation point, measure its basal area (square inches) or diameter at breast height (DBH) using a basal area tape or diameter tape, respectively, and record. *NOTE: If DBH is measured, convert values to basal area by applying the formula* $A = pi\ r^2$. *This must be done on an individual basis.* A tree is any nonclimbing, woody plant that has a DBH of $\geq$3.0 in., regardless of height.

b. Saplings/shrubs. Identify each sapling/shrub occurring within a 10-ft radius of the observation point, estimate its height, and record the midpoint of its class range using the following height classes (height is used as an indication of dominance; taller individuals exert a greater influence on the plant community):

Height Class	Height Class Range, ft		Midpoint of Range, ft
1	1	3	2
2	3	5	4
3	5	7	6
4	7	9	8
5	9	11	10
6	>11		12

A sapling/shrub is any woody plant having a height >3.2 ft but a stem diameter of <3.0 in., exclusive of woody vines.

c., Herbs. Place a 3.28- by 3.28-ft quadrat with one corner touching the observation point and one edge adjacent to the transect line. As an alternative, a 1.64-ft-radius plot with the center of the plot representing the observation point position may be used. Identify each plant species with foliage extending into the quadrat and estimate its percent cover by applying the following cover classes:

Cover Class	Class Range, %	Midpoint of Class Range, %
1	0 - 5	2.5
2	>5 - 25	15.0
3	>25 - 50	37.5
4	>50 - 75	62.5
5	>75 - 95	85.0
6	>95 - 100	97.5

Include all nonwoody plants and woody plants <3.2 ft in height.
NOTE: Total percent cover for all species will often exceed 100 percent.

d. Woody vines (lianas). Identify species of woody vines climbing each tree and sapling/shrub sampled in STEPS 9a and 9b above, and record the number of stems of each. Since many woody vines branch profusely, count or estimate the number of stems at the ground surface. Include only individuals rooted in the 10-ft radius plot. Do not include individuals <3.2 ft in height. PROCEED TO STEP 10.

• STEP 10 - Analyze Field Vegetation Data. Examine the vegetation data (STEP 9) and determine the dominant species in each vegetation layer *(The same species may occur as a dominant in more than one vegetation layer)* by completing the following:

a. Trees. Obtain the total basal area (square inches) for each tree species identified in STEP 9a by summing the basal area of all individuals of a species founi in the sample plot. Rank the species in descending order of dominance based on total basal area. Complete DATA FORM 2 for the tree layer.

b. Saplings/shrubs. Obtain the total height for each sapling/ shrub species identified in STEP 9b. Total height, which is an estimate of dominance, is obtained by summing the midpoints of height classes for all individuals of a species found in the sample plot. Rank the species in descending order of dominance based on sums of midpoints of height class ranges. Complete DATA FORM 2 for the sapling/shrub layer.

c. Herbs. Obtain the total cover for each herbaceous and woody seedling species identified in STEP 9c. Total cover is obtained by using the midpoints of the cover class range assigned to each species (only one estimate of cover is made for a species in a given plot). Rank herbs and woody seedlings in descending order of dominance based on percent cover. Complete DATA FORM 2 for the herbaceous layer.

d. Woody vines (lianas). Obtain the total number of individuals of each species of woody vine identified in STEP 9d. Rank the species in descending order of dominance based on number of stems. Complete DATA FORM 2 for the woody vine layer. PROCEED TO STEP 11.

• STEP 11 - Characterize Soil. If a soil survey is available (Section B), the soil type may already be known. Have a soil scientist confirm that the soil type is correct, and determine whether the soil series is a hydric soil (Appendix D, Section 2). *CAUTION: Mapping* units *on soil surveys sometimes have inclusions of soil series or phases not shown* on the *soil survey map,* If a hydric soil type is confirmed, record on DATA FORM I and PROCEED TO STEP 12. If not, dig a soil pit using a soil auger or spade (See Appendix D, Section 1) and look for indicators of hydric soils immediately below the A-horizon or 10 inches (whichever is shallower) (PART III, paragraphs 44 and/or 45). Record findings on DATA FORM 1. PROCEED TO STEP 12.

• STEP 12 - Characterize Hydrology. Examine the observation point for indicators of wetland hydrology (PART III, paragraph 49), and record observations on DATA FORM 1. Consider indicators in the same sequence as listed in paragraph 49. PROCEED TO STEP 13.

• STEP 13 - Determine Whether Hydrophytic Vegetation Is Present. Record the three dominant species from each vegetation layer (five species if only one or two layers are present) on DATA FORM 1.* *Record all dominant species when less than three are present in a vegetation layer.* Determine whether these species occur in wetlands by considering the following:

a. More than 50 percent of the dominant plant species are OBL, FACW, and/or FAC** on lists of plant species that occur in wetlands. *For the FAC-neutral option, see paragraph 35a.* Record the indicator status of all dominant species (Appendix C, Section I or 2) on DATA FORM 1. Hydrophytic vegetation is present when the majority of the dominant species have an indicator status of OBL, FACW, or FAC. *CAUTION: Not necessarily all plant communities composed of only FAC species are hydrophytic commnities. They are hydrophytic communities only when positive indicators of hydric soils and wetland hydrology are also found.* If this indicator is satisfied, complete the vegetation portion of DATA FORM 1 and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

b. Presence of adaptations for occurrence in wetlands. Do any of ihe-species listed on DATA FORM I have observed morphological or known physiological adaptations (Appendix C, Section 3) for occurrence in wetlands? If so, record species having such adaptations on DATA FORM 1. When two or more dominant species have observed morphological adaptations or known physiological adaptations for occurrence in wetlands, hydrophytic vegetation is present. If so, complete the vegetation portion of DATA FORM I and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

c. Other indicators of hydrophytic vegetation. Consider other indicators (see PART III, paragraph 35) that the species listed on DATA FORM I are commonly found in wetlands. If so, complete the vegetation portion of DATA FORM I bv recording sources of supporting information, and PROCEED TO STEP 14. If no indicator of hydrophytic vegetation is present, the area at the observation point is not a wetlands In such cases, it is unnecessary to consider soil and hydrology at that observation point. PROCEED TO STEP 17.

• STEP 14 - Determine Whether Hydric Soils Are Present. Examine DATA FORM 1 and determine whether any indicator of hydric soils is present. If so, complete the soils portion of DATA FORM I and PROCEED TO STEP 15. If not, the area at the observation point is not a wetlands. PROCEED TO STEP 17.

• STEP 15 - Determine Whether Wetland Hydrology Is Present. Examine DATA FORM 1 and determine whether any indicator of wetland hydrology is present. Complete the hydrology portion of DATA FORM I and PROCEED TO STEP 16.

• STEP 16 - Make Wetland Determination. When the area at the observation point presently or normally has wetland indicators of all three parameters, it is a wetlands When the area at the observation point presently or normally lacks wetland indicators of one or more parameters, it is a nonwetland. PROCEED TO STEP 17.

• STEP 17 - Make Wetland Determination at Second Observation Point. Locate the second observation point along the first transect and make a wetland determination by repeating procedures described in STEPS 9-16. When the area at the second observation point is the same as the area at the first observation point (i.e. both wetlands or both nonwetlands), PROCEED TO STEP 19. When the areas at the two observation points are different (i.e. one wetlands, the other nonwetlands), PROCEED TO STEP 18.

• STEP 18 - Determine the Wetland Boundary Between Observation Points. Determine the position of the wetland boundary by applying the following procedure:

a. Look for a change in vegetation or topography. *NOTE: The changes may sometimes be very subtle*. If a change is noted, establish an observation point and repeat STEPS 9-16. Complete a DATA FORM 1. If the area at this point is a wetlands proceed toward the nonwetland observation point until a more obvious change in vegetation or topography is noted and repeat the procedure. If there is no obvious change, establish the next observation point approximately halfway between the last observation point and the nonwetland observation point and repeat STEPS 9-16.

b. Make as many additional wetland determinations as necessary to find the wetland boundary. *NOTE: The completed DATA FORM 1's for the original two observation points often will provide a clue as to the parameters that change between the two points.*

c. When the wetland boundary is found, mark the boundary location on the base map and indicate on the DATA FORM 1 that this represents a wetland boundary. Record the distance of the boundary from one of the two regular observation points. Since the regular observation points represent known distances from the baseline, it will be possible to accurately pinpoint the boundary location on the base map. PROCEED TO STEP 19.

• STEP 19 - Make Wetland Determinations at All Other Required Observation Points Along All Transects. Continue to locate and sample all required observation points along all transects. *NOTE: The procedure described in Step 18 must be applied at every position where a wetzand boundary occurs between successive observation points.* Complete a DATA FORM 1 for each observation point and PROCEED TO STEP 20.

• STEP 20 - Synthesize Data to Determine the Portion of the Area Containing Wetlands. Examine all completed copies of DATA FORM 1 (STEP 19), and mark on a copy of the base map the locations of all-observation points that are wetlands with a W and all observation points that are nonwetlands with an N. Also, mark all wetland boundaries occurring along transacts with an X. If all the observation points are wetlands, the entire area is wetlands. If all observation points are nonwetlands, none of the area is wetlands. If some wetlands and some nonwetlands are present, connect the wetland boundaries (X) by following contour lines between transacts. *CAUTION: -If the determination is considered to be highly controversial, it may be necessary to be more precise in determining the wetland boundary between transacts. This is also true for very large areas where the distance between transects is greater. If this is necessary, PROCEED TO STEP 21.*

• STEP 21 - Determine Wetland Boundary Between Transects. Two procedures may be used to determine the wetland boundary between transacts, both of which involve surveying:

a. Survey contour from wetland boundary along transacts. The first method involves surveying the elevation of the wetland boundaries along transacts and then extending the survey to determine the same contour between transacts. This procedure will be adequate in areas where there is no significant elevational change between transacts. However, if a significant elevational change occurs between transacts, either the surveyor must adjust elevational readings to accommodate such changes or the second method must be used. *NOTE: The surveyed wetland boundary must be examined to ensure that no anomalies exist. If these occur, additional wetland determinations will be required in the portion of the area where the anomalies occur, and the wetland boundary must be adjusted accordingly.*

b. Additional wetland determinations between transacts. This procedure consists of traversing the area between transects and making additional wetland determinations to locate the wetland boundary at sufficiently close intervals (not necessarily standard intervals) so that the area can be surveyed. Place surveyor flags at each wetland boundary location. Enlist a surveyor to survey the points between transacts. From the resulting survey data, produce a map that separates wetlands from nonwetlands.

Section F. Atypical Situations

71. Methods described in this section should be used only when a determination has already been made in Section D or E that positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology could not be found due to effects of recent human activities or natural events. This section is applicable to delineations made in the following types of situations:

a. Unauthorized activities. Unauthorized discharges requiring Tnf-orcement actions may result in removal or covering of indicators of one or more wetland parameters. Examples include, but are not limited to: (1) alteration or removal of vegetation; (2) placement of dredged or fill material over hydric soils; and/or (3) construction of levees, drainage systems, or dams that significantly alter the area hydrology. *NOTE: This section should not be used for activities that have been previously authorize3-or those that are exempted from CE regulation. For example, this section is not applicable to areas that have been drained under CE authorization or that did not require CE authorization. Some of these areas may still be wetlands, but procedures described in Section D or E must be used in these cases.*

b. Natural events. Naturally occurring events may result in either creation or alteration of wetlands. For example, recent beaver dams may impound water, thereby resulting in a shift of hydrology and vegetation to wetlands. However, hydric soil indicators may not have developed due to insufficient time having passed to allow their development. Fire, avalanches, volcanic activity, and changing river courses are other examples. *NOTE: It is necessary to determine whether alterations to an area have resulted in changes that are now the "normal circumstances."* The relative permanence of the change and whether the area is now functioning as a wetland must be considered.

c. Man-induced wetlands. Procedures described in Subsection 4 are for use in delineating wetlands that have been purposely or incidentally created by human activities, but in which wetland indicators of one or more parameters are absent. For example, road construction may have resulted in impoundment of water in an area that previously was nonwetland, thereby effecting hydrophytic vegetation and wetland hydrology in the area. However, the area may lack hydric soil indicators. *NOTE: Subsection D is not intended to bring into CE jurisdiction those manmade wetlands that are exempted under CE regulations or policy*. It is also important to consider whether the man-induced changes are now the "normal circumstances" for the area. Both the relative permanence of the change and the functioning of the area as a wetland are implied.

72. When any of the three types of situations described in paragraph 71 occurs, application of methods described in Sections D and/or E will lead to the conclusion that the area is not a wetland because positive wetland indicators for at least one of the three parameters will be absent. Therefore, apply procedures described in one of the following subsections (as appropriate) to determine whether positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology existed prior to alteration of the area. Once these procedures have

been employed, RETURN TO Section D or E to make a wetland determination. PROCEED TO the appropriate subsection.

Subsection 1 - Vegetation

73. Employ the following steps to determine whether hydrophytic vegetation previously occurred:

• STEP 1 - Describe the Type of Alteration. Examine the area and describe the type of alteration that occurred. Look for evidence of selective harvesting, clear cutting, bulldozing, recent conversion to agriculture, or other activities (e.g., burning, discing, or presence of buildings, dams, levees, roads, parking lots, etc.). Determine the approximate date* when the alteration occurred. Record observations on DATA FORM 3, and PROCEED TO STEP 2.

• STEP 2 - Describe Effects on Vegetation. Record on DATA FORM 3 a general description of how the activities (STEP 1) have affected the plant communities. Consider the following:

a. Has all or a portion of the area been cleared of vegetation?
b. Has only one layer of the plant community (e.g. trees) been removed?
c. Has selective harvesting resulted in removal of some species?
d. Has all vegetation been covered by fill, dredged material, or structures?
e. Have increased water levels resulted in the death of some individuals?

It is especially important to determine whether the alteration occurred prior to implementation of Section 404. PROCEED TO STEP 3.

• STEP 3 - Determine the Type of Vegetation That Previously Occurred. Obtain all possible evidence of the type of plant communities that occurred in the area prior to alteration. Potential sources of such evidence include:

a. Aerial photography. Recent (within 5 years) aerial photography
an often be used to document the type of previous vegetation. The general type of plant communities formerly present can usually be determined, and species identification is sometimes possible.
b. Onsite inspection. Many types of activities result in only partial removal of the previous plant communities, and remaining species may be indicative of hydrophytic vegetation. In other cases, plant fragments (e.g. stumps, roots) may be used to reconstruct the plant community types that occurred prior to site alteration. Sometimes, this can be determined by examining piles of debris resulting from land-clearing operations or excavation to uncover identifiable remains of the previous plant community.
c. Previous site inspections. Documented evidence from previous inspections of the area may describe the previous plant communities, particularly in cases where the area was altered after a permit application was denied.

d. Adjacent vegetation. Circumstantial evidence of the type of plant communities that previously occurred may sometimes be obtained by examining the vegetation in adjacent areas. If adjacent areas have the same topographic position, soils, and hydrology as the altered area, the plant community types on the altered area were probably similar to those of the adjacent areas.

e. SCS records. Most SCS soil surveys include a description of the plant community types associated with each soil type. If the soil type on the altered area can be determined, it may be possible to generally determine the type of plant communities that previously occurred.

f. Permit applicant. In some cases, the permit applicant may provide important information about the type of plant communities that occurred prior to alteration.

g. Public. Individuals familiar with the area may provide a good general description of the previously occurring plant communities.

h. NWI wetland maps. The NWI has developed wetland type maps for many areas. These may be useful in determining the type of plant communities that occurred prior to alteration.

To develop the strongest possible record, all of the above sources should be considered. If the plant community types that occurred prior to alteration can be determined, record them on DATA FORM 3 and also record the basis used for the determination. PROCEED TO STEP 4. If it is impossible to determine the plant community types that occurred on the area prior to alteration, a determination cannot be made using all three parameters. In such cases, the determination must be based on the other two parameters. PROCEED TO Subsection 2 or 3 if one of the other parameters has been altered, or return to the appropriate Subsection of Section D or to Section E, as appropriate.

• STEP 4 - Determine Whether Plant Community Types Constitute Hydrophytic Vegetation. Develop a list of species that previously occurred on the site (DATA FORM 3). Subject the species list to applicable indicators of hydrophytic vegetation (PART III, paragraph 35). If none of the indicators are met, the plant communities that previously occurred did not constitute hydrophytic vegetation. If hydrophytic vegetation was present and no other parameter was in question, record appropriate data on the vegetation portion of DATA FORM 3, and return to either the appropriate subsection of Section D or to Section E. If either of the other parameters was also in question, PROCEED TO Subsection 2 or 3.

Subsection 2 - Soils

74. Employ the following steps to determine whether hydric soils previously occurred:

• STEP 1 - Describe the Type of Alteration. Examine the area and describe the type of alteration that occurred. Look for evidence of:

a. Deposition of dredged or fill material or natural sedimentation. In many cases the presence of fill material will be obvious. If so, it will be necessary to dig a hole to reach the original soil (sometimes several feet deep). Fill material will usually be a different color or texture than the original soil (except when fill material has been obtained from like areas onsite). Look for decomposing vegetation between soil layers and the presence of buried organic or hydric soil layers. In accreting or recently formed sandbars in riverine situations, the soils may support hydrophytic vegetation but lack hydric soil characteristics.

b. Presence of nonwoody debris at the surface. This can only be applied in areas where the original soils do not contain rocks.

Nonwoody debris includes items such as rocks, bricks, and concrete fragments.

c. Subsurface plowing. Has the area recently been plowed below he A-horizon or to depths of greater than 10 in.?

d. Removal of surface layers, Has the surface soil layer been removed by scraping or natural landslides? Look for bare soil surfaces with exposed plant roots or scrape scars on the surface.

e. Presence of man-made structures. Are buildings, dams, levees, roads, or parking lots present?

Determine the approximate date (I*t is especially important to determine whether the alteration occurred prior to implementation of Section 404.*) when the alteration occurred. This may require checking aerial photography, examining building permits, etc. Record on DATA FORM 3, and PROCEED TO STEP 2.

• Step 2 - Describe Effects on Soils. Record on DATA FORM 3 a general description of how identified activities in STEP 1 have affected the soils. Consider the following:

a. Has the soil been buried? If so, record the depth of fill material and determine whether the original soil is intact.

b. Has the soil the original been mixed at a depth below the A-horizon or greater than 10 inches? If so, it will be necessary to examine soil at a depth immediately below the plowed zone. Record supporting evidence.

c. Has the soil been sufficiently altered to change the soil phase? Describe these changes. PROCEED TO STEP 3.

• STEP 3 - Characterize Soils That Previously Occurred. Obtain all possible evidence that may be used to characterize soils that previously occurred on the area. Consider the following potential sources of information:

a. Soil surveys. In many cases, recent soil surveys will be available. If so, determine the soil series that were mapped for the area, and compare these soil series with the list of hydric soils (Appendix D, Section 2). If all soil series are listed as hydric soils, the entire area had hydric soils prior to alteration.

b. Characterization of buried soils. When fill material has been placed over the original soil without physically disturbing the soil, examine and characterize the buried soils. To accomplish this, dig a hole through the fill material until the original soil is encountered. Determine the point at which the original soil material begins. Remove 12 inches of the original soil from the hole and look for indicators of hydric soils (PART III, paragraphs 44 and/or 45) immediately below the A-horizon or 10 inches (whichever is shallower). Record on DATA FORM 3 the color of the soil matrix, presence of an organic layer, presence of mottles or gleying, and/or presence of manganese concretions. If the original soil is motthe chroma of the soil matrix is 2 or less, *(The matrix chroma must be 1 or less if no mottles are present (see paragraph 44). The soil must be moist when colors are determined.)*, a hydric formerly present on the site. If any of these indicafound, the original soil was a hydric soil. *(NOTE: fill material is a thick layer, it might be necessary to use backhoe or posthole digger to excavate the soil pit.)* If USGS quadrangle maps indicate distinct variation in area topography, this procedure must be applied in each portion of the area that originally had a different surface elevation. Record findings on DATA FORM 3.

c. Characterization of plowed soils. Determine the depth to which the soil has been disturbed by plowing. Look for hydric soil characteristics (PART III, paragraphs 44 and/or 45) immediately below this depth. Record findings on DATA FORM 3.

d. Removal of surface layers. Dig a hole (Appendix D, Section 1) and determine whether the entire surface layer (A-horizon) has been removed. If so, examine the soil immediately below the top of the subsurface layer (B-horizon) for hydric soil characteristics. As an alternative, examine an undisturbed soil of the same soil series occurring in the same topographic position in an immediately adjacent area that has not been altered. Look for hydric soil indicators immediately below the A-horizon or 10 inches (whichever is shallower), and record findings on DATA FORM 3.

If sufficient data on soils that existed prior to alteration can be obtained to determine whether a hydric soil was present, PROCEED TO STEP 4. If not, a determination cannot be made using soils. Use the other parameters (Subsections 1 and 3) for the determination.

• STEP 4 - Determine Whether Hydric Soils Were Formerly Present. Examine the available data and determine whether indicators of hydric soils (PART III, paragraphs 44 and/or 45) were formerly present. If no indicators of hydric soils were found, the original soils were not hydric soils. If indicators of hydric soils were found, record the appropriate indicators on DATA FORM 3 and PROCEED TO Subsection 3 if the hydrology of the area has been significantly altered or return either to the appropriate subsection of Section D or to Section E and characterize the area hydrology.

Subsection 3 - Hydrology

75. Apply the following steps to determine whether wetland hydrology previously occurred:

• STEP 1 - Describe the Type of Alteration. Examine the area and describe the type of alteration that occurred. Look for evidence of:

a. Dams. Has recent construction of a dam or some natural event (e.g. beaver activity or landslide) caused the area to become increasingly wetter or drier? *NOTE: This activity could have occurred a considerable distance away from the site in question.*

b. Levees, dikes, and similar structures. Have levees or dikes recently been constructed that prevent the area from becoming periodically inundated by overbank flooding?

c. Ditching. Have ditches been constructed recently that cause the area to drain more rapidly following inundation?

d. Filling of channels or depressions (land-leveling). Have natural channels or depressions been recently filled?

e. Diversion of water. Has an upstream drainage pattern been altered that results in water being diverted from the area?

f. Ground-water extraction. Has prolonged and intensive pumping of ground water for irrigation or other purposes significantly lowered the water table and/or altered drainage patterns?

g. Channelization. Have feeder streams recently been channelized sufficiently to alter the frequency and/or duration of inundation?

Determine the approximate date* *It is especially important to determine whether the alteration occurred prior to implementation of Section 404.* when the alteration occurred. Record observations on DATA FORM 3 and PROCEED TO STEP 2.

• STEP 2 - Describe Effects of Alteration on Area Hydrology. Record on DATA FORM 3 a general description of how the observed alteration (STEP 1) has affected the area. Consider the following:

a. Is the area more frequently or less frequently inundated than prior to alteration? To what degree and why?

b. Is the duration of inundation and soil saturation different than prior to alteration? How much different and why? PROCEED TO STEP 3.

• STEP 3 - Characterize the Hydrology That Previously Existed in the Area. Obtain all possible evidence that may be used to characterize the hydrology that previously occurred. Potential sources of information include:

a. Stream or tidal gage data. If a stream or tidal gaging station is located near the area, it may be possible to calculate elevations representing the upper limit of wetlands hydrology based on duration of inundation. Consult hydrologists from the local CE District Office for assistance. The resulting mean sea level elevation will represent the upper limit of inundation for the area in the absence of any alteration. If fill material has not been placed on the area, survey this elevation from the nearest USGS benchmark. Record elevations representing zone boundaries on DATA FORM 3. If fill material has been placed on the area, compare the calculated elevation with elevations shown on a USGS quadrangle or any other survey map that predated site alteration.

b. Field hydrologic indicators. Certain field indicators of wetland hydrology (PART III, paragraph 49) may still be present. Look for watermarks on trees or other structures, drift lines, and debris deposits. Record these on DATA FORM 3. If adjacent undisturbed areas are in the same topographic position and are similarly influenced by the same sources of inundation, look for wetland indicators in these areas.

c. Aerial photography. Examine any available aerial photography and determine whether the area was inundated at the time of the photographic mission. Consider the time of the year that the aerial photography was taken and use only photography taken during the growing season and prior to site alteration.

d. Historical records. Examine any available historical records for evidence that the area has been periodically inundated. Obtain copies of any such information and record findings on DATA FORM 3.

e. Floodplain Management Maps. Determine the previous frequency of inundation of the area from Floodplain Management Maps (if available). Record flood frequency on DATA FORM 3.

f. Public or local government officials. Contact individuals who might have knowledge that the area was periodically inundated.

If sufficient data on hydrology that existed prior to site alteration can be obtained to determine whether wetland hydrology was previously present, PROCEED TO STEP 4. If not, a determination involving hydrology cannot be made. Use other parameters (Subsections 1 and 2) for the wetland determination. Return to either the appropriate subsection of Section D or to Section E and complete the necessary data forms. PROCEED TO STEP 4 if the previous hydrology can be characterized. *

• STEP 4 - Determine Whether Wetland Hydrology Previously Occurred. Examine the available data and determine whether indicators of wetland hydrology (PART III, paragraph 49) were present prior to site alteration. If no indicators of wetland hydrology were found, the original hydrology of the area was not wetland hydrology. If indicators of wetland hydrology were found, record the appropriate indicators on DATA FORM 3 and return either to the appropriate subsection of Section D or to Section E and complete the wetland determination.

Subsection 4 - Man-Induced Wetlands

76. A man-induced wetland is an area that has developed at least some characteristics of naturally occurring wetlands due to either intentional or incidental human activities. Examples of man-induced wetlands include irrigated wetlands, wetlands resulting from impoundment (e.g. reservoir shorelines), wetlands resulting from filling of formerly deepwater habitats, dredged material disposal areas, and wetlands resulting from stream channel realignment. Some man-induced wetlands may be subject to Section 404. In virtually all cases, man-induced wetlands involve a significant change in the hydrologic regime, which may either increase or decrease the wetness of the area. Although wetland indicators of all three parameters (i.e. vegetation, soils, and hydrology) may be found in some man-induced wetlands, indicators of hydric soils are usually absent. Hydric soils require long periods (hundreds of years) for development of wetness characteristics, and most man-induced wetlands have not been in existence for a sufficient period to allow development of hydric soil characteristics. Therefore, application of the multiparameter approach in making wetland determinations in man-induced wetlands must be based on the presence of hydrophytic vegetation and wetland hydrology. *(Uplands that support hydrophytic vegetation due to agricultural irrigation and that have an obvious hydrologic connection to other "waters of the United States" should not be delineated as wetlands under this subsection).* There must also be documented evidence that the wetland resulted from human activities. Employ the following steps to determine whether an area consists of wetlands resulting from human activities:

• STEP I - Determine Whether the Area Represents a Potential Man-Induced Wetland. Consider the following questions:

a. Has a recent man-induced change in hydrology occurred that caused the area to become significantly wetter?
b. Has a major man-induced change in hydrology that occurred in the past caused a former deepwater aquatic habitat to become significantly drier?
c. Has man-induced stream channel realignment significantly altered the area hydrology?
d. Has the area been subjected to long-term irrigation practices? If the answer to any of the above questions is YES, document the approximate time during which the change in hydrology occurred, and PROCEED TO STEP 2. If the answer to all of the questions is NO, procedures described in Section D or E must be used.

• STEP 2 - Determine Whether a Permit Will be Needed if the Area is Found to be a Wetland. Consider the current CE regulations and policy regarding man-induced wetlands. If the type of activity resulting in the area being a potential man-induced wetland is exempted by regulation or policy, no further action is needed. If not exempt, PROCEED TO STEP 3.

• STEP 3 - Characterize the Area Vegetation, Soils, and Hydrology, Apply procedures described in Section D (routine determinations) or Section E (comprehensive determinations) to the area. Complete the appropriate data forms and PROCEED TO STEP 4.

• STEP 4 - Wetland Determination. Based on information resulting from STEP 3, determine whether the area is a wetland. When wetland indicators of all three parameters are found, the area is a wetland. When indicators of hydrophytic vegetation and wetland hydrology are found and there is documented evidence that the change in hydrology occurred so recently that soils could not have developed hydric characteristics, the area is a wetland. In such cases, it is assumed that the soils are functioning as hydric soils. *CAUTION: if hydrophytic vegetation is being-maintained only because of man-induced wetland hydrology that would no longer exist if the activity (e.g. irrigation) were to be terminated., the area should not be considered a wetland.*

Section G - Problem Areas

77. There are certain wetland types and/or conditions that may make application of indicators of one or more parameters difficult, at least at certain times of the year. These are not considered to be atypical situations. Instead, they are wetland types in which wetland indicators of one or more parameters may be periodically lacking due to normal seasonal or annual variations in environmental conditions that result from causes other than human activities or catastrophic natural events.

Types of problem areas

78. Representative examples of potential problem areas, types of variations that occur, and their effects on wetland indicators are presented in the following subparagraphs. Similar situations may sometimes occur in other wetland types. *Note: This section is not intended to*

bring nonwetland areas having wetzand indicators of two, but not all three, parameters into Section 404 jurisdiction.

a. Wetlands on drumlins. Slope wetlands occur in glaciated areas Tn-which thin soils cover relatively impermeable glacial till or in which layers of glacial till have different hydraulic conditions that produce a broad zone of ground-water seepage. Such areas are seldom, if ever, flooded, but downslope groundwater movement keeps the soils saturated for a sufficient portion of the growing season to produce anaerobic and reducing soil conditions. This fosters development of hydric soil characteristics and selects for hydrophytic vegetation. Indicators of wetland hydrology may be lacking during the drier portion of the growing season.

b. Seasonal wetlands. In many regions (especially in western states), depression areas occur that have wetland indicators of all three parameters during the wetter portion of the growing season, but normally lack wetland indicators of hydrology and/or vegetation during the drier portion of the growing season. Obligate hydrophytes and facultative wetland plant species (Appendix C, Section 1 or 2) normally are dominant during the wetter portion of the growing season, while upland species (annuals) may be dominant during the drier portion of the growing season. These areas may be inundated during the wetter portion of the growing season, but wetland hydrology indicators may be totally lacking during the drier portion of the growing season. It is important to establish that an area truly is a water body. Water in a depression normally must be sufficiently persistent to exhibit an ordinary high-water mark or the presence of wetland characteristics before it can be considered as a water body potentially subject to Clean Water Act jurisdiction. The determination that an area exhibits wetland characteristics for a sufficient portion of the growing season to qualify as a wetland under the Clean Water Act must be made on a case-by-case basis. Such determinations should consider the respective length of time that the area exhibits upland and wetland characteristics, and the manner in which the area fits into the overall ecological system as a wetland. Evidence concerning the persistence of an area's wetness can be obtained from its history, vegetation, soil, drainage characteristics, uses to which it has been subjected, and weather or hydrologic records.

c. Prairie potholes. Prairie potholes normally occur as shallow depressions in glaciated portions of the north-central United States. Many are landlocked, while others have a drainage outlet to streams or other potholes. Most have standing water for much of the growing season in years of normal or above normal precipitation, but are neither inundated nor have saturated soils during most of the growing season in years of below normal precipitation. During dry years, potholes often become incorporated into farming plans, and are either planted to row crops (e.g. soybeans) or are mowed as part of a haying operation. When this occurs, wetland indicators of one or more parameters may be lacking. For example, tillage would eliminate any onsite hydrologic indicator, and would make detection of soil and vegetation indicators much more difficult.

d. Vegetated flats. In both coastal and interior areas throughout the Nation, vegetated flats are often dominated by annual species that are categorized as OBL. Application of procedures described in Sections D and E during the growing season will clearly result in a positive wetland determination. However, these areas will appear to be unvegetated mudflats when examined during the nongrowing season, and the area would not qualify at that time as a wetland due to an apparent lack of vegetation.

Wetland determinations in problem areas

79. Procedures for making wetland determinations in problem areas are presented below. Application of these procedures is appropriate only when a decision has been made in Section D or E that wetland indicators of one or more parameters were lacking, probably due to normal seasonal or annual variations in environmental conditions. Specific procedures to be used will vary according to the nature of the area, site conditions, and parameters) affected by the variations in environmental conditions. A determination must be based on the best evidence available to the field inspector, including:

a. Available information (Section B).
b. Field data resulting from an onsite inspection.
c. Basic knowledge of the ecology of the particular community
type(s) and environmental conditions associated with the community type.

NOTE: The procedures described below should only be applied to parameters not adequately characterized in Section D or E. Complete the following steps:

• STEP 1 - Identify the Parameter(s) to be Considered. Examine the DATA FORM 1 (Section D or E) and identify the parameter(s) that must be given additional consideration. PROCEED TO STEP 2.

• STEP 2 - Determine the Reason for Further Consideration. Determine the reason why the parameters) identified in STEP 1 should be given further consideration. This will require a consideration and documentation of:

a. Environmental condition(s) that have impacted the parameters).
b. Impacts of the identified environmental condition(s) on the parameter(s) in question.

Record findings in the comments section of DATA FORM 1. PROCEED TO STEP 3.

• STEP 3 - Document Available Information for Parameter(s) in Question. Examine the available information and consider personal ecological knowledge of the range of normal environmental conditions of the area. Local experts (e.g. university personnel) may provide additional information. Record information on DATA FORM 1. PROCEED TO STEP 4.

• STEP 4 - Determine Whether Wetland Indicators are Normally Present During a Portion of the Growing Season. Examine the information resulting from STEP 3 and determine whether wetland indicators are normally present during part of the growing season. If so, record on

DATA FORM 1 the indicators normally present and return to Section D or Section E and make a wetland determination. If no information can be found that wetland indicators of all three parameters are normally present during part of the growing season, the determination must be made using procedures described in Section D or Section E.

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APPENDIX A: GLOSSARY

Active water table - A condition in which the zone of soil saturation fluctuates, resulting in periodic anaerobic soil conditions. Soils with an active water table often contain bright mottles and matrix chromas of 2 or less.

Adaptation - A modification of a species that makes it more fit for existence under the conditions of its environment. These modifications are the result of genetic selection processes.

Adventitious roots Roots found on plant stems in positions where they normally do not occur.

Aerenchymous tissue A type of plant tissue in which cells are unusually large and arranged in a manner that results in air spaces in the plant organ. Such tissues are often referred to as spongy and usually provide increased buoyancy.

Aerobic - A situation in which molecular oxygen is a part of the environment.

Anaerobic - A situation in which molecular oxygen is absent (or effectively so) from the environment.

Aquatic roots - Roots that develop on stems above the normal position occupied by roots in response to prolonged inundation.

Aguic moisture regime - A mostly reducing soil moisture regime nearly free of dissolved oxygen due to saturation by ground water or its capillary fringe and occurring at periods when the soil temperature at 19.7 in. is greater than 50 C.

Arched roots - Roots produced on plant stems in a position above the normal position of roots, which serve to brace the plant during and following periods of prolonged inundation.

Areal cover - A measure of dominance that defines the degree to which aboveground portions of plants (not limited to those rooted in a sample plot) cover the ground surface. It is possible for the total areal cover in a community to exceed 100 percent because (a) most plant communities consist of two or more vegetative strata; (b) areal cover is estimated by vegetative layer; and (c) foliage within a single layer may overlap.

Atypical situation - As used herein, this term refers to areas in which one or more parameters (vegetation, soil, and/or hydrology) have been sufficiently altered by recent human activities or natural events to preclude the presence of wetland indicators of the parameter.

Backwater flooding - Situations in which the source of inundation is overbank flooding from a nearby stream.

Basal area - The cross-sectional area of a tree trunk measured in square inches, square centimetres, etc. Basal area is normally measured at 4.5 ft above the ground level and is used as a measure of dominance. The most easily used tool for measuring basal area is a tape marked in square inches. When plotless methods are used, an angle gauge or prism will provide a means for rapidly determining basal area. This term is also applicable to the crosssectional area of a clumped herbaceous plant, measured at 1.0 in. above the soil surface.

Bench mark - A fixed, more or less permanent reference point or object, the elevation of which is known. The US Geological Survey (USGS) installs brass caps in bridge abutments or otherwise permanently sets bench marks at convenient locations nationwide. The elevations on these marks are referenced to the National Geodetic Vertical Datum (NGVD), also commonly known as mean sea level (MSL). Locations of these bench marks on USGS quadrangle maps are shown as small triangles. However, the marks are sometimes destroyed by construction or vandalism. The existence of any bench mark should be field verified before planning work that relies on a particular reference point. The USGS and/or local state surveyor's office can provide information on the existence, exact location, and exact elevation of bench marks.

Biennial - An event that occurs at 2-year intervals.

Buried soil - A once-exposed soil now covered by an alluvial, loessal, or other deposit (including man-made).

Canopy layer - The uppermost layer of vegetation in a plant community. In forested areas, mature trees comprise the canopy layer, while the tallest herbaceous species constitute the canopy layer in a marsh.

Capillary fringe - A zone immediately above the water table (zero gauge pressure) in which water is drawn upward from the water table by capillary action.

Chemical reduction - Any process by which one compound or ion acts as an electron donor. In such cases, the valence state of the electron donor is decreased.

Chroma - The relative purity or saturation of a color; intensity of distinctive hue as related to grayness; one of the three variables of color.

Comprehensive wetland determination - A type of wetland determination that is based on the strongest possible evidence, requiring the collection of quantitative data.

Concretion - A local concentration of chemical compounds (e.g. calcium carbonate, iron oxide) in the form of a grain or nodule of varving size, shape, hardness, and color. Concretions of significance in hydric soils are usually iron and/or manganese oxides occurring at or near the soil surface, which develop under conditions of prolonged soil saturation.

Contour - An imaginary line of constant elevation on the ground surface. The corresponding line on a map is called a "contour line."

Criteria - Standards, rules, or tests on which a judgment or decision may be based.

Deepwater aquatic habitat - Any open water area that has a mean annual water depth >6.6 ft, lacks soil, and/or is either unvegetated or supports only floating or submersed macrophytes.

Density - The number of individuals of a species per unit area.

Detritus - Minute fragments of plant parts found on the soil surface. When fused together by algae or soil particles, this is an indicator that surface water was recently present.

Diameter at breast height (DBH) - The width of a plant stem as measured at 4.5 ft above the ground surface.

Dike - A bank (usually earthen) constructed to control or confine water.

Dominance - As used herein, a descriptor of vegetation that is related to the standing crop of a species in an area, usually measured by height, areal cover, or basal area (for trees).

Dominant species - As used herein, a plant species that exerts a controlling influence on or defines the character of a community.

Drained - A condition in which ground or surface water has been reduced or eliminated from an area by artificial means.

Drift line An accumulation of debris along a contour (parallel to the water flow) that represents the height of an inundation event.

Duration (inundation/soil saturation) - The length of time during which water stands at or above the soil surface (inundation), or during which the soil is saturated. As used herein, duration refers to a period during the growing season.

Ecological tolerance - The range of environmental conditions in which a plant species can grow.

Emergent plant - A rooted herbaceous plant species that has parts extending above a water surface.

Field capacity - The percentage of water remaining in a soil after it has been saturated and after free drainage is negligible.

Fill material - Any material placed in an area to increase surface elevation.

Flooded - A condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources.

Flora - A list of all plant species that occur in an area.

Frequency (inundation or soil saturation) - The periodicity of coverage of an area by surface water or soil saturation. It is usually expressed as the number of years (e.g. 50 years) the soil is inundated or saturated at least once each year during part of the growing season per 100 years or as a l-, 2-, 5-year, etc., inundation frequency.

Frequency (vegetation) - The distribution of individuals of a species in an area. It is quantitatively expressed as

$$\frac{\text{Number of samples containing species A}}{\text{Total number of samples}} \times 100$$

More than one species may have a frequency of 100 percent within the same area.

Frequently flooded - A flooding class in which flooding is likely to occur often under normal weather conditions (more than 50-percent chance of flooding in any year or more than 50 times in 100 years).

Gleyed - A soil condition resulting from prolonged soil saturation, which is manifested by the presence of bluish or greenish colors through the soil mass or in mottles (spots or streaks) among other colors. Gleying occurs under reducing soil conditions resulting from soil saturation, by which iron is reduced predominantly to the ferrous state.

Ground water - That portion of the water below the ground surface that is under greater pressure than atmospheric pressure.

Growing season - The portion of the year when soil temperatures at 19.7 inches below the soil surface are higher than biologic zero (5' C) (US Department of Agriculture - Soil Conservation Service 1985). For ease of determination this period can be approximated by the number of frost-free days (US Department of the interior 1970).

Habitat - The environment occupied by individuals of a particular species, population, or community.

Headwater flooding - A situation in which an area becomes inundated directly by surface runoff from upland areas.

Herb - A nonwoody individual of a macrophytic species. In this manual, seedlings of woody plants (including vines) that are less than 3.2 ft in height are considered to be herbs.

Herbaceous layer - Any vegetative stratum of a plant community that is composed predominantly of herbs.

Histic epipedon - An 8- to 16-in. soil layer at or near the surface that is saturated for 30 consecutive days or more during the growing season in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when 60 percent or greater clay is present.

Histosols - An order in soil taxonomy composed of organic soils that have organic soil materials in more than half of the upper 80 cm or that are of any thickness if directly overlying bedrock.

Homogeneous vegetation - A situation in which the same plant species association occurs throughout an area.

Hue - A characteristic of color that denotes a color in relation to red, yellow, blue, etc; one of the three variables of color. Each color chart in the Munsell Color Book (Munsell Color 1975) consists of a specific hue.

Hydric soil - A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (US Department of Agriculture-Soil Conservation Service 1985). Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

Hydric soil condition - A situation in which characteristics exist that are associated with soil development under reducing conditions.

Hydrologic regime - The sum total of water that occurs in an area on average during a given period.

Hydrologic zone - An area that is inundated or has saturated soils within a specified range of frequency and duration of inundation and soil saturation.

Hydrology - The science dealing with the properties, distribution, and circulation of water.

Hydrophyte - Any macrophyte that grows in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content; plants typically found in wet habitats.

Hydrophytic vegetation - The sum total of macrophytic plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content. When hydrophytic vegetation comprises a community where indicators of hydric soils and wetland hydrology also occur, the area has wetland vegetation.

Hypertrophied lenticels - An exaggerated (oversized) pore on the surface of stems of woody plants through which gases are exchanged between the plant and the atmosphere. The enlarged lenticels serve as a mechanism for increasing oxygen to plant roots during periods of inundation and/or saturated soils.

Importance value - A quantitative term describing the relative influence of a plant species in a plant community, obtained by summing any combination of relative frequency, relative density, and relative dominance.

Indicator - As used in this manual, an event, entity, or condition that typically characterizes a prescribed environment or situation; indicators determine or aid in determining whether or not certain stated circumstances exist.

Indicator status - One of the categories (e.g. OBL) that describes the estimated probability of a plant species occurring in wetlands.

Intercellular air space - A cavity between cells in plant tissues, resulting from variations in cell shape and configuration. Aerenchymous tissue (a morphological adaptation found in many hydrophytes) often has large intercellular air spaces.

Inundation - A condition in which water from any source temporarily or permanently covers a land surface.

Levee - A natural or man-made feature of the landscape that restricts movement of water into or through an area.

Liana - As used in this manual, a layer of vegetation in forested plant communities that consists of woody vines. The term may also be applied to a given species.

Limit of biological activity - With reference to soils, the zone below which conditions preclude normal growth of soil organisms. This term often is used to refer to the temperature (5' C) in a soil below which metabolic processes of soil microorganisms, plant roots, and animals are negligible.

Long duration (flooding) - A flooding class in which the period of inundation for a single event ranges from 7 days to 1 month.

Macrophyte Any plant species that can be readily observed without the aid of optical magnification. This includes all vascular plant species and mosses (e.g., Sphagnum spp.), as well as large algae (e.g. *Chara* spp., kelp).

Macrophytic - A term referring to a plant species that is a macrophyte.

Major portion of the root zone. The portion of the soil profile in which more than 50 percent of plant roots occur. In wetlands, this usually constitutes the upper 12 in. of the profile.

Man-induced wetland - Any area that develops wetland characteristics due to some activity (e.g., irrigation) of man.

Mapping unit - As used in this manual, some common characteristic of soil, vegetation, and/or hydrology that can be shown at the scale of mapping for the defined purpose and objectives of a survey.

Mean sea level - A datum, or "plane of zero elevation," established by averaging all stages of oceanic tides over a 19-year tidal cycle or "epoch." This plane is corrected for curvature of the earth and is the standard reference for elevations on the earth's surface. The correct term for mean sea level is the National Geodetic Vertical Datum (NGVD).

Mesophytic - Any plant species growing where soil moisture and aeration conditions lie between extremes. These species are typically found in habitats with average moisture conditions, neither very dry nor very wet.

Metabolic processes - The complex of internal chemical reactions associated with life-sustaining functions of an organism.

Method - A particular procedure or set of procedures to be followed.

Mineral soil - A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter usually containing less than 20-percent organic matter.

Morphological adaptation - A feature of structure and form that aids in fitting a species to its particular environment (e.g. buttressed base, adventitious roots, aerenchymous tissue).

Mottles - Spots or blotches of different color or shades of color interspersed within the dominant color in a soil layer, usually resulting from the presence of periodic reducing soil conditions.

Muck - Highly decomposed organic material in which the original plant parts are not recognizable.

Multitrunk - A situation in which a single individual of a woody plant species has several stems.

Nonhydric soil - A soil that has developed under predominantly aerobic soil conditions. These soils normally support mesophytic or xerophytic species.

Nonwetland - Any area that has sufficiently dry conditions that indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology are lacking. As used in this manual, any area that is neither a wetland, a deepwater aquatic habitat, nor other special aquatic site.

Organic pan - A layer usually occurring at 12 to 30 inches below the soil surface in coarse-textured soils, in which organic matter and aluminum (with or without iron) accumulate at the point where the top of the water table most often occurs. Cementing of the organic matter slightly reduces permeability of this layer.

Organic soil - A soil is classified as an organic soil when it is: (1) saturated for prolonged periods (unless artificially drained) and has more than 30-percent organic matter if the mineral fraction is more than 50-percent clay, or more than 20-percent organic matter if the mineral fraction has no clay; or (2) never saturated with water for more than a few days and having more than 34-percent organic matter.

Overbank flooding - Any situation in which inundation occurs as a result of the water level of a stream rising above bank level.

Oxidation-reduction process - A complex of biochemical reactions in soil that influences the valence state of component elements and their ions. Prolonged soil saturation during the growing season elicits anaerobic conditions that shift the overall process to a reducing condition.

Oxygen pathway - The sequence of cells, intercellular spaces, tissues, and organs, through which molecular oxygen is transported in plants. Plant species having pathways for oxygen transport to the root system are often adapted for life in saturated soils.

Parameter - A characteristic component of a unit that can be defined. Vegetation, soil, and hydrology are three parameters that may be used to define wetlands.

Parent material - The unconsolidated and more or less weathered mineral or organic matter from which a soil profile develops.

Ped - A unit of soil structure (e.g. aggregate, crumb, prism, block, or granule) formed by natural processes.

Peraquic moisture regime - A soil condition in which a reducing environment always occurs due to the presence of ground water at or near the soil surface.

Periodically - Used herein to define detectable regular or irregular saturated soil conditions or inundation, resulting from ponding of ground water, precipitation, overland flow, stream flooding, or tidal influences that occur(s) with hours, days, weeks, months, or even years between events.

Permeability- A soil characteristic that enables water or air to move through the profile, measured as the number of inches per hour that water moves downward through the saturated soil. The rate at which water moves through the least permeable layer governs soil permeability.

Physiognomy - A term used to describe a plant community based on the growth habit (e.g., trees, herbs, lianas) of the dominant species.

Physiological adaptation - A feature of the basic physical and chemical activities that occurs in cells and tissues of a species, which results in it being better fitted to its environment (e.g. ability to absorb nutrients under low oxygen tensions).

Plant community - All of the plant populations occurring in a shared habitat or environment.

Plant cover - See areal cover.

Pneumatophore - Modified roots that may function as a respiratory organ in species subjected to frequent inundation or soil saturation (e.g., cypress knees).

Ponded - A condition in which water stands in a closed depression. Water may be removed only by percolation, evaporation, and/or transpiration.

Poorly drained - Soils that commonly are wet at or near the surface during a sufficient part of the year that field crops cannot be grown under natural conditions. Poorly drained conditions are caused by a saturated zone, a layer with low hydraulic conductivity, seepage, or a combination of these conditions.

Population - A group of individuals of the same species that occurs in a given area.

Positive wetland indicator - Any evidence of the presence of hydrophytic vegetation, hydric soil, and/or wetland hydrology in an area.

Prevalent vegetation - The plant community or communities that occur in an area during a given period. The prevalent vegetation is characterized by the dominant macrophytic species that comprise the plant community.

Quantitative - A precise measurement or determination expressed numerically.

Range - As used herein, the geographical area in which a plant species is known to occur.

Redox potential - A measure of the tendency of a system to donate or accept electrons, which is governed by the nature and proportions of the oxidizing and reducing substances contained in the system.

Reducing environment - An environment conducive to the removal of oxygen and chemical reduction of ions in the soils.

Relative density - A quantitative descriptor, expressed as a percent, of the relative number of individuals of a species in an area; it is calculated by

$$\frac{\text{Number of individuals of species A}}{\text{Total number of individuals of all species}} \times 100$$

Relative dominance - A quantitative descriptor, expressed as a percent, of the relative size or cover of individuals of a species in an area; it is calculated by

$$\frac{\text{Amount* of species A}}{\text{Total amount of all species}} \times 100$$

*The amount of a species may be based on percent areal cover, basal area, or height.

Relative frequency - A quantitative descriptor, expressed as a percent, of the relative distribution of individuals of a species in an area; it is calculated by

$$\frac{\text{Frequency of species A}}{\text{Total frequency of all species}} \times 100$$

Relief - The change in elevation of a land surface between two points; collectively, the configuration of the earth's surface, including such features as hills and valleys.

Reproductive adaptation - A feature of the reproductive mechanism of a species that results in it being better fitted to its environment (e.g. ability for seed germination under water).

Respiration - The sum total of metabolic processes associated with conversion of stored (chemical) energy into kinetic (physical) energy for use by an organism.

Rhizosphere - The zone of soil in which interactions between living plant roots and microorganisms occur.

Root zone - The portion of a soil profile in which plant roots occur.

Routine wetland determination - A type of wetland determination in which office dat and/or relatively simple, rapidly applied onsite methods are employed to determine whether or not an area is a wetland. Most wetland determinations are of this type, which usually does not require collection of quantitative data.

Sample plot - An area of land used for measuring or observing existing conditions.

Sapling/shrub - A layer of vegetation composed of woody plants <3.0 in. in diameter at breast height but greater than 3.2 ft in height, exclusive of woody vines.

Saturated soil conditions - A condition in which all easily drained voids (pores) between soil particles in the root zone are temporarily or permanently filled with water to the soil surface at pressures greater than atmospheric.

Soil - Unconsolidated mineral and organic material that supports, or is capable of supporting, plants, and which has recognizable properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief over time.

Soil horizon - A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics (e.g. color, structure, texture, etc.).

Soil matrix - The portion of a given soil having the dominant color. In most cases, the matrix will be the portion of the soil having more than 50 percent of the same color.

Soil permeability - The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.

Soil phase - A subdivision of a soil series having features (e.g. slope, surface texture, and stoniness) that affect the use and management of the soil, but which do not vary sufficiently to differentiate it as a separate series. These are usually the basic mapping units on detailed soil maps produced by the Soil Conservation Service.

Soil pore - An area within soil occupied by either air or water, resulting from the arrangement of individual soil particles or peds.

Soil profile - A vertical section of a soil through all its horizons and extending into the parent material.

Soil series - A group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface horizon.

Soil structure - The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil surface - The upper limits of the soil profile. For mineral soils, this is the upper limit of the highest (Al) mineral horizon. For organic soils, it is the upper limit of undecomposed. dead organic matter.

Soil texture - The relative proportions of the various sizes of particles in a soil.

Somewhat poorly drained - Soils that are wet near enough to the surface or long enough that planting or harvesting operations or crop growth is markedly restricted unless artificial drainage is provided. Somewhat poorly drained soils commonly have a layer with low hydraulic conductivity, wet conditions high in the profile, additions of water through seepage, or a combination of these conditions.

Stilted roots - Aerial roots arising from stems (e.g., trunk and branches), presumably providing plant support (e.g., *Rhizophora mangle*).

Stooling - A form of asexual reproduction in which new shoots are produced at the base of senescing stems, often resulting in a multitrunk growth habit.

Stratigraphy - Features of geology dealing with the origin, composition, distribution, and succession of geologic strata (layers).

Substrate - The base or substance on which an attached species is growing.

Surface water - Water present above the substrate or soil surface.

Tidal - A situation in which the water level periodically fluctuates due to the action of lunar and solar forces upon the rotating earth.

Topography - The configuration of a surface, including its relief and the position of its natural and man-made features.

Transect - As used herein, a line on the ground along which observations are made at some interval.

Transition zone - The area in which a change from wetlands to nonwetlands occurs. The transition zone may be narrow or broad.

Transpiration - The process in plants by which water vapor is released into the gaseous environment, primarily through stomata.

Tree - A woody plant >3.0 in. in diameter at breast height, regardless of height (exclusive of woody vines).

Typical - That which normally, usually, or commonly occurs.

Typically adapted - A term that refers to a species being normally or commonly suited to a given set of environmental conditions, due to some feature of its morphology, physiology, or reproduction.

Unconsolidated parent material - Material from which a soil develops, usually formed by weathering of rock or placement in an area by natural forces (e.g. water, wind, or gravity).

Under normal circumstances - As used in the definition of wetlands, this term refers to situations in which the vegetation has not been substantially altered by man's activities.

Uniform vegetation - As used herein, a situation in which the same group of dominant species generally occurs throughout a given area.

Upland - As used herein, any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring within floodplains are more appropriately termed nonwetlands.

Value (soil color) - The relative lightness or intensity of color, approximately a function of the square root of the total amount of light reflected from a surface; one of the three variables of color.

Vegetation - The sum total of macrophytes that occupy a given area.

Vegetation layer - A subunit of a plant community in which all component species exhibit the same growth form (e.g., trees, saplings/shrubs, herbs).

Very long duration (flooding) - A duration class in which the length of a single inundation event is greater than I month.

Very poorly drained - Soils that are wet to the surface most of the time. These soils are wet enough to prevent the growth of important crops (except rice) unless artificially drained.

Watermark - A line on a tree or other upright structure that represents the maximum static water level reached during an inundation event.

Water table - The upper surface of ground water or that level below which the soil is saturated with water. It is at least 6 in. thick and persists in the soil for more than a few weeks.

Wetlands - Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetland boundary - The point on the ground at which a shift from wetlands to nonwetlands or aquatic habitats occurs. These boundaries usually follow contours.

Wetland determination - The process or procedure by which an area is ad udged a wetland or nonwetland.

Wetland hydrology - The sum total of wetness characteristics in areas that are inundated or have saturated soils for a sufficient duration to support hydrophytic vegetation.

Wetland plant association - Any grouping of plant species that recurs wherever certain wetland conditions occur.

Wetland soil - A soil that has characteristics developed in a reducing atmosphere, which exists when periods of prolonged soil saturation result in anaerobic conditions. Hydric soils that are sufficiently wet to support hydrophytic vegetation are wetland soils.

Wetland vegetation - The sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. As used herein, hydrophytic vegetation occurring in areas that also have hydric soils and wetland hydrology may be properly referred to as wetland vegetation.

Woody vine - See liana.

Xerophytic - A plant species that is typically adapted for life in conditions -where a lack of water is a limiting factor for growth and/or reproduction. These species are capable of growth in extremely dry conditions as a result of morphological, physiological, and/or reproductive adaptations.

APPENDIX C: VEGETATION

1. This appendix contains three sections. Section 1 is a subset of the regional list of plants that occur in wetlands, but includes only those species having an indicator status of OBL, FACW, or FAC. Section 2 is a list of plants that commonly occur in wetlands of a given region. Since many geographic areas of Section 404 responsibility include portions of two or more plant list regions, users will often need more than one regional list; thus, Sections 1 and 2 will be published separately from the remainder of the manual. Users will be furnished all appropriate regional lists.

2. Section 3, which is presented herein, describes morphological, physiological, and reproductive adaptations that can be observed or are known to occur in plant species that are typically adapted for life in anaerobic soil conditions.

Section 3 - Morphological, Physiological, and Reproductive Adaptations of Plant Species for Occurrence in Areas Having Anaerobic Soil Conditions

Morphological adaptations

3. Many plant species have morphological adaptations for occurrence in wetlands. These structural modifications most often provide the plant with increased buoyancy or support. In some cases (e.g. adventitious roots), the adaptation may facilitate the uptake of nutrients and/or gases (particularly oxygen). However., not all species occurring in areas having anaerobic soil conditions exhibit morphological adaptations for such conditions. The following is a list of morphological adaptations that a species occurring in areas having anaerobic soil conditions may possess (a partial list of species with such adaptations is presented in Table Cl):

a. Buttressed tree trunks. Tree species (e.g. *Taxodium distichum)* may develop enlarged trunks (Figure Cl) in response to frequent inundation. This adaptation is a strong indicator of hydrophytic vegetation in nontropical forested areas.

b. Pneumatophores. These modified roots may serve as respiratory organs in species subjected to frequent inundation or soil saturation. Cypress knees (Figure C2) are a classic example, but other species (e.g., *Nyssa aquatics, Rhizophora* mangze) may also develop pneumatophores.

c. Adventitious roots. Sometimes referred to as “water roots,” Adventitious roots occur on plant stems in positions where roots normally are not found. Small fibrous roots protruding from the base of trees (e.g. *Salix nigra)* or roots on stems of herbaceous plants and tree seedlings in positions immediately above the soil surface (e.g. *Ludwigia* spp.) occur in response to inundation or soil saturation (Figure C3). These usually develop during periods of sufficiently prolonged soil saturation to destroy most of the root system. *CAUTION: Not all adventitious roots develop as a result of inundation or soil saturation. For example, aerial* *roots on woo(ty vines are not normally produced as a response to inundation or soil saturation.*

d. Shallow root systems. When soils are inundated or saturated for long periods during the growing season, anaerobic conditions develop in the zone of root growth. Most species with deep root systems cannot survive in such conditions. Most species capable of growth during periods when soils are oxygenated only near the surface have shallow root systems. In forested wetlands, windthrown trees (Figure C4) are often indicative of shallow root systems.

e. Inflated leaves, stems, or roots. Many hydrophytic species, particularly herbs (e.g. *Limnobium spongia*, *Ludwigia* spp.), have or develop spongy (aerenchymous) tissues in leaves, stems, and/or roots that provide buoyancy or support and serve as a reservoir or passageway for oxygen needed for metabolic processes. An example of inflated leaves is shown in Figure C5.

f. Polymorphic leaves. Some herbaceous species produce different types of leaves, depending on the water level at the time of leaf formation. For example, Alisma spp. produce strap-shaped leaves when totally submerged, but produce broader, floating leaves when plants are emergent. *CAUTION: Many upland species also produce polymorphic leaves.*

g. Floating leaves. Some species (e.g. *Nymphaea* spp.) produce leaves that are uniquely adapted for floating on a water surface (Figure C6). These leaves have stomata primarily on the upper surface and a thick waxy cuticle that restricts water penetration. The presence of species with floating leaves is strongly indicative of hydrophytic vegetation.

h. Floating stems. A number of species (e.g., *Alternanthera philoxeroides)* produce matted stems that have large internal air spaces when occurring in inundated areas. Such species root in shallow water and grow across the water surface into deeper areas. Species with floating stems often produce adventitious roots at leaf nodes.

i. Hypertrophied lenticels. Some plant species (e.g. *GZeditsia* aquatica) produce enlarged lenticels on the stem in response to prolonged inundation or soil saturation. These are thought to increase oxygen uptake through the stem during such periods.

j. Multitrunks or stooling. Some woody hydrophytes characteristical.ly produce several trunks of different ages (Figure C7) or produce new stems arising from the base of a senescing individual (e.g. *Forestiera acuminata, Nyssa ogechee)* in response to inundation.

k. Oxygen pathway to roots. Some species (e.g. Spartina alterniflora) have a specialized cellular arrangement that facilitates diffusion of gaseous oxygen from leaves and stems to the root system.

<u>Physiological adaptations</u>

4. Most, if not all, hydrophytic species are thought to possess physiological adaptations for occurrence in areas that have prolonged periods of anaerobic soil conditions. However, relatively few species have actually been proven to possess such adaptations, primarily due to the limited research that has been conducted. Nevertheless, several types of physiological adaptations known to occur in hydrophytic species are discussed below, and a list of species having one or more of these adaptations is presented in Table C2. *NOTE: Since it is impossible to detect these adaptations* in the *field, use of this indicator will be limited to observing the species* in the *field and checking the list in Table C2 to determine whether the species is known to have a physiological adaptation for occurrence in areas having anaerobic soil conditions):*

<u>a</u>. <u>Accumulation of</u> malate. Malate, a nontoxic metabolite, accumuYat-es in roots of many hydrophytic species (e.g. *Glyceria maxima, Nyssa sylvatica var. biflora*). Nonwetland species concentrate ethanol, a toxic by-product of anaerobic respiration, when growing in anaerobic soil conditions. Under such conditions, many hydrophytic species produce high concentrations of malate and unchanged concentrations of ethanol, thereby avoiding accumulation of toxic materials. Thus, species having the ability to concentrate malate instead of ethanol in the root system under anaerobic soil conditions are adapted for life in such conditions, while species that concentrate ethanol are poorly adapted for life in anaerobic soil conditions.

<u>b</u>. <u>Increased levels of nitrate reductase</u>. Nitrate reductase is an enzyme involved in conversion of nitrate nitrogen to nitrite nitrogen, an intermediate step in ammonium production. Ammonium ions can accept electrons as a replacement for gaseous oxygen in some species, thereby allowing continued functioning of metabolic processes under low soil oxygen conditions. Species that produce high levels of nitrate reductase (e.g. *Larix* Zaricina) are adapted for life in anaerobic soil conditions.

<u>c</u>. <u>Slight increases in metabolic rates</u>. Anaerobic soil conditions effect short-term increases in metabolic rates in most species. However, the rate of metabolism often increases only slightly in wetland species, while metabolic rates increase significantly in nonwetland species. Species exhibiting only slight increases in metabolic rates (e.g. *Larix laricina, Senecio vulgaris)* are adapted for life in anaerobic soil conditions.

<u>d</u>. <u>Rhizosphere oxidation</u>. Some hydrophytic species (e.g. *Nyssa aquatica, Myrica gale)* are capable of transferring gaseous oxygen from the root system into soil pores immediately surrounding the roots. This adaptation prevents root deterioration and maintains the rates of water and nutrient absorption under anaerobic soil conditions.

<u>e</u>. <u>Ability for root growth</u> <u>in low oxygen tensions</u>. Some species (e.g. *Typha angustifotia, Juncus effusus)* have the ability to maintain root growth under soil oxygen concentrations as low as 0.5 percent. Although prolonged (>1 year) exposure to soil oxygen concentrations

lower than 0.5 percent generally results in the death of most individuals, this adaptation enables some species to survive extended periods of anaerobic soil conditions.

f. Absence of alcohol dehydrogenase (ADH) activity. ADH is an enzyme associated with increased ethanol production. When the enzyme is not functioning, ethanol production does not increase significantly. Some hydrophytic species (e.g. *Potentilla anserina, Polygonum amphibium*) show only slight increases in ADH activity under anaerobic soil conditions. Therefore, ethanol production occurs at a slower rate in species that have low concentrations of ADH.

Reproductive adaptations

5. Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. The following have been identified in the technical literature as reproductive adaptations that occur in hydrophytic species:

a. Prolonged seed viability. Some plant species produce seeds that may remain viable for 20 years or more. Exposure of these seeds to atmospheric oxygen usually triggers germination. Thus, species (e.g., *Taxodium distichum)* that grow in very wet areas may produce seeds that germinate only during infrequent periods when the soil is dewatered. *NOTE: Many upland species also have prolonged seed viability, but the trigger mechanism for germination is not exposure to atmospheric oxygen.*

b. Seed germination under low oxygen concentrations. Seeds of some hydrophytic species germinate when submerged. This enables germination during periods of early-spring inundation, which may provide resulting seedlings a competitive advantage over species whose seeds germinate only when exposed to atmospheric oxygen.

c. Flood-tolerant seedlings. Seedlings of some hydrophytic species (e.g. *Fraxinus pennsylvanica)* can survive moderate periods of total or partial inundation. Seedlings of these species have a competitive advantage over seedlings of flood-intolerant species.

Table C1

Partial List of Species With Known Morphological Adaptations for Occurrence in Wetlands*

Species	Common Name	Adaptation
Acer negundo	Box elder	Adventitious roots
Acer rubrum	Red maple	Hypertrophied lenticels
Acer saccharinum	Silver maple	Hypertrophied lenticels: adventitious roots (juvenile plants)
Alisma spp.	Water plantain	Polymorphic leaves
Alternanthera philoxeroides	Alligatorweed	Adventitious roots; inflated, floating stems
Avicennia nitida	Black mangrove	Pneumatophores; hypertrophied lenticels
Brasenia schreberi	Watershield	Inflated, floating leaves
Cladium mariscoides	Twig rush	Inflated stems
Cyperus spp. (most species)	Flat sedge	Inflated stems and leaves
Eleocharis spp. (most species)	Spikerush	Inflated stems and leaves
Forestiera acuminata	Swamp privet	Multi-trunk, stooling
F-raxinus pennsylvanica	Green ash	Buttressed trunks; adventitious roots
Gleditsia aquatics	Water locust	Hypertrophied lenticels
Juncus spp.	Rush	Inflated stems and leaves
Limnobium spongia	Frogbit	Inflated, floating leaves
Ludwigia spp.	Waterprimrose	Adventitious roots; inflated floating stems
Menyanthes trifoliata	Buckbean	Inflated stems (rhizome)
Myrica gale	Sweetgale	Hypertrophied lenticels
Nelumbo spp.	Lotus	Floating leaves
Nuphar spp.	Cowlily	Floating leaves
Nymphaea spp.	Waterlily	Floating leaves
Nyssa aquatics	Water tupelo	Buttressed trunks; pneumatophores; adventitious roots
Nyssa ogechee	Ogechee tupelo	Buttressed trunks; multi-trunk; stooling

* Many other species exhibit one or more morphological adaptations for occurrence in wetlands. However, not all individuals of a species will exhibit these adaptations under field conditions, and individuals occurring in uplands characteristically may not exhibit them.

Table C1 (Continued)

Partial List of Species With Known Morphological Adaptations for Occurrence in Wetlands*

Species	Common Name	Adaptation
Nyssa sylvatica var. *biflora*	Swamp blackgum	Buttressed trunks
Platanus occidentalis	Sycamore	Adventitious roots
Populus deltoides	Cottonwood	Adventitious roots
Quercus laurifolia	Laurel oak	Shallow root system
Quercus palustris	Pin oak	Adventitious roots
Rhizophora mangle	Red mangrove	Pneumatophores
Sagittaria spp.	Arrowhead	Polymorphic leaves
Salix spp.	Willow	Hypertrophied lenticels; adventitious roots; oxygen pathway to roots
Scirpus spp.	Bulrush	Inflated stems and leaves
Spartina alterniflora	Smooth cordgrass	Oxygen pathway to roots
Taxodium distichum	Bald cypress	Buttressed trunks; pneumatophores

* Many other species exhibit one or more morphological adaptations for occurrence in wetlands. However, not all individuals of a species will exhibit these adaptations under field conditions, and individuals occurring in uplands characteristically may not exhibit them.

Table C2
Species Exhibiting Physiological Adaptations for Occurrence in Wetlands

Species	Physiological Adaptation
Alnus incana	Increased levels of nitrate reductase; malate accum.
Alnus rubra	Increased levels of nitrate reductase
Baccharis viminea	Ability for root growth in low oxygen tensions
Betula pubescens	Oxidizes the rhizosphere; malate accumulation
Carex arenaria	Malate accumulation
Carex flacca	Absence of ADH activity
Carex lasiocarpa	Malate accumulation
Deschampsia cespitosa	Absence of ADH activity
Filipendula ulmaria	Absence of ADH activity
Fraxinus pennsyzvanica	Oxidizes the rhizosphere
Glyceria maxima	Malate accumulation; absence of ADH activity
Juncus effusus	Ability for root growth in low oxygen tensions; absence of ADH activity
Larix laricina	Slight increases in metabolic rates; increased levels of nitrate reductase
Lobelia dortmanna	Oxidizes the rhizosphere
Lythrum salicaria	Absence of ADH activity
Molinia caerulea	Oxidizes the rhizosphere
Myrica gale	Oxidizes the rhizosphere
Nuphar lutea	Organic acid production
Nyssa aquatica	Oxidizes the rhizosphere
Nyssa sylvatica var. biflora	Oxidizes the rhizosphere; malate accumulation
Phalaris arundinacea	Absence of ADH activity; ability for root growth in low oxygen tensions
Phragmites australis	Malate accumulation
Pinus contorta	Slight increases in metabolic rates; increased levels of nitrate reductase
Polygonum amphibium	Absence of ADH activity
Potentilla anserina	Absence of ADH activity; ability for root
Ranunculus flammula	Malate accumulation; absence of ADH activity
Salix cinerea	Malate accumulation
Salix fragilis	Oxidizes the rhizosphere
Salix lasiolepis	Ability for root growth in low oxygen tensions
Scirpus maritimus	Ability for root growth in low oxygen tensions
Senecio vulgaris	Slight increases in metabolic rates
Spartina alterniflora	Oxidizes the rhizosphere
Trifoliun subterraneum	Low ADH activity
Typha angustifolia	Ability for root growth in low oxygen tensions

APPENDIX D: HYDRIC SOILS

1. This appendix consists of two sections. Section 1 describes the basic procedure for digging a soil pit and examining for hydric soil indicators. Section 2 is a list of hydric soils of the United States.

Section 1 - Procedures for Digging a Soil Pit and Examining for Hydric Soil Indicators

Digging a soil pit

2. Apply the following procedure: Circumscribe a 1-ft-diameter area, preferably with a tile spade (sharpshooter). Extend the blade vertically downward, cut all roots to the depth of the blade, and lift the soil from the hole. This should provide approximately 16 inches of the soil profile for examination. *Note: Observations are usually made immediately below the A-horizon or 10 inches (whichever is shallower).* In many cases, a soil auger or probe can be used instead of a spade. If so, remove successive cores until 16 inches of the soil profile have been removed. Place successive cores in the same sequence as removed from the hole. *Note: An auger or probe cannot be effectively used when the soil profile is loose, rocky, or contains a large volume of water (e.g. peraquic moisture regime).*

Examining the soil

3. Examine the soil for hydric soils indicators (paragraphs 44 and/or 45 of main text (for sandy soils)). *Note: It may not be necessary to conduct a classical characterization (e.g. texture, structure, etc.) of the soil.* Consider the hydric soil indicators in the following sequence *(Note: THE SOIL EXAMINATION CAN BE TERMINATED WHEN A POSITIVE HYDRIC S01-L INDICATOR IS FOUND)* :

Nonsandy soils.

a. Determine whether an organic soil is present (see paragraph 44 of the main text). If so, the soil is hydric.

b. Determine whether the soil has a histic epipedon (see paragraph 44 of the main text). Record the thickness of the histic epipedon on DATA FORM 1.

c. Determine whether sulfidic materials are present by smelling the soil. The presence of a “rotten egg” odor is indicative of hydrogen sulfide, which forms only under extreme reducing conditions associated with prolonged inundation/soil saturation.

d. Determine whether the soil has an aquic or peraquic moisture regime (see paragraph 44 of the main text). If so, the soil is hydric.

e. Conduct a ferrous iron test. A calorimetric field test kit has been developed for this purpose. A reducing soil environment is present when the soil extract turns pink upon addition of α-α-dipyridil.

f. Determine the color(s) of the matrix and any mottles that may be present. Soil color is characterized by three features: hue, value, and chroma. Hue refers to the soil color in relation to red, yellow, blue, etc. Value refers to the lightness of the hue. Chroma refers to the strength of the color (or departure from a neutral of the same lightness). Soil colors are determined by use of a Munsell Color Book (Munsell Color 1975). Each Munsell Color Book has color charts of different hues, ranging from 10R to 5Y. Each page of hue has color chips that show values and chromas. Values are shown in columns down the page from as low as 0 to as much as 8, and chromas are shown in rows across the page from as low as 0 to as much as 8. In writing Munsell color notations, the sequence is always hue, value, and chroma (e.g. 10YR5/2). To determine soil color, place a small portion of soil (moistened) in the openings behind the color page and match the soil color to the appropriate color chip. *Note: Match the soil to the nearest color chip.* Record on DATA FORM 1 the hue, value, and chroma of the best matching color chip. *CAUTION: Never place soil on the face or front of the color page because this might smear the color chips.* Mineral hydric soils usually have one of the following color features immediately below the A-horizon or 10 inches (whichever is shallower):

(1) Gleyed soil.

Determine whether the soil is gleyed. If the matrix color best fits a color chip found on the gley page of the Munsell soil color charts, the soil is gleyed. This indicates prolonged soil saturation, and the soil is highly reduced.

(2) Nongleyed soil.

(a) Matrix chroma of 2 or less in mottled soils. (moistened)

(b) Matrix chroma of 1 or less in unmottled soils. (moistened)

(c) Gray mottles within 10 inches of the soil surface in dark (black) mineral soils (e.g., Mollisols) that do not have characteristics of (a) or (b) above.

Soils having the above color characteristics are normally saturated for significant duration during the growing season. However, hydric soils with significant coloration due to the nature of the parent material (e.g. red soils of the Red River Valley) may not exhibit chromas within the range indicated above. In such cases, this indicator cannot be used.

g. Determine whether the mapped soil series or phase is on the national list of hydric soils (Section 2). *CAUTION: It will often be necessary to compare the profile description of the soil with that of the soil series or phase indicated on the soil map to verify that the soil was correctly mapped. This is especially true when the soil survey indicates the presence of inclusions or when the soil is mapped as an association of two or more soil series.*

h. Look for iron and manganese concretions. Look for small (>0.08-inch) aggregates within 3 inches of the soil surface. These are usually black or dark brown and reflect prolonged saturation near the soil surface.

Sandy soils.

Look for one of the following indicators in sandy soils:

a. A layer of organic material above the mineral surface or high organic matter content in the surface horizon (see paragraph 45a of the main text). This is evidenced by a darker color of the surface layer due to organic matter interspersed among or adhering to the sand particles. This is not observed in upland soils due to associated aerobic conditions.

h. Streaking of subsurface horizons (see paragraph 45c of the main text). Look for dark vertical streaks in subsurface horizons. These streaks represent organic matter being moved downward in the profile. When soil is rubbed between the fingers, the organic matter will leave a dark stain on the fingers.

c. Organic pans (see paragraph 45b of the main text). This is evidenced by a thin layer of hardened soil at a depth of 12 to 30 inches below the mineral surface.

Section 2. Hydric Soils of the United States

(Note: not included here as the list from 1987 is out of date)

(Contact your County or State NRCS office)

Modifications and Clarifications to the 1987 Wetland Delineation Manual

These modifications and clarifications were issued after Congress removed the 1989 Manual from use in making wetland determinations.

CECW-OR 23 August 1991
MEMORANDUM

SUBJECT: Wetlands Delineation and the 1992 Energy and Water Development Appropriations Act

1. The 1992 Energy and Water Development Appropriations Act (Act) contains the following provisions:

a. None of the funds of the Act shall be used to identify or delineate any land as a “water of the United States” under the Federal Manual for Identifying and Delineating Jurisdictional Wetlands that was adopted in January 1989 (1989 Manual) or any subsequent manual not adopted in accordance with the requirements for notice and public comment of the rule-making process of the Administrative Procedure Act.

b. In addition, regarding Corps of Engineers ongoing enforcement actions and permit applications involving lands which the Corps or the Environmental Protection Agency (EPA) has delineated as “waters of the United States” under the 1989 Manual, and which have not yet been completed on the date of enactment of the Act (i.e., August 17, 1991), the landowner or permit applicant shall have the option to elect a new delineation under the Corps 1987 Wetlands Delineation Manual (1987 Manual) (Technical Report Y-87-1, Waterways Experiment Station (WES), January 1987) or completion of the permit process or enforcement action based on the 1989 Manual delineation, unless the Corps of Engineers determines, after investigation and consultation with other appropriate parties, including the landowner or permit applicant, that the delineation would be substantially the same under either the 1987 or the 1989 Manual.

c. None of the funds in the Act shall be used to finalize or implement the proposed regulations to amend the fee structure for the Corps of Engineers regulatory program which were published in Federal Register, Vol. 55, No. 197, Thursday, October 11, 1991.

The provisions of the Act make it necessary for the Corps to change some regulatory procedures, as described below. This guidance has been reviewed and approved by the Office of the Assistant Secretary of the Army for Civil Works.

2. After August 17, 1991, initial delineations will be made using the Corps 1987 Manual. WES will provide field of floes copies of the 1987 Manual. Supplementary guidance will be provided by CECW-OR under separate cover.

3. The following general guidance will apply:

a. For the purposes of this guidance, ongoing permit applications are defined as: formal individual permit applications (ENG FORM 4345), letters requesting verification of authorization under regional or nationwide permits, or predischarge notices as required by nationwide permits, received before August 17, 1991, where no permit has been issued, verified or denied, and existing jurisdictional delineations where no permit has been requested. Individual permit decisions are considered final when the District Engineer signs the decision document. The 20 day predischarge notification clock (nationwide permit 26) will be stopped and the information considered incomplete until the options are explained and the general permitted responds, at which time the clock restarts.

b. Only applications involving section 404, where the jurisdictional delineation (Corps or EPA) involved wetlands identified as waters of the United States using the 1989 Manual are subject to the options provided by the Act.

4. Landowners/applicants involved in ongoing applications, as defined in 3. a. & b., will be notified of their options, as follows:

a. The district may investigate and determine, for some or all of the district's area, on a generic or case-by-case basis, whether delineations using the 1989 Manual are substantially the same or substantially different than would have been made using the 1987 Manual. In every case the Corps must notify the landowner/applicant by letter of the Corps initial determination and provide the landowner/applicant an opportunity for consultation (not to exceed 30 days), before proceeding with the final determination in accordance with paragraph b. or c. below. In the interest of timeliness, districts are encouraged to use generic initial determinations and form letters requesting the landowner's/applicant's consultation.

b. Where, after considering all applicable information (including any obtained during consultation with the landowner/applicant and other appropriate parties), the Corps determines that a delineation using the 1989 Manual is substantially the same as would have been made using the 1987 Manual, each landowner/applicant will be notified by letter of the Corps' determination. The Corps letter will inform the landowner/applicant that the delineation will be considered binding and the evaluation of any formal application will proceed based on this delineation.

c. Where the Corps determines that delineations using the 1989 Manual are substantially different than would have been made using the 1987 Manual, each landowner/applicant will be notified by letter of the Corps determination. The letter will provide the landowner/applicant the following options: (1) proceeding with the ongoing application using the delineation made under the 1989 Manual; or (2), electing to have the area redelineated using the 1987 Manual. The Corps letter will also include an indication of the approximate time required by the district to complete a redelineation of the area using the 1987 Manual and a statement that the landowner/applicant must reply in writing concerning their choice of the above options. Evaluation, including a redelineation if necessary, of any application will proceed upon receipt of the landowner's/applicant's letter.

5. Where an ongoing permit application, involving wetlands delineations made using the 1989 Manual, does not fit the circumstances described above, districts will compare the old (1989 Manual) delineation with the provisions of the 1987 Manual to determine if there would be a substantial change in the area delineated. If there would be a substantial change, the landowner/applicant will be provided the opportunity to have a new delineation made using the 1987 Manual.

6. The final decision concerning whether a substantial difference exists between delineations based on the use of the 1989 and the 1987 Manuals rests solely with the Corps. The Corps may consult with other experts in delineating wetlands, such as the Waterways Experiment Station, EPA, the Fish and Wildlife Services or the Soil Conservation Service, in reaching a decision Landowners/applicants and other appropriate parties may provide the Corps documentation for use in tile decision making process, but in all cases the Corps district decision will be final.

7. The Office of Counsel (CECC-K) is providing through Counsel channels guidance concerning the steps to be taken for ongoing enforcement actions that fall within the provision of the Act. A copy of that guidance is enclosed for reference and use.

8. The Army will take no further action, at this time, on its proposal to amend regulatory fees, as published in the Federal Register, Vol. 55, No. 197, Thursday, October 11,1990. No decision has been made concerning future actions to change the fee structure.

FOR THE DIRECTOR OF CIVIL WORKS
SIGNED

JOHN P. ELMORE Chief
Operations, Construction and Readiness Division
Directorate of Civil Works

CECW-OR 27 August 1991
MEMORANDUM

SUBJECT: Implementation of the 1987 Corps Wetland Delineation Manual

1. The purpose of this memorandum is to provide guidance concerning the implementation of the 1987 Corps of Engineers Wetlands Delineation Manual (1987 Manual)(Waterways Experiment Station Technical Report Y-87-1, January 1987). This guidance supersedes the guidance provided in John Studt's 21 August memorandum to the field. Further, this guidance is to be used in conjunction with memoranda dated 23 August, 1991, concerning wetlands

delineation and the 1992 Energy and Water Development Appropriations Act (Act). In accordance with the Act and the 23 August memoranda, the 1987 Manual is now used to delineate potentially jurisdictional wetlands in place of the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands.

2. The guidance in paragraph 3 will be followed in the application of the 1987 Manual.

3. Use of the 1987 Manual is mandatory, however, the Appendices are modified as discussed below:

a. Appendix A: The definition of “under normal circumstances” provided in this glossary is modified pursuant to Regulatory Guidance Letter (RGL) #90-7;

b. Appendix B: Use of the data sheets provided is recommended, but is not mandatory;

c. Appendix C: Sections 1 and 2 - These sections are replaced with the May 1988 National List of Plant Species That Occur in Wetlands and associated regional lists (U.S. Fish and Wildlife Service, Summary 88(24) and Biological Reports 88(26.1- 26.13). The referenced lists will be used to determine the wetland indicator status of plant species and any subsequent updates will be adopted;

d. Appendix D: Section 2 - The most recent Hydric Soils of the United States list developed by the U.S. Department of Agriculture, Soil Conservation Service (SCS), will be used to determine if a particular soil has been designated as hydric by the National Technical Committee for Hydric Soils. The current hydric soils list was published by SCS in December 1987, and any subsequent updates will be adopted.

4. All other current policy considerations concerning wetlands in general (e.g., RGLs) remain in effect during interim use of the 1987 Corps Manual.

5. The Waterways Experiment Station will provide each division and district copies of the 1987 Manual. In addition, a copy of the Environmental Effects of Dredging Technical Notes (EEDP-04-7) dated January 1988, an article which summarizes the methods for delineating wetlands as presented in the 1987 Manual, will follow under separate cover. The article does not reflect the guidance contained in this memorandum; however, it does provide a general overall summary of the 1987 Manual.

JOHN P. ELMORE
Chief, Operations, Construction and Readiness Division
Directorate of Civil Works

SUBJECT: Questions & Answers on 1987 Manual

1. In response to questions from the field, the Qs & As on the 1987 Corps of Engineers Wetland Delineation Manual (1987 Manual) have been further clarified (in particular, questions #7 and #8). We clarified that for saturated-only systems, the saturation must be to the surface for the appropriate number of days during the growing season. Furthermore, we clarified that the number of days for inundation or saturation to the surface are consecutive, not cumulative. The enclosed Qs and As dated 7 October, 1991 supersede those previously distributed under the cover memorandum of 16 September, 1991.

2. I want to again emphasize that the 1987 Manual stresses the need to verify that all three parameters exist prior to identifying and delineating an area as a wetland. Further, the 1987 Manual focuses on hydrology (i.e., inundation and/or saturation to the surface). In situations where hydrology is questionable, the 1987 Manual requires stronger evidence regarding the hydrophytic nature of the vegetation. The 1987 Manual also stresses the need to use sound professional judgment, providing latitude to demonstrate whether an area is a wetland or not based on a holistic and careful consideration of evidence for all three parameters. As indicated in the 1987 Manual and the attached Qs and As, careful professional judgment must be used in situations where indicators of hydrology are not clear and the dominant vegetation is facultative.

JOHN F. STUDT
Chief, Regulatory Branch
Operations, Construction and Readiness Division
Directorate of Civil Works
October 7, 1991

Questions and Answers on 1987 Corps of Engineers Manual

1.Q. What is the definition and practical interpretation of the growing season which should be used in the application of the 1987 Manual?

A. The 1987 Manual defines the growing season as “the portion of the year when soil temperatures at 19.7 inches below the soil surface are higher than biological zero (5 degrees C)”. This is the definition found in Soil Taxonomy, and growing season months can be assumed based on temperature regimes (e.g., mesic: March- October). The 1987 Manual further states this period can be approximated by the number of frost-free days. The Waterways Experiment Station (WES) indicates that the county soil surveys, which utilize 32 degrees, provide the growing season for each county. There is some flexibility in the determination of the growing season in the 1987 Manual. The growing season, based on air temperature in the county soil surveys can be approximated as the period of time between the average date of the first killing frost to average date of the last killing frost, which sometimes does not accurately reflect the period of time when the soil temperatures are higher than biological zero. The source of the information may vary, however, the growing season generally is to be determined by the number of killing frost-free days. In certain parts of the country where plant communities in general have become more adapted to regional conditions, local means of determining growing season may be more appropriate and can be used.

2.Q. Should the determination of hydric soils be based on the presence of an indicator listed in the 1987 Manual higher on the list than the soils list or on the fact that a soil appears on the Hydric Soils of the United States. an indicator which is listed as less reliable in the hierarchy of hydric soil indicators in the 1987 Manual?

A. The order of soil indicators reliability as listed in the 1987 Manual remains valid and will be used. The reliability of the indicators is based on the fact that field verification of a soil's hydric characteristics is more accurate than mapping or soils lists. Soils listed on the most recent Hydric Soils list have been determined by the National Technical Committee for Hydric Soils to meet the criteria for hydric soils. When in the field, verification that mapped hydric soils actually exhibit indicators identified in me 1987 Manual for hydric soils is recommended. Although a soil may appear on the list of hydric soils, inclusions or disturbances may alter this designation to some degree, so the list alone may not always be reliable. In obvious wetlands, if the soil is on the list and the area meets the hydrology and vegetation criteria, the area is a wetland. As found with me 1989 Manual, one cannot rely solely on the fact that a soil is mapped as hydric in making the wetland delineation. all cases, best professional judgment should be used. The county lists provide valuable information, but again should not solely be relied on to make a final determination as to whether hydric soils are present. Verification of the presence of at least one of the indicators for hydric soils on the list (pages. 30-34) is required in conjunction with the use of a county soils list. The national soils list to be used has recently been updated by the NTCHS (June 1991), and this list will be used by the Corps in conjunction with the 1987 Manual.

3.Q. How should the 1987 Manual be applied with respect to the definition of “normal circumstances”?

A. The definition of “under normal circumstances” in the 1987 Manual states briefly that “this term refers to situations in which the vegetation has not been substantially altered by man's activities”. As stated in item #3 of the memorandum of 27 August, 1991, the definition of normal circumstances used in the 1987 Manual has been clarified by Regulatory Guidance Letter (RGL) 90-7. Although this RGL deals primarily with agricultural activities in wetlands, paragraphs #3 & #4 discuss normal circumstances with respect to all areas potentially subject to 404. Further guidance on normal circumstances is found in RGL 86-9 regarding construction sites and irrigated wetlands. The guidance should be followed in preferential sequence of; 1) RGL 90-7, 2) RGL 86-9, and 3) 1987 Manual.

4.Q. Does the vegetation criteria in the 1987 manual require the use of the facultative(FAC) - neutral vegetation test (i.e., count the dominant species wetter and drier than FAC, and ignore all of the FACs in the vegetation determination)?

A. While the 1987 Manual mentions use of the FAC - neutral test for determining the presence of wetland vegetation in several places, the first indicator of wetland vegetation criteria is the presence of more than 50% of the dominant plant species FAC or wetter (not including FAC- species, which are considered non-wetland indicators under the 1987 manual). The indicator status of each of the dominant species is determined by consulting the current regional plant list published by the FWS. The 1987 Manual provides an option in this determination of applying the FAC - neutral test in cases where the delineator questions the status designation of a particular plant species on a subregional basis (see page 233. As always, any deviation from established protocol requires documentation. The FAC - neutral option may also prove useful in questionable areas or when the determination relies on the vegetation call in an area that is not otherwise an obvious wetland. Specifically, the 1987 Manual is replete with cautions and guidance that the Corps regulators must be confident that the area is wetland when the area has a FAC-dominated plant community. Uncertainty regarding the status of an area as a wetland where the dominant vegetation is FAC would be a valid reason to use the FAC - neutral option. Situations exist where use of the FAC - neutral method will not serve to provide any additional information as to the hydrophytic nature of the plant community (e.g., all species are FAC or there is an equal number of species wetter and drier than FAC such that they cancel each other out). In these cases, it is appropriate to consider the + and - modifiers associated with some FAC species, which indicate the species frequency of occurrence in a wetter or drier environment, in the overall assessment of the vegetation parameter. Documentation supporting reasons for using the FAC - neutral option must always be provided and acceptance of delineations, as always, remains up to the discretion of the District.

5.Q. Can indicators for any of the criteria in the 1989 Manual be used as indicators for verification of the same or other criteria presented in the 1987 Manual?

A. The indicators of hydrology in the 1987 Manual differ from those of the 1989 Manual, and are not interchangeable. In particular, the hydrology determination in the 1989 Manual often relied on evidence of properties from the soil and/or vegetation parameters. Indicators provided in the 1989 Manual for field verification of a certain criterion that are not presented in the 1987 Manual for application with the same criterion cannot be used except as additional information in support of the verification. It is unlikely that an area which is a wetland will fail to meet a criteria utilizing the indicators which are listed in the 1987 Manual.

6.Q. Will the other Federal agencies be utilizing the 1987 Manual in their wetland determinations as well as the Corps of Engineers?

A. EPA has concurred with the Corps using the 1987 Manual for all actions. Further, we understand that EPA will likely use the 1987 Manual for EPA's delineations as well. The other agencies (SCS & FWS) typically do not make delineations for purposes of Section 404.

7.Q. To what depth should one look in the soil to find indicators of hydrology?

A. In accordance with the 1987 Manual's guidance on reading soil color (D2), after digging a 16” soil pit observations should be made immediately below the A-horizon or within 10” of the soil surface (whichever is shallower). This guidance pertains to observations of indicators of the soil criterion. For indicators of saturation to the surface in the hydrology criterion, observations are made within a major portion of the root zone (usually within 12”), again in the 16” pit. Visual observation of standing water within 12” of the surface may, under certain circumstances, be considered a positive indicator of wetland hydrology (i.e., saturation to the surface) as stated on page 38. When using water table within 12” of the surface as an indicator of hydrology, care must be used to consider conditions and the soil types (i.e., to ensure that the capillary ability of the soil texture is considered in regard to the water table depth). Vegetation and soil properties used in the determination of hydrology in the 1989 Manual, are typically not available for field verification of this criterion in the 1987 Manual. However, the 1987 Manual allows for some flexibility with regards to indicators of wetland hydrology, and states that indicators are not limited to those listed on pages 37-41. Other indicators, such as some type of recorded data (e.g., soil surveys which provide specific and strong information about the soil series' hydrology) may be used to verify a wetland hydrology call in a saturated but not inundated area. Appropriate documentation to support the call is necessary in all cases.

8.Q. What length of time must wetland hydrology be present for an area to be determined a wetland under the 1987 Manual?

A. In the hydrology section of Part III, the 1987 Manual discusses the hydrologic zones which were developed through research at WES to indicate the duration of inundation and/or soil saturation during the growing season. Wetland hydrology is defined in the 1987 Manual as the sum total of wetness characteristics in areas that are inundated or have saturated soils for a sufficient duration to support hydrophytic vegetation. The 1987 Manual discusses hydrology in terms of a percent of the growing season when an area is wet (page 36). Generally speaking, areas which are seasonally inundated and/or saturated to the surface for more than 12.5% of the growing season are wetlands. Areas saturated to the surface between 5% and 12.5% of the growing season are sometimes wetlands and sometimes uplands. Areas saturated to the surface for less than 5% of the growing season are non-wetlands. The percent of growing season translates to a number of days, depending on the length of the growing season in any particular area (e.g., 12.5% of a 170-day growing season is 21 consecutive days). This system for classification of hydrologic zones based on stream gauge data transformed to mean sea level elevations is useful as a guide to time frames of wetness sufficient to create wetlands. The length of time an area is wet for hydrology is based on consecutive days during the growing season. If an area is only saturated to the surface for a period of between 5% and 12.5% of the growing season and no clear indicators of wetland hydrology exist (i.e., recorded or field data; also see answer #7 above), then the vegetation test should be critically reviewed. Specifically, in such cases a vegetative community dominated by FAC species would generally indicate that the area is not a wetland (unless the FAC- neutral test was indicative of wetlands). The actual number of days an area is inundated and/or saturated to the surface for an area to be called a wetland varies; the identification of an indicator of recorded or field data is necessary to document that an area meets the wetland hydrology criterion of the 1987 Manual (i.e., the list of hydrology indicators on pages 37-41, which are to be used in the preferential order shown; also see question #7). The number of days specified in the June 1991 Hydric Soils of the United States (i.e., usually more than 2 weeks during the growing season) as the criteria for hydric soils pertains to hydric soils and not the hydrology criterion of the 1987 Manual, which varies with the growing season as previously discussed.

9.Q. Will delineations made now under the 1987 Corps Manual be subject to redelineation under the revised 1989 Manual after it is finalized?

A. Wetland determinations made after 17 August, 1991, are made following the guidance provided in the 1987 Corps Manual and memoranda of 23 and 27 August, 1991 and these questions and answers. These delineations are subject to and remain valid for the period of time described in RGL 90-6. As discussed in Issue #4 of the preamble to the proposed revisions to the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands issued 14 August in the Federal Register, wetland calls made after the issuance date of these revisions but prior to finalization of the revised manual may be subject to redelineation under the new manual at the request of the landowner. Final actions will generally not be reopened. Wetland calls made under the 1989 Manual are already subject to redelineation under the 1987 Manual in accordance with the guidance issued 23 August. Until such time as the proposed revisions to the 1989 Manual are finalized, it is unclear as to what effect, if any, the equity provision in the preamble to the proposed revisions will have on the 404 program. Therefore, written delineations made with the 1987 Manual will explicitly state they are final for a period of three years as specified in RGL 90-6, subject to any equity provisions that may be adopted as part of implementation of the final revisions to the 1989 Manual.

10.Q. How does the 1987 Manual compare to the 1989 Manual or its proposed revisions?

A. The various manuals have been compared by WES and the side-by-side comparison is available for your information.

11.Q. Will applicants be subject to delay with use of the 1987 Manual?

A. During the initial transition to use of the 1987 Manual for wetland delineations as of 17 August, some delays are unavoidable. The Corps field offices must adhere to the procedures provided in the 23 August memorandum, while striving to expedite the review process to the extent possible. No offices should indicate that they cannot operate due to lack of guidance during this transition period. HQUSACE recognizes that there will be delays associated with implementing the Corps 1987 Manual and we will take these delays into account when reviewing district application performance data (e.g., % of IPs evaluated in 60 days). Districts should not stop the permit clock, but should indicate where substantial impacts to permit evaluation performance have resulted from implementation of the 1987 Manual.

Field testing questions:

1.Q. Which procedure should be followed for the field testing since the guidance provided initially states both the routine and comprehensive?

A. Since the criteria for determining the presence of hydrophytic vegetation is proposed to be the prevalence index, the comprehensive method must be used as neither the routine nor intermediate on-site methods will yield a prevalence index. The point intercept sampling procedure on pages 40471-40473 yields a PI directly and is stated that it is the procedure to be used in the determination of the PI on page 40455 of the Federal Register. Routine or intermediate on-site determinations methods can be used for determination of the limits of hydric soils (Step 1, page 40471) and wetland hydrology (Step 16, page 40473) necessary to be considered in conjunction with the vegetation assessment as described on pages. 40472-40473 (Steps 6-15). Documentation of deviations from the prescribed methodology should be noted in the field testing reports.

2.Q. Must all plants or just the dominants be looked at to determine the prevalence index (data sheets say dominants while procedure looks at individuals)?

A. All plant species, not just dominant plants, are considered in the prevalence index determination of hydrophytic vegetation. However, the point intercept sampling procedure in the comprehensive methods which is used to yield a PI requires the identification of only those species which are intercepted by an imaginary line extended from the points every 2 feet along the transect.

3.Q. How is one to compare site determinations made using the 1989 Manual and the proposed revisions when different methods (e.g., routine vs. comprehensive) were used?

A. Comparing the data from delineations previously performed under the 1989 Manual (regardless of the method employed at the time) with the data recorded during the field testing of the proposed revisions of the 1989 Manual, should be done to the level of detail possible. The resultant delineations from these different manuals and/or procedures are what these tests are comparing; some discussion of any differences and why they exist (e.g., changes in the criteria, indicators, and methodologies utilized) should be provided based on the teams or individual's observations, experience and best professional judgment.

4.Q. Are the regional indicators listed in the proposed revisions to the 1989 Manual the same for soils and hydrology?

A. Yes, they are proposed for use as an indicator of the soil criterion as well as corroborative information for use with the secondary indicators of hydrology.

5.Q. Do you always need to prove 21 days saturation?

A. Yes, but identification of one or more of the primary indicators of hydrology is proof that the area meets the 21 day hydrology criterion.

6.Q. Is there a map that goes with the regional indicators?

A. Yes, the regional indicators of soil saturation continue to be developed and are being proposed for use with the manual for the four Department of Agriculture, Soil Conservation Service main regions; Northeast, South, Midwest and West (see enclosed map).

7.Q. Can the soils list be used as corroborative information with a secondary indicator for verification that the hydrology criterion is met?

A. No, only the information listed can be used. Comments on the appropriateness of the information and suggestions for others should be provided during the comment period.

8.Q. Can blackened leaves be used as hydrology indicator?

A. No, only those listed in the list of hydrology indicators.

9.Q. Must three transects always be evaluated for the methodology described to determine the prevalence index?

A. No, in most cases, only 1 transect is required for purposes of these tests. The following guidance provides the exact circumstances under which options concerning the number of transects are permitted before proceeding to Step 11 and repeating the two transects: - If the prevalence index value determined for the first transect is less than 2.5 or more than 3.5, and, in the professional judgment of the investigators repeated transects are likely to provide the same result, the investigators need not repeat the transect. In cases where this shortened method is used, this should be reflected in the results. While the agencies recognize that this change in protocol does not strictly adhere to the method contained in the revised manual, it is nevertheless a practical step to reduce the demands of using the comprehensive method.

10.Q. How are the frost-free dates determined under the proposed revisions which the field testing should utilize?

A. The frost-free dates are to be determined by using the summary of growing season data developed by NOAA referred to on the first page of the Interagency Protocol. This information is available for each state and will be provided to the Divisions for distribution to the field in the near future.

11.Q. Must sites visited and data collected prior to the recently released revised data sheets be redone using the new forms?

A. No, both versions collect essentially the same data. Sections I (Background) and VI (Wetland Evaluation) of the revised data sheets are identified as sections that will generally apply to the entire site, and in most cases will not have to be repeated for each individual transect. Besides the reorganization of these forms, revisions have been made to collect data on the 1987 Manual, include questions on the regional indicators, and clarify the functions and values assessments.

12.Q. How should the Corps provide comments on the proposed revisions to the 1989 manual?

A. Each District is to submit comments to their Division office for consolidation into one response to EPA (in accordance with the Federal Register issued 14 August) prior to the end of the comment period (currently 15 October); a copy of these comments are to be provided to CECW-OR. Each Division is encouraged to provide comments to HQUSACE at least one week prior to the end of the comment period so that key issues and concerns raised may be stressed in the comments which will come from Headquarters. In addition, the Corps has the opportunity to comment through the interagency field testing reports, which are due to HQUSACE by 1 November. HQUSACE and WES will continue to participate in interagency efforts to finalize revisions to the 1989 Manual until such time as the revisions become final. There is consideration being given as to the need for a time extension to the comment period (and therefore the field testing). If this becomes final, we will let the Divisions know as soon as possible.

13.Q. Is the information gathered during the inter agency field testing available for release to the public and may the public accompany the teams in the field?

A. The interagency field testing of the proposed revisions to the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands published in the 14 August, 1991 Federal Register is being performed to evaluate the technical validity, practical utility, and clarity of understanding of the proposed revisions. The results of the field testing will be taken into consideration during the final revisions to the 1989 Manual. The information gathered during the field testing is considered to be predecisional by HQUSACE and inappropriate for release prior to the finalization of the proposed revisions. Counsel is preparing written guidance on this issue and it will be distributed to the Divisions as soon as possible.

14.Q. Will delineations made now under the 1987 Corps Manual be subject to redelineation under the revised 1989 Manual after it is finalized?

A. Wetland determinations made after 17 August, 1991, are made following the guidance provided in the 1987 Corps Manual and memoranda of 23 and 27 August, 1991. These delineations are subject to and remain valid for the period of time described in RGL 9-6. As discussed in Issue #4 of the preamble to the proposed revisions to the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands issued 14 August in the Federal Register, wetland calls made after the issuance date of these revisions but prior to finalization of the revised manual may be subject to redelineation under the new manual at the request of the landowner. Final actions will generally not be reopened. Wetland calls made under the 1989 Manual are already subject to redelineation under the 1987 Manual in accordance with the guidance issued 23 August. Until such time as the proposed revisions to the 1989 Manual are finalized, it is unclear as to what effect, if any, the equity provision in the preamble to the proposed revisions will have on the 4U4 program. Therefore, written delineations made with the 1987 Manual will explicitly state they are final for a period of three years as specified in RGL 9~6, subject to any equity provisions that may be adopted as part of implementation of the final revisions to the 1989 Manual.

CECW-OR 20 Feb 1992
MEMORANDUM FOR ALL MAJOR
SUBORDINATE COMMANDS,
DISTRICT COMMANDS

SUBJECT: Regional Interpretation of the 1987 Manual

1. The purpose of this memorandum is to provide clarification to the divisions and districts concerning application of the 1987 Corms Wetlands Delineation Manual (1987 Manual). As you are aware, we have been using the 1987 Manual since 17 August 1991. All indications are that the 1987 Manual, when used in conjunction with the guidance provided in the 7 October 1991 Questions and Answers, is working well for the identification and delineation of wetlands. While the Administration's effort to finalize a revised Manual continues, the Corps of Engineers will continue to use the 1987 Manual.

2. Local procedures on the implementation of the 1987 Manual must be fully consistent with both the 1987 Manual and the Questions and Answers issued 7 October 1991. Any efforts to provide additional guidance regarding the use of the 1987 Manual must be reviewed and approved by HQUSACE (CECW-OR) prior to regional implementation. The data forms provided in the 1987 Manual are to be used, however, additional fields may be added to collect more detailed site specific information when taken from the list of indicators in the 1987 Manual. As pointed out in the 7 October 1991 Questions and Answers, there is flexibility in the 1987 Manual which can be applied on a case-by-case basis only. Local procedures must not add indicators of any of the three wetland parameters to the data sheets. We recognize that the indicators of hydrology in the 1987 Manual are sometimes difficult to demonstrate. However, additional regional indicators must only be used on a case-by-case basis to demonstrate that a parameter is met. For example, blackened leaves and oxidized rhizospheres could be used together to support a delineation where the listed indicators in the 1987 Manual are not directly observed, but where the FAC neutral test is met.

3. All guidance on the use of the 1987 Manual must come from HQUSACE to ensure the a consistent national approach is taken in the Corps application of the 1987 Manual.

FOR THE COMMANDER:

Signed
ARTHUR E. WILLIAMS
Major General, USA
Director of Civil Works

CECW-OR March 6, 1992
SUBJECT: Clarification and Interpretation of the 1987 Manual

1. The purpose of this memorandum is to provide additional clarification and guidance concerning the application of the Corps of Engineers Wetlands Delineation Manual, Technical Report Y-87-1, January 1987, Final Report (1987 Manual). As discussed in my 20 February 1992 memorandum, procedures for the identification and delineation of wetlands must be fully consistent with both the 1987 Manual and the Questions and Answers issued 7 October 1991. The technical and procedural guidance contained in paragraphs 2 thru 6 below has been prepared by the Waterways Experiment Station (WES) and is provided as further guidance. The following guidance is considered to be consistent with the 1987 Manual and the 7 October Questions and Answers. Further, this guidance will be presented in the upcoming Regulatory IV wetlands delineation training sessions in FY 92. The alternative technical methods of data gathering discussed below are acceptable as long as the basic decision rules (i.e., criteria and indicators) established in the 1987 Manual are applied. Also enclosed is a revised data form which may be used in lieu of the routine data sheet provided with the 1987 Manual, if desired. As discussed in my 20 February 1992 memorandum to the field, regional approaches and/or alternative data sheets must be reviewed and approved by HQUSACE (CECW-OR) prior to regional implementation. Notwithstanding this requirement, we encourage interagency coordination and cooperation on implementation of the 1987 Manual. Such cooperation can facilitate the continued success of our use of the 1987 Manual

2. Vegetation:

a. Basic rule: More than 50 percent of dominant species from all strata are OBL, FACW, or FAC (excluding FAC-) on the appropriate Fish and Wildlife Service regional list of plant species that occur in wetlands.

b. The 1987 Manual provides that the 3 most dominant species be selected from each stratum (select 5 from each stratum if only 1-2 strata are present). However, alternative ecologically based methods for selecting dominant species from each stratum are also acceptable. The dominance method described in the 1989 interagency manual is an appropriate alternative method. (1989 Manual, p. 9, para.3.3)

c. The 4 vegetation strata (tree, sapling/shrub, herb, and woody vine) described in the 1987 Manual are appropriate. However, a 5-stratum approach (tree, sapling, shrub, herb, and woody vine) is an acceptable alternative.

d. The 1987 Manual states on page 79 that hydrophytic vegetation is present if 2 or more dominant species exhibit morphological adaptations or have known physiological adaptations for wetlands. This rule should be used only after the basic rule is applied; use caution with adaptations (e.g., shallow roots) that can develop for reasons other than wetness. Furthermore, the morphological adaptations must be observed on most individuals of the dominant species.

e. In areas where the available evidence of wetlands hydrology or hydric soil is weak (e.g., no primary indicators of hydrology), the Facultative Neutral (FAC neutral) option may be used to help clarify a wetland delineation. Use of the FAC neutral option is explained in paragraph

35(a), page 23, of the 1987 Manual. Use of the FAC neutral option is at the discretion of the District. Further, the FAC neutral option cannot be used to exclude areas that meet the “basic vegetation rule” and the hydrology and hydric soil requirements.

3. Hydrology:

a. Areas which are seasonally inundated and/or saturated to the surface for a consecutive number of days for more than 12.5 percent of the growing season are wetlands, provided the soil and vegetation parameters are met. Areas wet between 5 percent and 12.5 percent of the growing season in most years (see Table 5, page 36 of the 1987 Manual) may or may not be wetlands. Areas saturated to the surface for less than 5 percent of the growing season are non-wetlands. Wetland hydrology exists if field indicators are present as described herein and in the enclosed data sheet.

b. To evaluate hydrologic data (e.g., from stream gages or groundwater wells) growing season dates are required. Soil temperature regime (i.e., period of the year when soil temperature at 20 inches below the surface is above 5 degrees C) is the primary definition of growing season, but data are rarely available for individual sites. Broad regions based on soil temperature regime (e.g., mesic, thermic) are not sufficiently site-specific. For wetland determinations, growing season can be estimated from climatological data given in most SCS county soil surveys (usually in Table 2 or 3 of modern soil surveys). Growing season starting and ending dates will generally be determined based on the “28 degrees F or lower” temperature threshold at a frequency of “5 years in 10”. In the south, at the discretion of the district, it may be more appropriate to use the 32 degree F threshold.

c. In groundwater-driven systems, which lack surface indicators of wetland hydrology, it is acceptable to use local Soil Conservation Service (SCS) soil survey information to evaluate the hydrology parameter (p. 37 in the Manual) in conjunction with other information, such as the FAC neutral test. Use caution in areas that may have been recently drained.

d. Oxidized rhizospheres surrounding living roots are acceptable hydrology indicators on a case-by-case basis and may be useful in groundwater systems. Use caution that rhizospheres are not relicts of past hydrology. Rhizospheres should also be reasonably abundant and within the upper 12 inches of the soil profile. Oxidized rhizospheres must be supported by other indicators of hydrology such as the FAC neutral option if hydrology evidence is weak.

4. Soil:

a. The most recent version of National Technical Committee for Hydric Soils hydric soil criteria will be used. At this writing, criteria published in the June 1991 Hydric Soils of the United States are current. These criteria specify at least 15 consecutive days of saturation or 7 days of inundation during the growing season in most years.

b. Local Lists of Hydric Soil Mapping Units recently developed by SCS and available from county or State SCS offices give local information about presence of hydric soils on a site. When available, these local lists take precedence over the national list for hydric soil determinations.

c. SCS is currently developing regional indicators of significant soil saturation. Until finalized and adopted, these indicators may not be used for hydrology or hydric soil determinations.

d. The statement (p.31 of the l987 Manual) that gleyed and low-chroma colors must be obscrved "immediately below thc A-horizon or 10 inches (whichever is shallower)" is intended as general guidance. Certain problem soils may differ.

5. Methods:

a. As stated in thc 1987 Manual (footnote p. 76), alternative plot sizes and dominance measures are acceptable.

h. For comprehensive determinations involving a patchy or diverse herb layer, a single, centrally localed 3.28 x 3.28-foot quadrat may not give a representative sample. As an alternative, the multiple-quadrat procedure presented in the 1989 Manual (p. 42) is recommended.

6. Problem Areas

a. Page 93, paragraph 78 of the 1987 Manual states that similar problem situations may occur in other wettand types, therefore, problem areas are not limited this list.

b. Problem soil situations mentioned elsewhere in the Manual include soils derived from red parent materials, some Entisols, Mollisols, and Spodosols.

7. Questions concerning this information should be directed to Ms. Karen A. Kochenbach, HQUSACE (CECW-OR), at (202) 272-1784, or Mr. James S. Wakeley, WES, at (601) 634-3702.

Signed by,:

Hugh F. Boyd III
for
ARTHUR E. WILLIAMS
Major General, USA
Director of Civil Works

United States
Environmental Protection
Agency

Office of Environmental
Information
Washington, DC 20460

EPA/600/R-96/055
August 2000

Guidance for the Data Quality Objectives Process

EPA QA/G-4

Foreword

The U.S. Environmental Protection Agency (EPA) has developed the Data Quality Objectives Process as the Agency's recommended planning process when environmental data are used to select between two opposing conditions. The Data Quality Objectives Process is used to develop Data Quality Objectives that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. When this Process is not immediately applicable (i.e., the objective of the program is estimation, research, or any other objective that does not select between two distinct conditions), the Agency requires the use of a systematic planning method for defining performance criteria. This document, *Guidance for the Data Quality Objectives Process (EPA QA/G-4)* provides a standard working tool for project managers and planners to develop Data Quality Objectives for determining the type, quantity, and quality of data needed to reach defensible decisions.

As required by EPA Manual 5360 (May 2000), this document is valid for a period of up to five years from the official date of publication. After five years, this document will be reissued without change, revised, or withdrawn from the EPA Quality System series documentation.

This document is one of the *EPA Quality System Series* documents which describe EPA policies and procedures for planning, implementing, and assessing the effectiveness of a quality system. Questions regarding this document or other *EPA Quality System Series* documents should be directed to:

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CHAPTER 0

INTRODUCTION

After reading this chapter you should understand the structure and function of EPA's Quality System, the kinds of programs that are a part of this System, and the benefits of using the Data Quality Objectives Process.

When data are being used to select between two alternative conditions (e.g., compliance or non-compliance with a standard), the Agency's recommended systematic planning tool is the Data Quality Objectives (DQO) Process. The DQO Process is a systematic planning process that is part of the EPA's Quality System.

***Who can use this guidance document*?** This guidance is intended for project managers, technical staff, regulators, stakeholders, and others who wish to use the DQO Process to plan data collection efforts and develop an appropriate data collection design to support decision making.

0.1 EPA Quality System Requirements

EPA Order 5360.1 A2 (EPA 2000a) and the applicable Federal regulations establish a mandatory Quality System that applies to all EPA organizations and organizations funded by EPA. Components of the Quality System are presented in Figure 0-1. Organizations must ensure that data collected for the characterization of environmental processes and conditions are of the appropriate type and quality for their intended use and that environmental technologies are designed, constructed, and operated according to defined expectations. Systematic planning is a key project-level component of the EPA Quality System (see Figure 0-1).

EPA policy is based on the national consensus standard, ANSI/ASQC E4-1994, *Specifications and Guidelines for Environmental Data Collection and Environmental Technology Programs*, developed by the American National Standards Institute and the American Society for Quality. This document describes the necessary management and technical area elements for developing and implementing a quality system by using a tiered approach to a quality system. The standard recommends first documenting each organization-wide quality system in a Quality Management Plan or Quality Manual (to address requirements of *Part A: Management Systems* of the standard), and then documenting the applicability of the quality system to technical activity-specific efforts in a Quality Assurance Project Plan or similar document (to address the requirements of *Part B: Collection and Evaluation of Environmental Data* of the standard). EPA has adopted this tiered approach for its mandatory Agency-wide Quality System. This document addresses Part B requirements of the standard for systematic planning for environmental data operations.

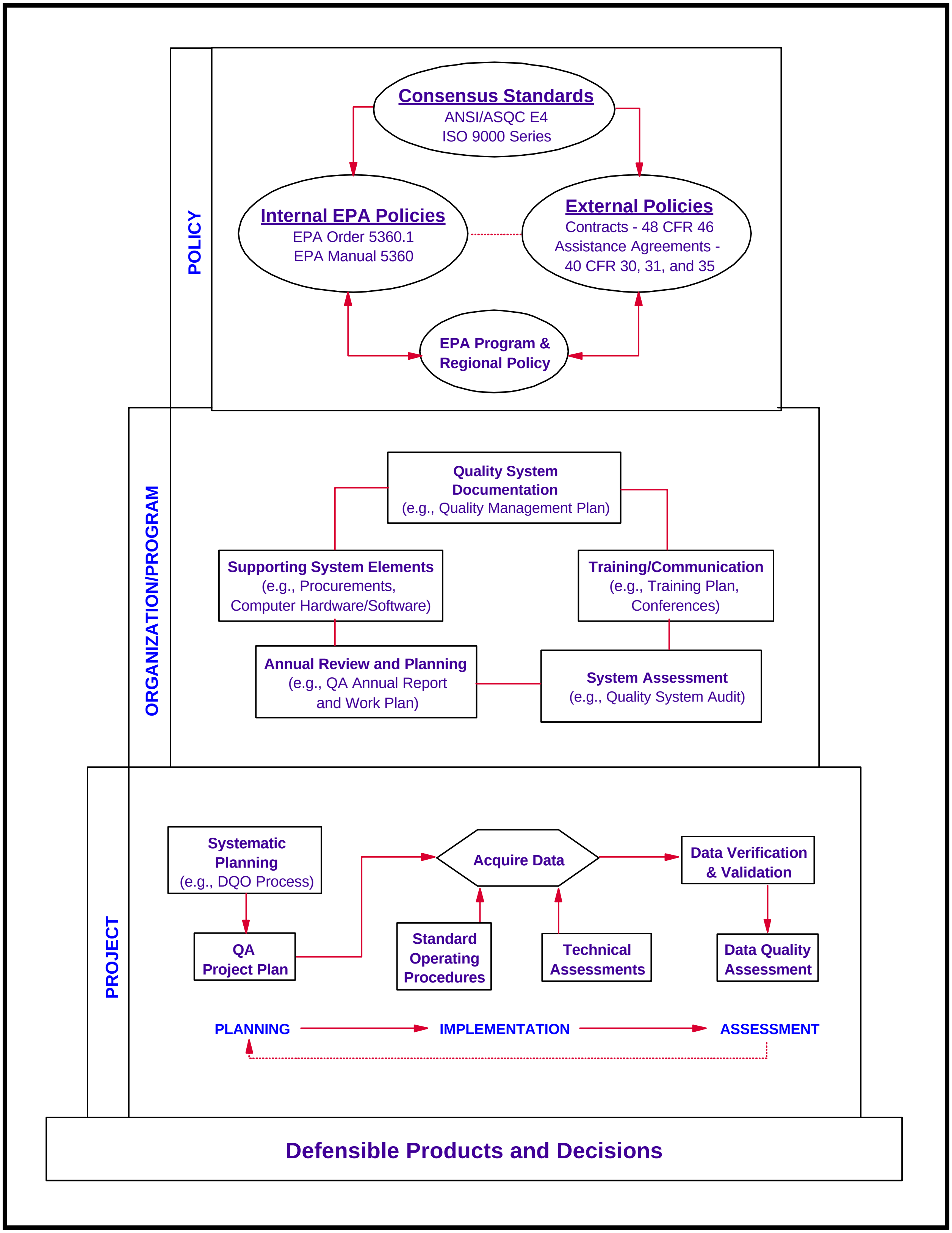


Figure 0-1. EPA Quality System Components and Tools

In accordance with EPA Order 5360.1 A2, the Agency requires that:

- Environmental programs performed for or by the Agency be supported by data of the type and quality appropriate to their expected use. EPA defines environmental data as information collected directly from measurements, produced from models, or compiled from other sources such as databases or literature.

- Decisions involving the design, construction, and operation of environmental technology be supported by appropriate quality assured engineering standards and practices. Environmental technology includes treatment systems, pollution control systems and devices, waste remediation, and storage methods.

EPA Order 5360.1 A2 is supported by the *EPA Quality Manual for Environmental Programs* (U.S. EPA, 2000b) that defines requirements for implementing EPA's Quality System. The Order defines the quality requirements and the Manual presents the mandatory "how to" for implementing these requirements.

EPA's Quality System (presented in Figure 0-1) comprises three levels – Policy, Organization/Program, and Project:

- Policy – this level addresses Agency-wide quality policies and regulations that both EPA organizations and external EPA-funded organizations must address;

- Organization/Program – this level addresses the management and implementation component of the individual Quality System; and

- Project – this level addresses the project-specific components that are applied to individual projects to ensure that the needs of the organization are met.

EPA has developed a *Quality System Series* of documents that provide guidelines to help organizations ensure that data collected for the characterization of environmental processes and conditions are of the appropriate type and quality for their intended use. Documents useful in planning for data collection include:

- *Decision Error Feasibility Trials (DEFT) Software for the Data Quality Objectives Process (EPA QA/G-4D),*
- *Guidance for the Data Quality Objectives Process for Hazardous Waste Sites (EPA QA/G-4HW),*
- *Guidance on Quality Assurance Project Plans (EPA QA/G-5),*
- *Guidance for the Preparation of Standard Operating Procedures for Quality-Related Documents (EPA QA/G-6),* and
- *Guidance for Data Quality Assessment: Practical Methods for Data Analysis (EPA QA/G-9).*

0.2 Systematic Planning and the DQO Process

EPA Order 5360.1 A2 requires that all EPA organizations (and organizations with extramural agreements with EPA) follow a systematic planning process to develop acceptance or performance criteria for the collection, evaluation, or use of environmental data. A systematic planning process is the first component in the *planning phase* of the project tier, while the actual data collection activities are in the *implementation phase* of this tier (Figure 0-1).

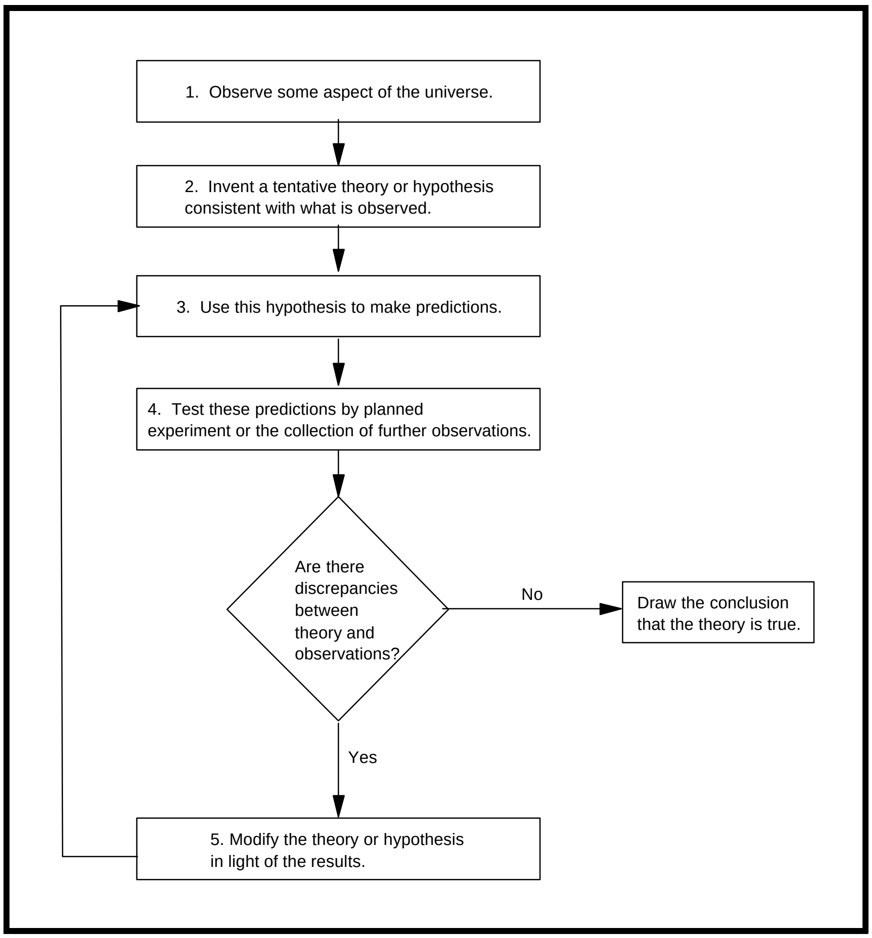


Figure 0-2. The Scientific Method

What is systematic planning? Systematic planning is a planning process that is based on the scientific method and includes concepts such as objectivity of approach and acceptability of results (Figure 0-2). Systematic planning is based on a common sense, graded approach to ensure that the level of detail in planning is commensurate with the importance and intended use of the work and the available resources. This framework promotes communication between all organizations and individuals involved in an environmental program. Through a systematic planning process, a team can develop acceptance or performance criteria for the quality of the data collected and for the quality of the decision. When these data are being used in decision making by selecting between two clear alternative conditions (e.g., compliance/non-compliance with a standard), the Agency's recommended systematic planning tool is called the DQO Process. Elements of the systematic planning process (from Section 3.3.8 of the EPA Quality Manual) and relationship to the DQO Process are shown in Table 0-1.

Table 0-1. Elements of the Systematic Planning Process

Elements of Systematic Planning Process	**Corresponding Step in the DQO Process**
Identifying and involving the project manager/decision maker, and project personnel	Step 1. Define the problem
Identifying the project schedule, resources, milestones, and requirements	Step 1. Define the problem
Describing the project goal(s) and objective(s)	Step 2. Identify the problem
Identifying the type of data needed	Step 3. Identify information needed for the decision
Identifying constraints to data collection	Step 4. Define the boundaries of the study
Determining the quality of the data needed	Step 5. Develop a decision rule Step 6. Specify limits on decision errors
Determining the quantity of the data needed	Step 7. Optimize the design for obtaining data
Describing how, when, and where the data will be obtained	Step 7. Optimize the design for obtaining data
Specifying quality assurance and quality control activities to assess the quality performance criteria	Part B of QA Project Plan
Describing methods for data analysis, evaluation, and assessment against the intended use of the data and the quality performance criteria	Part D of QA Project Plan; DQA Process

What are acceptance or performance criteria? Acceptance or performance criteria are based on the ultimate use of the data to be collected and needed quality assurance (QA) and quality control (QC) practices required to support the decision. In the decision making process, these criteria allow a user to limit decision errors to a fixed level for determining whether or not an Action Level (regulatory or risk-based) has been exceeded.

What is the DQO Process? The DQO Process is a seven-step planning approach to develop sampling designs for data collection activities that support decision making. This process uses systematic planning and statistical hypothesis testing to differentiate between two or more clearly defined alternatives. A summary of the seven steps is presented in Figure 0-3.

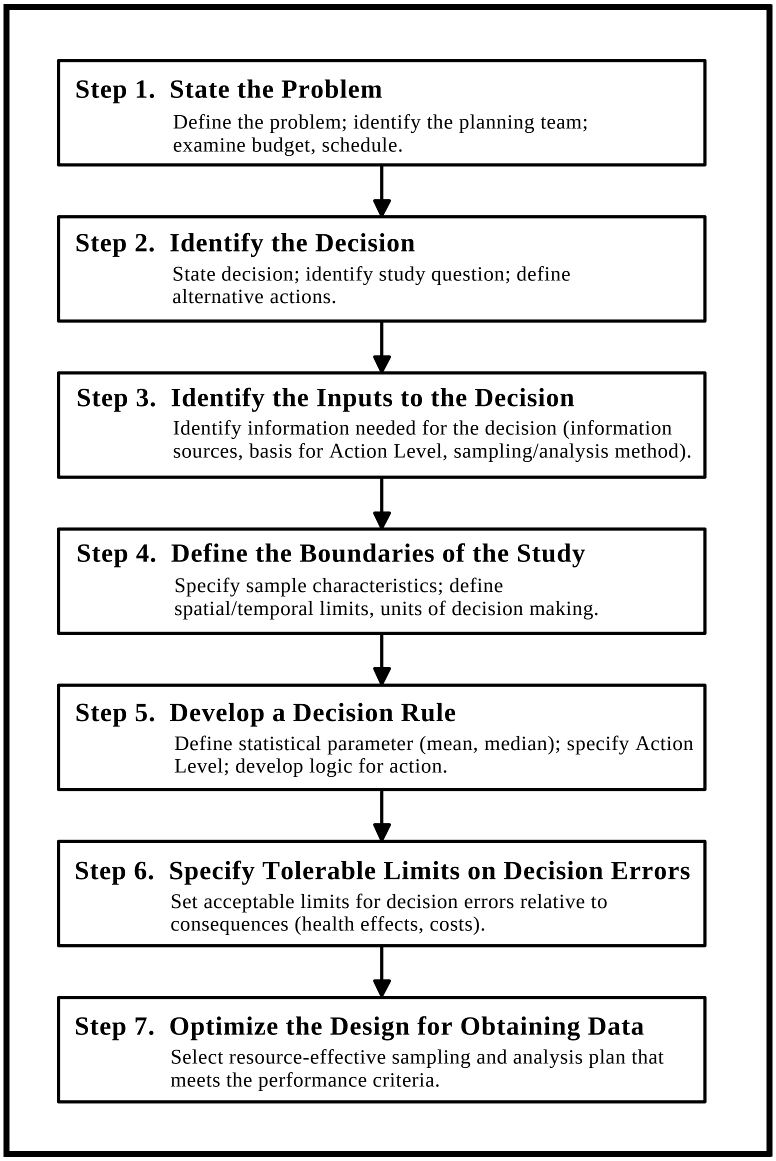


Figure 0-3. The Data Quality Objectives Process

The DQO Process is iterative and allows the planning team to incorporate new information and modify outputs from previous steps as inputs for a subsequent step. Although the principles of systematic planning and the DQO Process are applicable to all scientific studies, the DQO Process is particularly designed to address problems that require making a decision between two clear alternatives. The final outcome of the DQO Process is a design for collecting data (e.g., the number of samples to collect, and when, where, and how to collect samples), together with limits on the probabilities of making decision errors.

What are DQOs? DQOs are qualitative and quantitative statements, developed using the DQO Process, that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. DQOs define the performance criteria that limit the probabilities of making decision errors by considering the purpose of collecting the data; defining the appropriate type of data needed; and specifying tolerable probabilities of making decision errors.

What projects are covered by the DQO Process? The DQO Process may be applied to all programs involving the collection of environmental data used in decision making. The principles used in the DQO Process are also applicable to programs with objectives other than decision making (e.g., estimation and research studies).

Who should be included in the DQO Process? When applying the DQO Process, a planning team of senior program staff, technical experts, managers, data users (usually with some statistical expertise), a quality assurance specialist, regulators, and stakeholders are usually involved. It is important that the key persons participate (or stay informed) throughout the DQO Process so that each individual understands the problem/decision and objectives of the decision-making process. Individuals with specific areas of technical expertise may decide to be involved only in the steps of the DQO Process that require technical input.

When should the DQO Process be used? The DQO Process should be used during the planning stage of any study that requires data collection, *before* the data are collected. As the DQO Process is iterative by nature, steps within the process can be revisited before a final decision is reached. As shown in Figure 0-4, the planning team may choose to revisit selected parts of the DQO Process or to investigate the entire process cyclically.

Is the DQO Process only applicable to large studies or studies that require multiple decisions? The DQO Process applies to any study, regardless of its size. However, the depth and detail of DQO development will depend on the study objectives. The DQO Process is particularly applicable to a study in which multiple decisions must be reached because, by using this planning process, the planning team can clearly separate and delineate data requirements for each problem/decision. For projects that require multiple decisions or answers to more than one question, it is likely that the resolution of one decision will lead to the evaluation of subsequent decisions. In these cases, the DQO Process can be used repeatedly throughout the life cycle of a project. Often, the decisions that are made early in the project will be preliminary in nature; they might require only a limited planning and evaluation effort. As the study nears conclusion and the consequences of making a decision error become more critical, however, the level of effort needed to resolve a decision generally will become greater. Figure 0-4 illustrates this point.

What are the outputs of the DQO Process? The DQO Process leads to the development of acceptance or performance criteria based on the ultimate use of the data to be collected and define the quality required for the decision in terms of acceptance limits on the probabilities of committing a decision error. Each step of the DQO Process defines criteria that will be used to

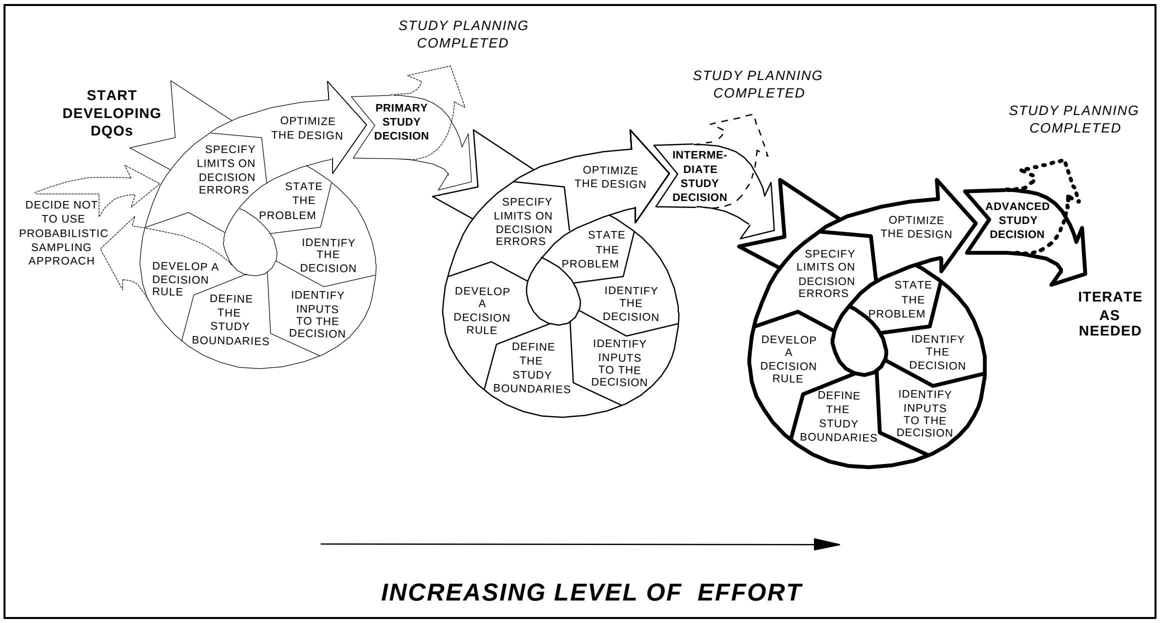


Figure 0-4. Repeated Application of the DQO Process throughout the Life Cycle of a Project

establish the final data collection design. The first five steps of the DQO Process are primarily focused on identifying qualitative criteria, such as:

- the nature of the problem that has initiated the study and a conceptual model of the environmental hazard to be investigated;
- the decisions that need to be made and the order of priority for resolving them;
- the type of data needed (i.e., geographic area, environmental medium, overall timing of data collection, etc.); and
- a decision rule that defines how the data will be used to choose among alternative actions.

The sixth step defines quantitative criteria, expressed as limits on the probability or chance (risk) of making a decision error, that the decision maker can tolerate. The seventh step is used to develop a data collection design based on the criteria developed in the first six steps. In this step the planning team considers the final product of the DQO Process, a data collection design that meets the quantitative and qualitative needs of the study using a specified number of samples that can be accommodated by the budget available. The outputs of the DQO Process are used to develop a QA Project Plan and for performing Data Quality Assessment (Chapter 8).

What is a data collection design? A data collection design specifies the number, location, physical quantity, and type of samples that should be collected to satisfy the DQOs. The sampling design designates where, when, and under what conditions samples should be collected; what variables are to be measured; and the QA and QC activities that will ensure that sampling design and measurement errors are managed sufficiently to meet the tolerable decision error rates specified in the DQOs. These QA and QC activities together with details of the data collection design are documented in the QA Project Plan.

Can existing data be used in the DQO Process to support your decision making? Existing data can be very useful. For example, pilot studies are often performed to provide a preliminary assessment of variability. In these cases, the existing data may provide valuable information to help develop a design for collecting data. It is critical to examine the existing data to ensure that their quality is acceptable for use, or for integration into a new data set. Some considerations include:

- determining if the existing data were collected within approximately the same spatial and temporal boundaries as the new data;
- examining the existing data to determine if this data set includes identical media and analytes;
- examining the performance of the analytical methods for the existing data (accuracy, precision, detection limits) and comparing this to the specifications in Step 3 of the DQO Process for new data to be collected; and
- examining the variability among samples in the existing and new data sets.

Combining existing data and new data can be a very complex operation and you should undertake this with great care. In many cases, statistical expertise is required to evaluate both data sets before they can be combined with confidence.

Will you always develop statistical/probabilistic sampling designs for data collection if you use the DQO Process? No. Although statistical methods for developing the data collection design are strongly encouraged, this guidance recognizes that not every sampling problem can be resolved with probabilistic sampling designs. However, the DQO Process can and should be used as a planning tool for studies even if a statistical data collection design ultimately will not be used. In these cases, the planning team is encouraged to seek expert advice on how to develop a non-statistical data collection design and how to evaluate the results of the data collection. When nonprobabilistic, judgmental, or quota sampling methods are used, be sure to consult with an EPA representative to ensure that program-specific QA requirements are satisfied.

How should you use this guidance? You should use this guidance as a tool to structure the planning activities for collecting environmental data. It should be used to organize meetings, focus the collection of background information, and facilitate communication between a team that includes technical experts, program managers, stakeholders, regulators, and decision makers.

0.3 Benefits of Using the DQO Process

The DQO Process integrates a multidisciplinary team and offers the advantages of using experience and resources of individuals who have different backgrounds, different kinds of knowledge, and who can collectively focus on achieving a successful project conclusion. During the initial planning stages, the planning team can concentrate on developing requirements for collecting the data and work to reach consensus on the type, quantity, and quality of data needed to support Agency decisions. This interaction results in a clear understanding of the problem and the options available for addressing it, the development of acceptance or performance criteria for decision making, a consensus-based approach to understanding the problem, and data being collected of appropriate quality. Organizations that have used the DQO Process have observed that:

- The structure of the DQO Process provides a convenient way to *document activities and decisions* and to communicate the data collection design to others. This documentation *facilitates rapid review and approval* by regulators and stakeholders.

- The DQO Process enables data users and relevant technical experts to participate collectively in data collection planning and to specify their particular needs prior to data collection. The DQO process fosters *communication among all participants,* one of the central tenets of quality management practices, and directs efforts to *achieving consensus* between decision makers, stakeholders, and regulators.

- The DQO Process helps to focus studies by encouraging data users to *clarify vague objectives* and to limit the number of decisions that will be made. Due to this clarification, *the consequences of decision errors are examined* and correct decisions will be made most frequently when the DQO Process is employed.

- The DQO Process is a planning tool that can *save resources* by making data collection operations more resource-effective. Good planning will streamline the study process and increase the likelihood of efficiently collecting appropriate and useful data.

- The DQO Process provides a method for *defining decision performance requirements* that are appropriate for the intended use of the data. This is done by considering the consequences of decision errors and then placing tolerable limits on the chance that the data will mislead the decision maker into committing a decision error. A statistical sampling design can then be generated to provide the most efficient method for managing decision errors and satisfying the DQOs.

Upon implementing the DQO Process, your environmental programs may be strengthened by:

- focused data requirements and optimized design for data collection,
- use of clearly developed work plans for collecting data in the field,
- uniformly documented data collection, evaluation, and use,
- clearly developed analysis plans,

- sound, comprehensive quality assurance project plans, and
- up-front buy-in by stakeholders to the sampling design and data collection process.

This can lead to:

- rapid review by regulators and other stakeholders,
- defensible results on which to base decisions,
- increased credibility with regulators and stakeholders, and
- a better use of resources.

Where else can the DQO Process be applied? The DQO Process is widely applicable. For example, the Department of Energy Environmental Management program considers the following potential applications for the DQO Process (Grumley, 1994):

- Waste management
  - Characterizing waste, using process knowledge verified by minimal sampling/ analysis data to meet acceptance criteria for treatment, storage, and disposal.
  - Designing optimal monitoring networks for ground water and surface water discharges, and air emissions.

- Environmental restoration
  - Focusing regulatory and public concerns associated with remediation.
  - Identifying target analytes of concern for remedial activities.
  - Determining when remediation has met cleanup levels.

- Facility transition and management
  - Performing characterization assessments, using existing information or collecting new data, to verify facilities for environmental management acceptance.
  - Evaluating alternative end-state conditions and planning facility deactivation in preparation for eventual decontamination and decommissioning.
  - Designing optimized short- and long-term environmental monitoring.

- Decontamination and decommissioning
  - Determining the location and levels of facility contamination.
  - Determining when decontamination and decommissioning is complete.

- Technology development

  - Determining what constitutes and acceptably demonstrates success in technology development and evaluation.

0.4 Organization of This Document

This document provides EPA's guidance specific to the design plans for collecting data for decision-making activities. EPA recognizes that by using systematic planning and the DQO Process to design environmental data collection efforts, the effectiveness, efficiency, and defensibility of decisions will be improved. This document presents:

- the advantages of using systematic planning for data collection,
- the seven steps of the DQO Process, including activities and outputs for each step, and
- three scenarios that each use a different statistical parameter (mean, median, and upper percentile) to develop a design for collecting data.

The objective of this guidance document is to describe how a planning team can use the DQO Process to generate a plan to collect data of appropriate quality and quantity for defensible decision making. This guidance replaces in its entirety EPA's September 1994 document, *Guidance for the Data Quality Objectives Process (EPA QA/G-4),* (U.S. EPA, 1994a), and is consistent with the *Data Quality Objectives Process for Hazardous Waste Site Investigations (EPA QA/G-4HW)* (U.S. EPA, 1999).

This document contains an introductory chapter that is followed by seven chapters that correspond to the seven steps of the DQO Process. Each chapter is divided into four sections:

1. Background — Provides background information on the DQO Process step, including the rationale for the activities in that step and the objective(s) of the chapter.
2. Activities — Describes the activities recommended for completing the DQO Process step, including how inputs to the step are used.
3. Outputs — Identifies the results that may be achieved by completing the DQO Process step.
4. Examples — Presents outputs from two different DQO scenarios for environmental contamination.

Chapter 8 shows how outputs of the DQO Process are used to develop a QA Project Plan.

Appendix A shows the derivation of the formula used to calculate sample size, and Appendix B gives a Bibliography of referenced books, papers, and publications. Appendix C shows a complete DQO example using the median as the parameter of interest and Appendix D contains a glossary of terms used in this document.

0.5 Background for the Two Examples

The following examples have been derived from real-life DQO development efforts to illustrate the use of mean and percentile in planning for decision making:

Example 1 - Use of the mean to make a decision about waste disposal of material.

Example 2 - Use of the percentile to make a decision relative to a regulatory limit value.

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

Cadmium is primarily used for corrosion protection on metal parts of cars, electrical appliances, and in some batteries. Cadmium and cadmium salts have been shown to be toxic to humans through both ingestion and inhalation. Ingestion of concentrations as low as 0.1 mg/kg/day causes mild to severe irritation of the gastrointestinal tract. Exposure from chronic (long-term) inhalation can cause increased incidence of emphysema and chronic bronchitis, as well as kidney damage.

A waste incineration facility located in the Midwest routinely removes fly ash from its flue gas scrubber system and disposes of it in a municipal landfill. Previously the waste fly ash was determined not to be hazardous according to RCRA program regulations. The incinerator, however, recently began accepting and treating a new waste stream. The representatives of the incineration company are concerned that the waste fly ash in a new waste stream could contain hazardous levels of cadmium from new waste sources. They have decided to test the ash to determine whether it should be sent to a hazardous waste landfill or continue to be sent to the municipal landfill.

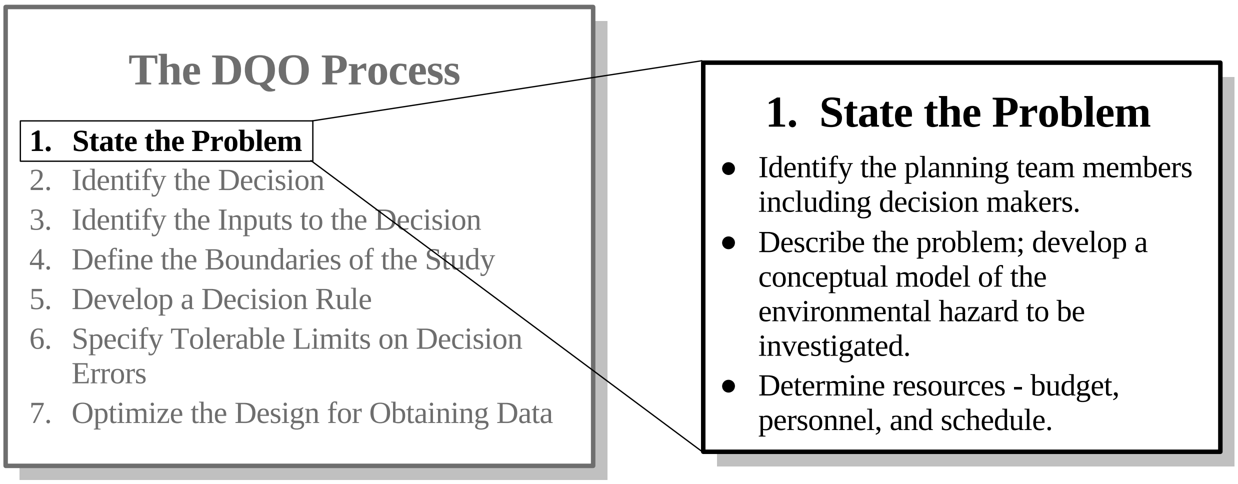
As a precursor to the DQO Process, the incineration company has conducted a pilot study of the fly ash to determine the variability in the concentration of cadmium within loads of waste fly ash leaving the facility and has determined that each load is fairly homogeneous. There is considerable variability between loads, however, due to the nature of the waste stream. The company has decided that testing each container load before it leaves the facility would be an economical approach to evaluating the potential hazard. They could then send containers of ash that exceeded the regulated standards to the higher cost RCRA landfills and continue to send the other containers to the municipal landfill. This example demonstrates use of the mean as the population parameter of concern. (The derivation of a sampling design using the mean is provided in Appendix A).

Example 2. Making Decisions About Urban Air Quality Compliance

In July 1997, the EPA established new ambient air quality standards for $PM_{2.5}$*, particulate matter smaller than 2.5 microns (40 CFR 50).* $PM_{2.5}$ *is comprised of fine particles about 1/30*th *the thickness of a human hair that are a complex mixture of acids, metals, and carbon. Because the health risks of the chemical components of* $PM_{2.5}$ *are not fully understood, EPA is implementing* $PM_{2.5}$ *standards and investigating scientific uncertainties associated with these components.*

This example involves monitoring urban air for the presence of $PM_{2.5}$*. Representatives of a primary metropolitan statistical area (PMSA) in the northeast wish to determine whether their PMSA is in attainment for* $PM_{2.5}$ *according to the National Ambient Air Quality Standards (NAAQS). If determined to be in nonattainment, control strategies will be implemented for the PMSA, as defined in its associated State Implementation Plan (SIP). This example uses an upper percentile as the primary population parameter of concern as it is specified in the Standards. Additionally, this example highlights DQO activities and outputs for the case when a data collection design (i.e., number of samples) already has been determined, but not necessarily in accordance with the DQO Process.*

CHAPTER 1
STEP 1. STATE THE PROBLEM



After reading this chapter you should understand how to assemble an effective planning team and how to describe the problem and examine your resources for investigating it.

1.1 Background

The first step in any systematic planning process is to define the problem that has initiated the study. As environmental problems are often complex combinations of technical, economic, social, and political issues, it is critical to the success of the process to separate each problem, define it completely, and express it in an uncomplicated format. A proven effective approach to solving a problem is to use a planning team composed of experts and stakeholders who have multidisciplinary backgrounds. A team of individuals with diverse backgrounds offers:

- the ability to develop a complete, concise description of complex problems, and
- multilateral experience and awareness of potential data uses.

If there is a potential that the data collected in the current investigation could be used in future studies (secondary uses of the data), it is important to consult, if possible, potential data users during the planning process.

1.2 Activities

The most important activities in this step are to:

- establish the planning team including the decision makers;
- describe the problem and develop a conceptual model of the environmental hazard to be investigated; and
- identify available resources, constraints, and deadlines.

How do you establish the planning team and decision makers? The DQO planning team is usually composed of the project manager, technical staff, data users (including those with a statistical background), and stakeholders. It is important to carefully select the planning team and leaders (or decision makers) because this team will work together through all seven steps of the planning process. The development of DQOs does not necessarily require a large planning team, particularly if the problem appears to be straightforward. The size of the planning team is usually directly proportional to the complexity and importance of the problem. As the DQO Process is iterative, team members may be added to address areas of expertise not initially considered.

Prior to or during the first meeting of the DQO team, members should identify the decision makers. The decision maker may be one or more individuals familiar with the problem, or with a vested interest in it. As the *technical project manager* is familiar with the problem and the budgetary/time constraints the team is facing, he or she will usually serve as one of the decision makers and will actively participate in all steps of DQO development. The *decision makers* will have the ultimate authority for making final decisions based on the recommendations of the planning team. In cases where the decision makers cannot attend DQO planning meetings, alternate staff members should attend and keep the decision makers informed of important planning issues.

The *technical staff and data users* should include individuals who are knowledgeable about technical issues (such as geographical layout, sampling constraints, analysis, statistics, and data interpretation). The planning team of multidisciplinary experts may include quality assurance managers, chemists, modelers, soil scientists, engineers, geologists, health physicists, risk assessors, field personnel, regulators, and data users with statistical experience.

Stakeholders are individuals or organizations who are directly affected by a decision, interested in a problem, and want to be involved, offer input, or seek information. Usually stakeholders will have multiple perspectives about a problem. The involvement of stakeholders early on in the DQO Process can provide a forum for communication as well as foster trust in the decision making process. An environmental example is the Common Sense Initiative Council, a group of stakeholders convened to offer EPA advice and recommendations on a number of topics. The Common Sense Initiative Council recognizes that involving stakeholders improves communication and assists in analyzing situations to determine the tools and expertise needed to address problems and maintain lasting agreements.

The identification of stakeholders is influenced by the issues under consideration, as well as the ability of stakeholders to articulate their interests. Because EPA is organized into multiple program areas that are concerned with different environmental media that address different regulatory areas (e.g., Clean Air Act, Resource Conservation and Recovery Act), stakeholder involvement activities are not centralized. EPA has developed a web page Introduction to Stakeholder Involvement (http://www.epa.gov/ooaujeag/stakeholders/people.htm) that identifies individuals in various EPA program offices who can offer assistance in stakeholder involvement activities. EPA provides additional information/resources on stakeholder involvement, including:

- EPA Resources for Non-Profit Organizations,
- Children's Health Protection Advisory Committee,
- EPA Voluntary Programs, and
- Partners of Wetlands, Oceans, and Watersheds.

Information for stakeholder involvement and consensus building processes for other federal agencies is also provided at this website. At the state level, information on potential stakeholders is often available. For example, the State of California has developed a directory of citizen groups, government agencies, and environmental education programs concerned with California environmental issues (Harbinger Communications, 1996).

You should identify the roles of team members and group members that have key and secondary roles, then consider the roles of the planning team members when coordinating meetings. While it is important for key members (e.g., decision makers and members involved in policy decisions) to either attend all meetings, or designate a representative to attend meetings that are missed, technical members (e.g., technical managers, field and laboratory personnel, data users, statisticians) may decide to be involved only in meetings where technical input is required. Stakeholders and regulators may elect to attend initial meetings, but miss meetings that address technical issues (e.g., sampling and analysis). When possible, the use of a facilitator or recorder at these meetings is encouraged.

How do you describe the problem and the environmental hazard to be investigated? In Step 1, the planning team describes the conditions or circumstances that are causing the problem and the reasons for undertaking the study. Typical examples for environmental problems include conditions that may pose a threat to human health or the environment or circumstances of potential noncompliance with regulations.

The team may be able to describe the problem as it is currently understood by briefly summarizing existing information, or they may conduct literature searches and examine past or ongoing studies. This will ensure that the problem is correctly defined and has not been solved previously. As you define the problem, you should consider similar studies and document information about the performance of sampling and analytical methods observed in these studies. This information may prove to be particularly valuable later in the DQO Process. You should organize and review all relevant information, indicate the source of the information, and evaluate its reliability.

The planning team should:

- examine the study objectives from a regulatory standpoint as necessary;
- identify individuals or organizations who are involved or have an interest in the study;
- examine political issues associated with the study;
- look at results of similar studies performed previously from the standpoint of:
  - study parameters,
  - regulatory or other constraints on sampling designs,
  - variability and quality of data collected;
- consider non-technical issues that may influence the sample design; and
- examine possible future uses of the data to be collected (e.g., the data to be collected may be eventually linked to an existing database).

It is **critical** to carefully develop an accurate conceptual model of the environmental problem in this step of the DQO Process, as this model will serve as the basis for all subsequent inputs and decisions. Errors in the development of the conceptual model will be perpetuated throughout the other steps of the DQO Process and are likely to result in developing a sampling and analysis plan that may not achieve the data required to address the relevant issues.

The conceptual model of the potential environmental hazard developed at the beginning of the DQO Process is often a diagram that shows:

- known or expected locations of contaminants,
- potential sources of contaminants,
- media that are contaminated or may become contaminated, and
- exposure scenarios (location of human health or ecological receptors).

If the problem is complex, the team may consider breaking it into more manageable pieces, which might be addressed by separate studies. Priorities may be assigned to individual segments of the problem and the relationship between the segments examined.

How do you identify available resources, constraints, and deadlines? You should examine limitations on resources and time constraints for collecting data. This estimate should include developing acceptance or performance criteria, preparing the QA Project Plan, collecting and analyzing samples, and interpreting data. At this time the planning team should also examine available personnel, and contracts (if applicable) and identify intermediate and final deadlines for collecting data.

1.3 Outputs

The major outputs of this step are:

- a list of the planning team members and their roles,
- identification of decision makers,
- a concise description of the problem and a conceptual model of the environmental problem to be investigated, and
- a summary of available resources and relevant deadlines for the study including budget, availability of personnel, and schedule.

1.4 Examples

Given the background of the three examples as outlined in Section 0.5, the following DQO Step 1 outputs were derived.

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

How were the planning team members selected? *The planning team included the incineration plant manager, a plant engineer, a quality assurance specialist with statistical experience, and a chemist with sampling experience in the RCRA program. The plant manager was the decision maker.*

How was the problem described and a conceptual model of the potential hazard developed? *The problem was described as determining which container loads of waste fly ash from a new waste stream needed to be sent to a RCRA landfill as a result of a change in an incinerator process that possibly increased the levels of cadmium in waste fly ash. The plant manager wanted to avoid expensive RCRA disposal of waste, if possible, but also needed to comply with regulations and permits.*

The conceptual model described fly ash that was created from industrial waste incineration and is a potential source of toxic metals that include cadmium. Ash is transferred to large containers via a conveyer belt. Containers are filled and trucked to a disposal site. If the waste fly ash is hazardous but disposed in a municipal (sanitary) landfill, then metals can leach into ground water and create runoff to streams, and other surface water bodies, which could pose a hazard to human health and ecological receptors. If such waste is disposed in a RCRA approved landfill, the hazards are contained.

What were the available resources and relevant deadlines? *Although the project was not constrained by cost, the waste generator (the incineration company) wished to hold sampling costs below $2,500. The incineration company also requested that the testing of the waste fly ash in each container be completed within one week.*

Example 2. Making Decisions About Urban Air Quality Compliance

How were the planning team members selected? *The planning team included senior program staff, technical experts, senior managers, a QA specialist, and an individual with statistical experimental design expertise. The most senior program staff member served as the decision maker.*

How was the problem described and a conceptual model of the potential hazard developed? *EPA had set NAAQS for fine particulate matter ($PM_{2.5}$) and other air pollutants (40 CFR 50). The problem was described as determining whether the primary metropolitan statistical area (PMSA) of concern was in attainment for fine particulate matter.*

The conceptual model of the potential hazard was considering the concentration of fine particulates in urban air that were primarily combustion products from point and mobile sources. The particulates posed potential sources of exposure from inhalation. As a rule, the PMSA was not concerned with long-term transport because over time particulates aggregated or became deposited on other materials such that the particles came within the purview of the Pm_{10} rule. The PMSA developed a Cartesian map indicating local $PM_{2.5}$ point sources, main roadways, and predominant wind patterns to identify areas of maximum potential exposure.

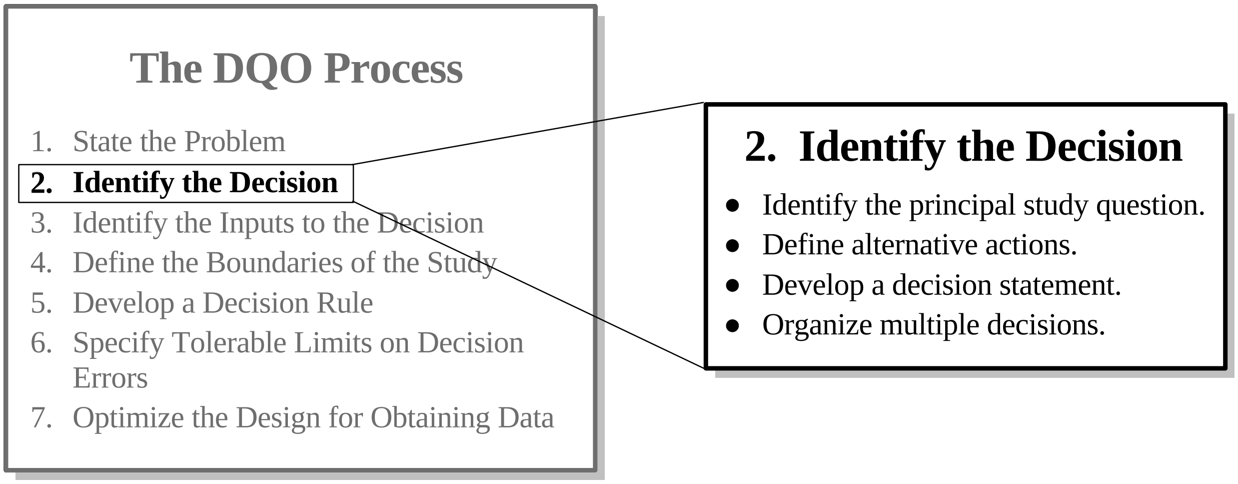
What were the available resources and relevant deadlines? *The monitoring network was already in place. It consisted of three fixed-site multiple filter gravimetric devices for measuring daily concentrations (24-hr average) once every 3 days. Thus, about 365 readings were obtained each year.*

Looking Ahead to other DQO Steps:

- Careful description of the problem will assist in Step 3, Identify the Inputs to the Decision, when considering additional use of data (link to databases, etc.).

- The conceptual model will assist in Step 4, Define the Boundaries of the Study, when
  - establishing spatial boundaries, and
  - considering regulatory and practical constraints for sampling.

CHAPTER 2
STEP 2. IDENTIFY THE DECISION



After reading this chapter you should know how to identify the principal study question and how to define options for addressing it (alternative actions).

2.1 Background

This step builds on the output of the previous step where you have:

- identified members of a planning team, including decision makers;
- concisely described the problem; and
- developed a conceptual model of the environmental problem to be investigated.

In Step 2 of the DQO Process, you should identify the key question that the study attempts to address and alternative actions that may be taken, depending on the answer to the key study question. Then you are able to combine these two elements to develop a decision statement. The decision statement is critical for defining decision performance criteria later in Step 6 of the Process.

In cases of multiple or complex problems, you should identify multiple decisions, organize the decisions sequentially (or logically), and examine the decisions to ensure consistency with the statement of the problem in Step 1. If the principal study question is not obvious and specific alternative actions cannot be identified, then the study may fall in the category of exploratory research, in which case this particular step of the DQO Process may not be needed.

2.2 Activities

In this step you should:

- identify the principal study question;
- define alternative actions;
- combine the principal study question and alternative actions into a decision statement and state each decision in terms of whether to take action. In some cases, this decision statement will be based on regulatory guidelines; and
- organize multiple decisions into an order of priority.

How do you identify the principal study question? Based on a review of the problem described in Step 1, you should identify the principal study question and state it as specifically as possible. A specific statement of the principal study question focuses the search for information needed to address the problem. The principal study question identifies key unknown conditions or unresolved issues that reveal the solution to the problem being investigated. EPA recommends that initially you should concentrate on only one principal study question and expand to other issues later. The following are examples of typical principal study questions:

- Does the concentration of contaminants in ground water exceed acceptable levels?
- Does the pollutant concentration exceed the National Ambient Air Quality Standard?
- Does a contaminant pose a human health or ecological risk?
- Is the contaminant concentration significantly above background levels (suggesting a release)?

In each case, the answer to the principal study question will provide the basis for determining the course of action that should be taken to solve the problem.

What are alternative actions and how should you define them? During this step, the planning team should identify the possible actions that may be taken to solve the problem, including an alternative that requires no action. The team should confirm that the alternative actions can resolve the problem (if it exists) and determine whether the actions satisfy regulations. An example of a principal study question and alternative actions is given in Table 2-1.

Table 2-1. An Example of a Principal Study Question and Alternative Actions

Principal Study Question	Alternative Actions
Are there significant levels of lead in floor dust at a children's residence.	Remove the children from the residence.
	Initiate a clean-up removal of lead-based paint.
	Take no action.

How do you develop a decision statement? After examining the alternative actions, you should combine the principal study question and alternative actions into a decision statement that expresses a choice among alternative actions. The following template may be helpful in drafting decision statements:

> Determine whether or not [unknown environmental conditions/issues/criteria from the principal study question] require (or support) [taking alternative actions].

Does the DQO Process address multiple decisions? If several separate decision statements must be defined to address the problem, you should examine how the decisions relate to one another and prioritize them in the order of the importance and sequence for resolving them. It may be helpful to document the prioritizing process proposed to resolve the problem using a diagram or a flow chart. An example is presented in Figure 2-1.

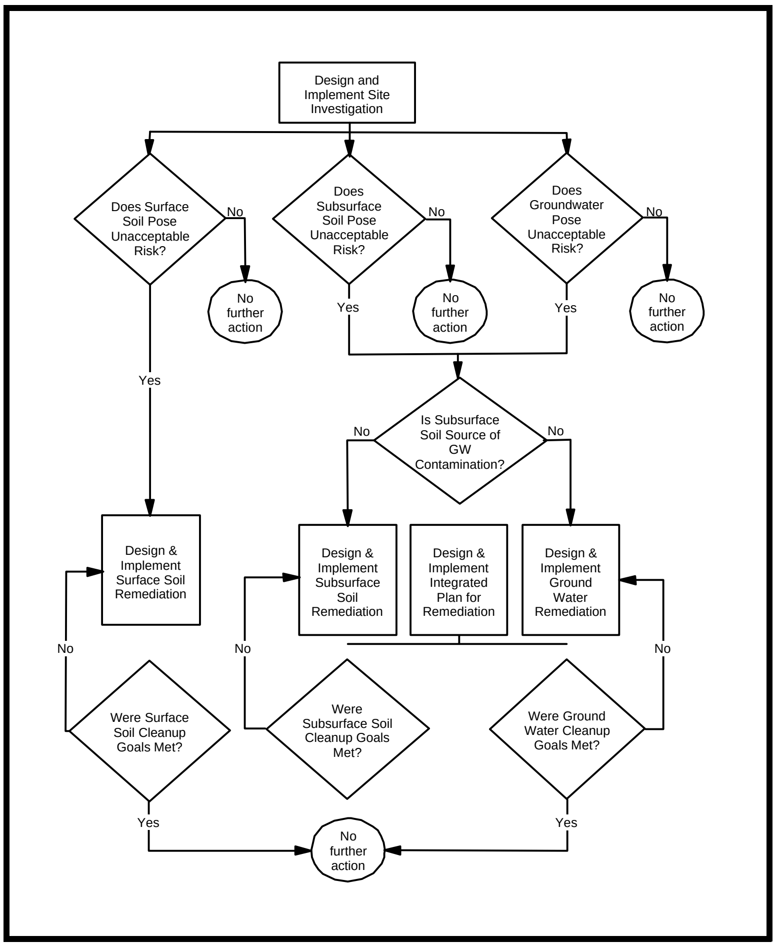


Figure 2-1. An Example of the DQO Process Applied to Multiple Decisions for a Hazardous Waste Investigation

2.3 Outputs

The output for this step is a decision statement that links the principal study question to possible actions that will solve the problem.

2.4 Examples

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

What was the Decision Statement? *The decision statement was determining whether waste fly ash was hazardous under RCRA regulations.*

What were the alternative actions? *If the waste was hazardous, disposal in a RCRA landfill was required. If it was not, the team decided that disposal in a sanitary landfill was acceptable.*

Example 2. Making Decisions About Household Dust for Lead Hazard Assessment

What was the Decision Statement? *The decision statement was determining if there were significant levels of lead in floor dust at the residence.*

What were the alternative actions? *If yes, the team planned follow-up testing to determine whether immediately dangerous contamination existed and the location of the contamination in the property. If no, the team decided there was not a potential lead hazard, and testing was discontinued.*

Example 3. Making Decisions About Urban Air Quality Compliance

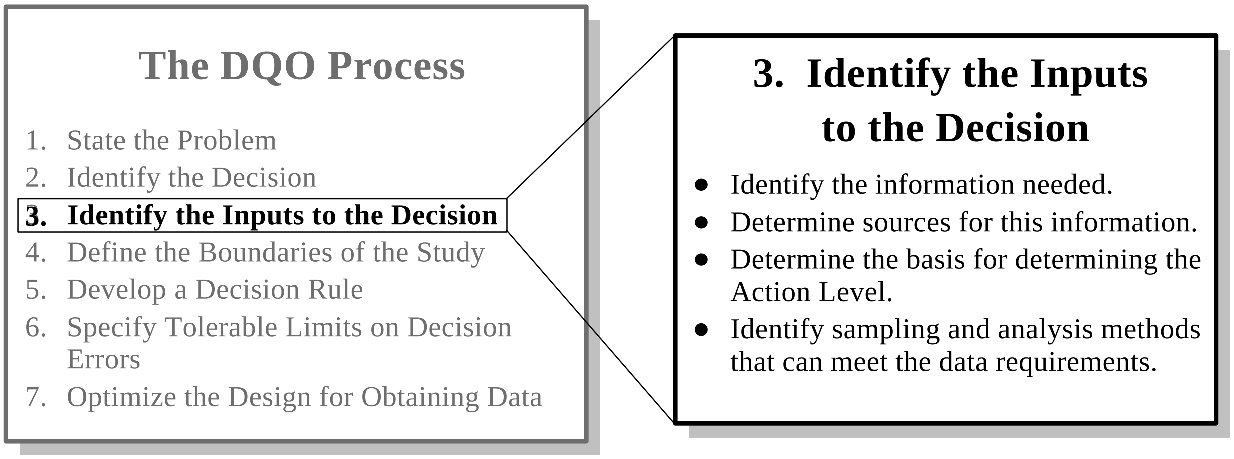
What was the decision statement? *The decision statement was determining if the PMSA of concern was in attainment for* $PM_{2.5}$.

What were the alternative actions? *If yes, monitoring was continued. If no, monitoring was continued and the* $PM_{2.5}$ *control strategies outlined in the State Implementation Plan (SIP) were implemented.*

Looking Ahead to other DQO steps:

- The principal study question will be used in constructing the baseline and alternative conditions in Step 6.
- Alternative actions will form the basis for determining the potential consequences of committing a decision error as addressed in Step 6.

CHAPTER 3
STEP 3. IDENTIFY THE INPUTS TO THE DECISION



After reading this chapter you should know the kinds of information that are required to investigate the problem and whether appropriate sampling and analytical methods are available.

3.1 Background

This step builds on the previous steps where you have:

- identified members of a planning team, including decision makers;
- concisely described the problem;
- developed a conceptual model of the environmental problem to be investigated; and
- identified the decision that needs to be made.

In Step 3 of the DQO Process you should identify the kind of information that is needed to resolve the decision statement and potential sources of this information (new data or existing data). This information should include the decision values (e.g., concentration of contaminants) information about its derivation. You should also determine if the appropriate analytical methodology exists to measure the environmental characteristics. Once you have determined what needs to be measured, you may refine the specifications and criteria for these measurements in later steps of the DQO Process.

3.2 Activities

In this step you should:

- identify the kinds of information needed;
- identify the sources of information;
- determine the basis for setting the Action Level; and
- confirm the appropriateness of proposed sampling and analyses methods.

How do you identify the kinds of information that you will need? You may identify information needs by asking the following questions:

- Is information on the physical properties of the media required?
- Is information on the chemical or radiological characteristics of the matrix needed?
- Can existing data be used to make the decision?
- Do we need to make new measurements of environmental characteristics?

If you decide that new measurements are needed, you should develop a list of characteristics that need to be measured to make the decision. For example, if the information can be obtained as an output from an environmental model (e.g., ground water transport), then the list of characteristics should include the inputs required for the model.

If the decision can be based on existing data, then the sources of these data should be examined to the extent possible to ensure that they are acceptable. If you consider integrating new data with existing data, parameters in the existing database need to be examined so that new samples can be collected (or analyzed) in a similar way and that the databases for new and existing data include common parameters. In some cases, statistical expertise is required to evaluate databases for possible aggregation because data collected for different purposes may not be compatible. For example, studies that model exposure to environmental contaminants may link environmental, toxicological, biological, geological, and census data. In these cases, issues such as physical properties of contaminants, environmental media, ingestion and inhalation rates, cancer slope factors, plant uptake rates, meteorological conditions, latitude, longitude, location of population centers and water bodies, and population density are inputs for evaluating exposure to the contaminant. Meta-data analysis offers the planning team options for using existing databases in conjunction with newly collected data. Existing data will also be evaluated quantitatively in Step 7, Optimize the Design for Obtaining Data.

How should you identify the source of the information? You should identify and document the sources for the information needed to resolve the decision. These sources may include results of previous data collections, historical records, regulatory guidance, professional judgment, scientific literature, or new data collections.

How do you determine the basis for the Action Level? The value for action is the threshold value (chosen in Step 5 of the DQO Process) that provides the criterion for choosing among alternative actions (e.g., whether to take action or not to take action or whether to choose action 1 versus action 2). Action Levels are concentrations of contaminants that are either based on regulatory requirements, based on risk assessments, based on performance criteria for analytical methodology (limitations of technology), or based on a reference standard. In this step, it is important for you to understand how the Action Level will be derived. In other words, you need to understand what information will be used to determine the Action Level, such as a promulgated regulation or a project-specific risk assessment. The actual numerical value of the Action Level need not be specified until DQO Process Step 5, Develop a Decision Rule, but a potential Action Level should be established. If the Action Level is based on a regulatory requirement, then the planning team will know the numerical value of the Action level at this step. However, if the Action Level is based on a risk assessment or other performance criterion, it may be best to defer the specification of the numerical value until after the study boundaries have been specified in DQO Process Step 4.

If the decision will be made relative to background concentrations (rather than a quantitative limit), then you should determine what constitutes background. Characteristics of the background need to be consistent with the characteristics of the area to be investigated. The actual numerical value of the Action Level will be established in Step 5, Develop a Decision Rule.

How should you identify that sampling and analysis methods that can meet the data requirements? Using the list of environmental characteristics that pertain to the decision, you should develop a list of sampling and analytical methods that may be appropriate for the problem being investigated. For example, you should specify sampling considerations (e.g., quantities) required for detecting analytes at low concentrations and procedures required to collect these sample quantities. You should also identify analytical methods that have appropriate detection limits (the minimum concentration that can be measured and reported with a specific confidence that the analyte concentration is greater than zero). Detection limits are analyte-, matrix- and instrument-specific. For example, atomic absorption spectroscopy or inductively coupled plasma emission spectrometry may not be sensitive enough to measure lead levels in water samples; however, graphite furnace atomic absorption spectroscopy would be capable of making these measurements.

Great importance should be given to the problem of minimizing bias as this is an important performance characteristic of sampling and analysis. The decision error rates to be established in Step 6 of the DQO Process rely on bias being kept to a minimum. Six major causes of bias have been identified for environmental sampling and analysis (1) non-representative sampling; (2) instability of samples between sampling and analysis; (3) interferences and matrix effects in analysis; (4) inability to determine the relevant forms of the parameter being measured; (5) calibration; and (6) failure to blank-correct. Some of the EPA methods are particularly subject to bias in calibration. For example, EPA methods for analyses of phenols in water exhibit around 50% bias due to calibration. Methods known to exhibit large biases should be avoided if possible.

Additional considerations include requirements for certification of personnel, and laboratory accreditation or Performance-Based Measurement Systems (PBMS). Laboratories analyzing environmental samples should follow standard protocols and procedures or use performance-based methods. When measurement requires the analysis of chemical, biological, or radioactive samples, it is advisable to select a laboratory that is accredited to perform the analyses. Requirements for accreditation include having qualified personnel, appropriate instrumentation, standard operating procedures, and proficiency in the analysis of samples for specific analytes or programs. For example, laboratories analyzing lead in paint, dust, and soil samples must be accredited through the National Lead Laboratory Accreditation Program (NLLAP) to become "EPA recognized." According to the Department of Housing and Urban Development's Guidelines (HUD, 1995), "property owners, risk assessors, inspector technicians, and contractors should ensure that laboratory analyses are performed by an 'EPA-recognized' laboratory;" a requirement also of EPA and many States.

3.3 Outputs

The outputs from Step 3 are:

- a list of environmental characteristics that will be measured to enable the planning team to make the decision;
- a list of information sources or methods that indicate how each Action Level will be derived;
- a list of information that may be applicable to uses of the data in future investigations [e.g., inputs to models, associated meta-data analysis (e.g., using latitude, longitude, census data) that may be appropriate to use for combining existing databases with newly collected data]; and
- confirmation that sampling and analytical methods exist (or can be developed) to meet the detection limit criteria required for collecting data, given the appropriate magnitude of the Action Level.

3.4 Examples

It is in this step that numerical quantities start making their appearance in the DQO Process.

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

Identify the kind of information. *To resolve the decision statement, the planning team decided to measure the cadmium concentration in the leachate resulting from Toxicity Characteristic Leaching Procedure (TCLP) extraction. Existing pilot study data provided information about variability, but there was not enough information to resolve the decision statement.*

Identify the source of information. *The Action Level was based on RCRA toxicity regulations for cadmium in TCLP leachate which is specified as 1.0 mg L.*

What sampling and analytical methods were appropriate? *Cadmium was measured in the leachate according to the method specified in 40 CFR 261, App. II. The detection limit was well below the Action Level.*

Example 2. Making Decisions About Urban Air Quality Compliance

Identify the kind of information. *To resolve the decision statement, the planning team obtained three years of $PM_{2.5}$ concentration measurements from the existing monitoring network within the PMSA of concern.*

Identify the source of information. *The 24-hr $PM_{2.5}$ federal standard of 65 µg/m^3 is attained when 98 percent of the daily concentrations, measured over three years, are equal to or less than the standard.*

What sampling and analytical methods were appropriate? *The existing network consisted of three IMPROVE samplers, each equipped with a polytetrafluoroethylene (PTFE) membrane filter to collect aerosols for mass measurement. Gravimetry (electro-microbalance) was used as the method of quantitative analysis. The detection limit was well below the standard used for the Action Level.*

Looking Ahead to other DQO Steps:

- The effect of sampling methods (e.g., compositing) may affect the required detection limit and should be considered relative to analytical measurement methods. These issues are also considered in Steps 5 and Step 7.
- Criteria for existing data will be examined in Step 7, Optimize the Design for Collecting Data.
- Method detection limit and method quantitation limits identified in this step will be revisited in Step 7, Optimizing the Design for Collecting Data.

CHAPTER 4

STEP 4. DEFINE THE BOUNDARIES OF THE STUDY

The DQO Process

1. State the Problem
2. Identify the Decision
3. Identify the Inputs to the Decision
4. **Define the Boundaries of the Study**
5. Develop a Decision Rule
6. Specify Tolerable Limits on Decision Errors
7. Optimize the Design for Obtaining Data

4. Define the Boundaries of the Study

- Define the target population of interest.
- Specify the spatial boundaries that clarify what the data must represent.
- Determine the time frame for collecting data and making the decision.
- Determine the practical constraints on collecting data.
- Determine the smallest subpopulation, area, volume, or time for which separate decisions must be made.

After reading this chapter you should understand how to define the geographic and temporal boundaries of the problem, how to examine any practical constraints to collecting data, and factors that affect your selection of the unit for decision making.

4.1 Background

This step builds on the previous steps where you have:

- identified members of the planning team, including decision makers;
- concisely described the problem;
- developed a conceptual model of the environmental problem to be investigated;
- identified the decision that needs to be made; and
- identified sources of information, potential Action Levels, and possible measurement methods that are appropriate.

In Step 4 of the DQO Process, you should identify the target population of interest and specify the spatial and temporal features of that population that are pertinent for decision making.

It is difficult to interpret data that have not been drawn from a well-defined target population. The term "target population" refers to the total collection or universe of objects, or sampling units, to be studied and from which samples will be drawn. (In this context, the term "sample" means the individual member, or unit, of the target population that is selected and measured or observed, such as a 100-gram scoop of soil, a cubic meter of air, a single fish, or single radiation measurement.) The term "sampling unit" is used in the more general and theoretical context when defining how the target population will be broken down into elementary components or members that can be selected and measured or observed. When the target population is made up of "natural units," such as people, plants, or fish, then the definition of a sampling unit is straightforward. However, many environmental studies involve target populations made up of continuous media, such as air, water, or soil. In this context, the sampling unit must be defined as some volume or mass to be selected which is often called the sample support (Myers, 1997). The actual determination of the optimal size of a sampling unit for environmental data collection efforts can be complicated, and usually will be addressed as a part of the sampling design in Step 7. Here in Step 4, the planning team should be able to provide a first approximation of the sampling unit definition when specifying the target population.

Quite often in environmental studies the target population is the set of all possible environmental samples (e.g., volume of soil, water, or air) that, taken together, constitute the geographic area of interest. The purpose of this step is to unambiguously define the spatial and temporal features of each environmental medium within a specific area or time period covered in the decision. A clear definition of the target population and its characteristics to the decision maker will make data interpretation more straightforward. The boundaries of the population include:

- spatial boundaries that define the physical area to be studied and generally where samples will be collected, and
- temporal boundaries that describe the time frame that the study will represent and when the samples should be taken.

You should use boundaries to ensure that the data collection design incorporates the time periods in which the study and decision should be implemented, areas where samples will be collected, and the time period to which the decision should apply. This should help you collect data that are representative of the population being studied. Defining boundaries before the data are collected can also prevent inappropriate combining of data sets in a way that masks useful information. The conceptual model that you developed in Step 1 of the DQO Process should provide essential input into defining the spatial boundaries.

Practical constraints that could interfere with sampling should also be identified in this step. A practical constraint is any hindrance or obstacle (such as fences, property access, water bodies) that may interfere with collecting a complete data set. These constraints may limit the spatial and/or temporal boundaries or regions that will be included in the study population and hence, the inferences (conclusions) that can be made with the study data.

As the final decision depends on data that are aggregated, you should carefully identify the size of "decision" units within which the data will be combined to make the decision. Factors such as areas of potential risk, limits of remediation technology, future land uses, and activity patterns, may impact the size of the decision unit selected.

4.2 Activities

In this step you should:

- define the target population,
- determine the spatial and temporal boundaries,
- identify practical constraints, and
- define the scale of decision making.

How do you define the target population? It is important for you to clearly define the target population to be sampled. The target population is usually the set of all environmental samples about which the decision maker wants to draw conclusions. In a number of cases, defining the target population for an environmental study requires specifying the medium, such as ground water, ambient air, surface soil, etc. It may be helpful to "work backwards" and think of how you would define an individual sampling unit when trying to develop a clear definition of the target population.

How do you determine the spatial boundaries of the decision statement?

1. Define the geographic area applicable for the decision making.

You should define the entire geographic area where data are to be collected using distinctive physical features such as volume, length, width, or boundaries. Some examples of geographic areas are the metropolitan city limits, the soil within the property boundaries down to a depth of 6 inches, a specific water body, length along a shoreline, or the natural habitat range of a particular animal species. It is important to state as definitively as possible the media and geographic area; this statement may include soil depth, water depth, or distance inside a fence line. You should be careful when designating areas that are on the periphery of the geographic area because peripheral samples are subject to edge effects and contamination that is not associated with the spatial boundaries designated for the decision making. In Figure 4-1 the geographic area of the study has been indicated on a map in the area with a grid.

2. Divide the population into subsets that have relatively homogeneous characteristics.

You may consider dividing the target population into subpopulations that are relatively homogeneous within each area or subunit. When combined with an appropriate sampling design in Step 7, Optimize the Design for Obtaining Data, this approach can reduce the

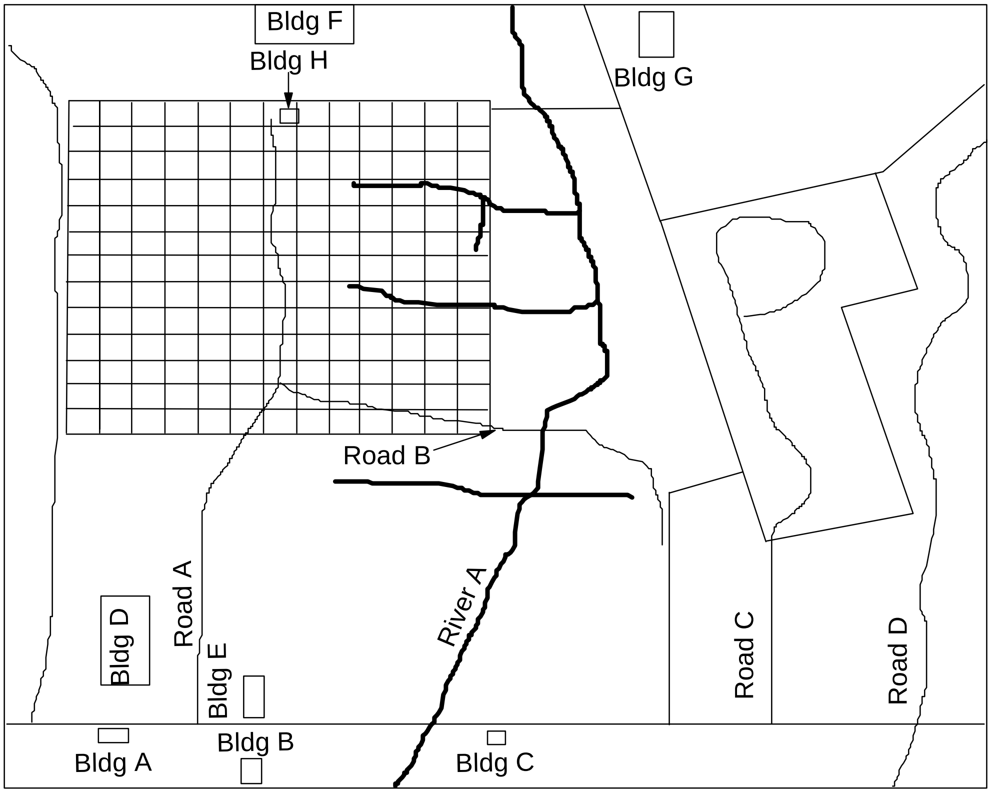


Figure 4-1. Geographic Boundaries Delineated Using a Map

number of samples required to meet the tolerable limits on decision errors (Step 6), and, thus, allow more efficient use of resources. It is often helpful to consider subdividing the target population in this way at this step because the planning team is focused on their understanding of how the target population's features and characteristics relate to the decision. The planning team can use its knowledge of the conceptual model (developed in Step 1, State the Problem) to consider how the characteristics of interest for the target population vary or change over space and time. This information will be useful when completing the subsequent activities in this step, and when considering alternative sampling designs (such as stratified random sampling) in Step 7, Optimize the Design for Collecting Data.

How do you determine the temporal boundaries of the decision statement?

1. Determine when to collect data.

Conditions may vary over the course of a study because of time-related phenomena such as weather conditions, seasons, operation of equipment under different environmental conditions, or activity patterns. Examples of these variations include seasonal ground water levels, daily or hourly airborne contaminant levels in metropolitan areas, and fluctuations in pollutant discharges from industrial sources. These variations may impact the success of your data collection and the interpretation of data results. You should determine when conditions are most favorable for collecting data and select the most appropriate time period to collect data. For example, you may consider the measurement stability of the following:

- measurement of lead in dust on window sills may show higher concentrations during the summer when windows are raised and paint/dust accumulates on the window sill;

- terrestrial background radiation levels may change due to shielding effects related to soil dampness;

- measurement of pesticides on surfaces may show greater variations in the summer because of higher temperatures and volatilization;

- instruments may not give accurate measurements when temperatures are colder; or

- measurements of airborne particulate matter may not be accurate if the sampling is conducted in the wetter winter months rather than the drier summer months.

2. Determine the time frame for decision making.

It may not be possible to collect data over the full time period to which the decision will apply. This is particularly true for decisions that project future uses, such as "Brownfields" (an inactive property being put back into productive economic use after the relevant environmental agencies agree that contaminants once present at the property no longer pose an unacceptable risk to human health or to the environment). You should evaluate the population and determine the optimum time frame for collecting data, given that the medium may change over time, or the time constraints of the study relative to the decision making. You should specify if you are making a decision on whether the current medium meets a criterion, or if the medium will meet the criterion for some future time periods. You should define time frames for the overall population and for any subpopulation of interest; then address discrepancies that may arise from the short time frame of data collection relative to the long time periods for implementing decisions. For example, you may develop a statement for the decision to be based on:

- the condition of contaminant leaching into ground water over a period of a hundred years, or

- the risk conditions of an average resident over their average length of residence, which is estimated to be 8 years.

What kinds of practical constraints on collecting data should you identify? You should discuss the proposed data collection activities in light of any practical constraints that are related to the spatial or temporal boundaries of the study, to the availability of personnel, or to time and budgetary constraints (identified in Step 1 of the DQO Process). These constraints could include access to the property, availability and operation of equipment, and environmental conditions when sampling is not possible (high humidity, freezing temperatures). For example:

- it may not be possible to take surface soil samples beyond the east boundaries of a property under investigation because permission has not been granted by the owner of the adjacent property, or

- it may not be possible to collect dust wipe samples (for lead) if certified risk assessors are not available to supervise the sampling.

How do you define the scale of decision making? The scale of decision making refers to the way the planning team has delineated decision units and identified the smallest unit of area, volume, or time where data will be collected, analyzed, aggregated, and interpreted to make a decision and control decision error. The consequences of making incorrect decisions (Step 6) are associated with the size, location, and shape of the decision unit. It is important to consider present and future uses for the decision unit, where the decision unit is located (remote area versus densely populated area) and requirements for potential remediation. The consequences of a wrong decision (even if quite small) should be carefully considered. For example, if a decision, based on the data collected, results in a large land area being cleaned (soil removed to a certified disposal area) when the true conditions would not warrant a cleanup action, then the decision maker may have to incur a large cost unnecessarily. The area of land being sampled (decision unit) should be appropriate to the potential risk of an incorrect decision. When establishing the scale of decision making, take care that this is not so large that an incorrect decision could result in either an unacceptable resource expense or unacceptable threat to human health or the environment.

The question of using one large decision unit versus a number of small decision units is also an important consideration for the planning team. If there are many decision units and multiple decisions are made, then the team needs to consider whether they want to limit the probability of leaving *at least* one contaminated unit unremediated (rather than just *any* one unit). The chance of at least one incorrect decision increases exponentially. This is known as "comparison-wise" versus "experiment-wise" error rates. If multiple decisions are expected, and the planning team determines that the overall probability of making at least one decision error must be controlled, then consultation with a statistician is advisable.

The planning team may establish decision units based on several considerations:

- Risk – The scale of decision making based on risk is determined by the potential exposure an area presents; an individual unit of risk is called an exposure unit. For example, in a study where the *decision statement* is, "Determine whether or not the concentration of lead in soil poses an unacceptable health risk to children and requires remediation," the *geographic area* is the top 6 inches of soil within the property boundaries, and the *population* is the collection of individual volumes of soil that could be selected for inclusion in a sample. The *scale of decision making* could be the size that corresponds to the area where children derive the majority of their exposure (such as a play area or an average residential lot size if the future land use will be residential). Studying the area at this scale will be protective of children, a sensitive population in risk assessment.

- Technological Considerations – A technological scale for decision making is defined as the most efficient area or volume that can be remediated with a selected technology. An example of a remediation unit would be the area of soil that can be removed by available technology under estimated working conditions if the decision will be made on the basis of bulldozer-pass-volume.

- Temporal Considerations – A temporal scale of decision making is based on exposure from constituents in media that change over time. For example, in order to regulate water quality, it would be useful to set a scale of decision making that reduces the time between sampling events. Using this scale the planning team could minimize the potential adverse effects in case the water quality changed between sampling events.

- Financial Scale – The financial scale is based on the actual cost to remediate a specified decision unit. For example, if a large exposure unit is identified, the costs of remediation could be prohibitive. In this case, the planning team may want to develop a different scale to narrow the data collection process and identify the distinct areas of contamination.

- Other – The possibility of “hot spots” (areas of high concentration of a contaminant) may be apparent to the planning team from the history of the property. In cases where previous knowledge (or planning team judgment) includes identification of areas that have a higher potential for contamination, a scale may be developed to specifically represent these areas.

Further information on sampling designs and associated definitions on methods may be obtained from Gilbert (1987) and Thompson (1992).

4.3 Outputs

The outputs of this step are:

- detailed descriptions of the characteristics that define the population to be sampled,
- detailed descriptions of geographic limits (spatial boundaries) that are appropriate for the data collection and decision making,
- time frame appropriate for collecting data and making the decision,
- list of practical constraints that may interfere with the data collection, and
- appropriate scale for decision making.

4.4 Examples

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

What population was sampled? *Individual samples of fly ash that comprise the container were sampled and analyzed. The fly ash was not mixed with any other constituents except water (used for dust control). Each container of ash filled at least 70% of the waste container. In cases where the container was less than 70% full, the container was kept on-site until more ash was produced and the container was filled to capacity.*

What were the spatial boundaries? *Decisions applied to each container load of fly ash waste as the actual container made a natural physical boundary.*

What was an appropriate time frame for sampling? *The decision was to be based on the current concentration of cadmium in the waste fly ash. Contained in the containers, the waste did not pose a threat to humans or the environment. Additionally, since the fly ash was not subject to change, disintegration, or alteration, the decision about the waste characteristics was not influenced by temporal constraints. To expedite decision making, however, the planning team placed deadlines on sampling and reporting. The waste fly ash was tested within 48 hours of being loaded onto waste containers. The analytical results from each sampling round were completed and reported within 5 working days of sampling. The container was not used again until analysis had been completed and evaluated.*

What were the practical constraints for collecting data? *The most important practical constraint was the ability to take samples from the waste fly ash stored in the containers. Although the containers had open access, special procedures and methods based on EPA protocols were implemented so that samples were representative of the entire depth of the waste fly ash.*
What was the scale for decision making? *The decision unit was each container of waste fly ash.*

Example 2. Making Decisions about Urban Air Quality Compliance

What population was sampled? *The volume from samplers that represented fine particulate matter from urban air was sampled and analyzed.*

What were the spatial boundaries? *The spatial boundary was defined by the region represented by the PMSA of concern.*

What was an appropriate time frame for sampling? *The temporal boundaries had two components. Individual observations (i.e., daily concentrations) were based on 24-hour averages obtained each day of monitoring. The standard required that a decision be made, and subsequent action taken, after 3 years of data collection. Monitoring results were assumed to characterize both the near past (i.e., previous 3 years) and current air quality, unless substantial upward or downward trends were observed in daily* $PM_{2.5}$ *concentrations.*

What were the practical constraints for collecting data? *Given that the monitoring network and sampling plan were already established, the only potential practical constraint was the continual operation of the monitoring network. If a monitor became defective, the planning team decided to either collect a smaller sample size (number of samples) over the 3-year period, or to extend the period for collecting data to obtain the required number of samples.*

What was the scale for decision making? *The decision unit was the geographic region represented by the PMSA over the 3-year period of data collection.*

Looking ahead to other DQO steps:

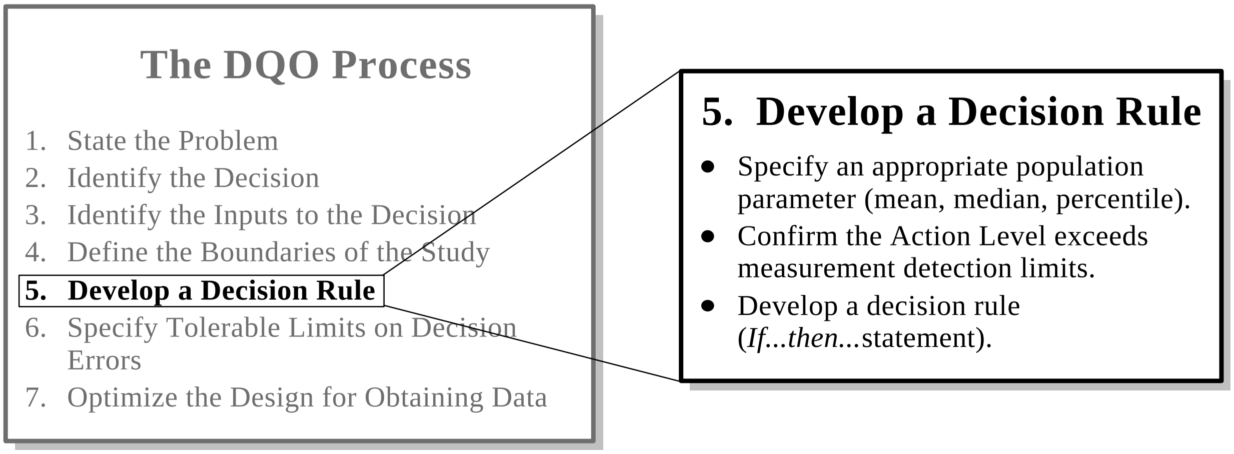
- The way in which you divide the problem into strata may affect the number of samples required to meet the tolerable limits for decision errors specified in Step 6.

- The scale of decision making may have an impact on the performance criteria and the consequences of decision errors in Step 6.

- Outputs from Step 4 may potentially affect the sampling design developed in Step 7.

CHAPTER 5

STEP 5. DEVELOP A DECISION RULE



After reading this chapter you should know how to construct a theoretical "If...then..." decision rule that defines how the decision maker would choose among alternative actions if the true state of nature could be known with certainty.

5.1 Background

This step builds on the previous steps where you have:

- identified members of the planning team, including decision makers;
- concisely described the problem;
- developed a conceptual model of the environmental problem to be investigated;
- identified the decision that needs to be made;
- identify sources of information, potential Action Levels, and possible measurement methods that are appropriate; and
- decided on the spatial/temporal boundaries of the decision.

In Step 5 of the DQO Process, you should imagine that perfect information will be available for making decisions. Under the assumption that there is no uncertainty in the decision making process, the planning team integrates the outputs from previous steps with inputs developed in Step 5 into an unambiguous "*If...then...*" statement (*theoretical* decision rule). This rule describes the conditions under which possible alternative actions would be chosen.

You need to conduct the following activities in this step:

- specify the population parameter (e.g., mean, median, percentile, or total amount) that the DQO planning team considers to be important to make decisions about the target population;

- choose an Action Level (if not already established) that sets the boundary between one outcome of the decision process and another outcome;

- select the measurement and analysis methods capable of performing over the expected rate of values and verify that the Action Level is greater than the detection limit of the measurement method that will be used; and

- construct the theoretical "*If...then...*" decision rule by combining the *true* value of the selected population parameter and the Action Level (from above) with the scale of decision making (from Step 4) and the alternative actions (from Step 2). This decision rule will state the alternative actions that would be taken depending on the true value of the parameter relative to the Action Level.

Note that the "*If...then...*" decision rule is a *theoretical* rule because it is stated in terms of the *true* value of the population parameter, even though in reality the true value is never known. In practice, the decision is made by using an *operational* decision rule that uses an *estimate* (based on the actual data) of the true value of the population parameter. The reason for specifying the *theoretical* rule is to focus the attention of the DQO planning team on how they would make decisions if they had perfect knowledge of the population. This helps clarify what the team really wants to know to support the decision. In Step 7 of the DQO Process, the planning team will select the operational decision rule they believe will most efficiently meet the requirements specified in the first six steps of the DQO process.

5.2 Activities

In this step you should:

- define the population parameter;
- determine what action is needed; and
- confirm that the Action Level exceeds minimum detection limits.

What population parameter best characterizes the population of interest? In this step you should select a population parameter (such as the true mean, median, percentile, or total amount) that summarizes the critical characteristic or feature of the population that will be compared to the Action Level to make a decision. In some cases, the parameter that must be used may be specified in a regulation. In other cases, the DQO planning team will select the parameter based on specific needs and considerations. A comparison of the different population parameters and their application to a decision rule is presented in Table 5-1.

Table 5-1. Population Parameters and Their Applicability to a Decision Rule

Parameter	**Definition**	**Example of Use**
Mean	Average	Central tendency: Comparison of middle part of population to Action Level. Appropriate for chemical that could cause cancer after a long-term chronic exposure. Use of the mean and the total amount of media (e.g., mass of soil or water) allows a planning team to estimate the total amount of a contaminant contained in the soil or water body. The mean is greatly influenced by extremes in the contaminant distribution, and not very useful if a large proportion of values are below the detection limit.
Median	Middle observation of distribution; 50th percentile; half of data is above and half is below	Better estimate of central tendency for a population that is highly skewed (nonsymmetrical). Also may be preferred if the population contains many values that are less than the measurement detection limit. The median is not a good choice if more than 50% of the population is less than the detection limit because a true median does not exist in this case. The median is not influenced by the extremes of the contaminant distribution.
Percentile	Specifies percent of sample that is below the given value; e.g., the 80th percentile should be chosen if you are interested in the value that is greater than 80% of the population.	For cases where only a small portion of the population can be allowed to exceed the Action Level. Sometimes selected if the decision rule is being developed for a chemical that can cause acute health effects. Also useful when a large part of the population contains values less than the detection limit. Often requires larger sample sizes than mean or median.

It must be noted, however, that the more complex the parameter chosen, the more complex will be the decision rule and accompanying data collection design. The most common parameter used in decision making is the population mean because the mean is frequently used to model random exposure to environmental contamination. Aside from scientific or policy considerations, the mathematical and statistical properties of the mean are well understood. You should consult a statistician if you are uncertain as to the choice of an appropriate parameter.

What Action Level is needed for the decision? In addition to specifying the population parameter, you will need to specify the Action Level that will be used to choose between courses of action. For example, the decision maker may take one action if the true value of the parameter exceeds a specified value (Action Level) and a different action otherwise. There are basically two kinds of Action Levels – those predetermined and those determined during the DQO Process.

Examples of predetermined Action Levels are fixed standards such as drinking water standards or technology-based standards. For example, in the area of childhood lead poisoning prevention, EPA's Office of Pollution Prevention and Toxics has proposed hazard levels for lead in residential dust and soil to protect children from significant lead exposures (40 CFR 745). Also, in the area of air quality control, EPA's Office of Air and Radiation has promulgated National Ambient Air Quality Standards for priority pollutants such as carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter (PM_{10}), and sulfur dioxide, as well as other pollutants that include fine particulate matter ($PM_{2.5}$) (40 CFR 50).

Examples of investigation-specific Action Levels are background standards or specific risk-based standards. For the case of investigation-specific Action Levels, one consideration in selecting the Action Level is its degree of conservatism, i.e., whether the level is a very low value or a higher value. You will need to decide whether to set the Action Level at a threshold of real concern, or at a lower (more conservative) value that, if exceeded to some degree, may not necessarily pose a serious risk. A more conservative Action Level may require a more sensitive analytical method that has appropriate detection limits.

Does the Action Level exceed measurement detection limits? You will need to determine the detection limit for each potential measurement method identified in Step 3. If the detection limit for a measurement method exceeds the Action Level, then a more sensitive method should be specified or a different approach should be used.

Detection limits are defined specific to an intended purpose. The DQO planning team should choose the definition that is most appropriate to the "*If...then...*" decision rule being used. For example, if the decision rule is used to decide if a contaminant exists at the study site, then the detection limit should be one that provides for a high probability of positive identification and presence in the matrix and a low probability of false confirmation. However, if the decision rule is used to compare a mean to a threshold action level, then the detection limit should be defined in terms of the reliability of quantitation.

5.3 Outputs

After you have completed the above activities, you can construct the theoretical "*If...then...*" decision rule by combining the selected population parameter and Action Level with the scale of decision making (from Step 4) and the alternative actions (from Step 2). An example of a theoretical decision rule is:

> *If* the true mean dioxin concentration in the surface 2 inches of soil of a decision unit (20 ft by 100 ft) exceeds 1 ppb, *then* remove a 6 inch layer of soil. *If* the true mean is not greater than 1 ppb, *then* do nothing.

5.4 Examples

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

What was the decision rule and Action Level? *The planning team was interested in the true mean concentration of cadmium in the TCLP leachate for each container. If the true mean concentration of cadmium from the fly ash leachate in each container load was greater than 1.0 mg/L, then the waste was considered hazardous and disposed of at a RCRA landfill. If the true mean concentration of cadmium from the waste fly ash leachate was less than 1.0 mg/L, then the waste was considered nonhazardous and disposed of in a sanitary landfill.*

Example 2. Making Decisions About Urban Air Quality Compliance

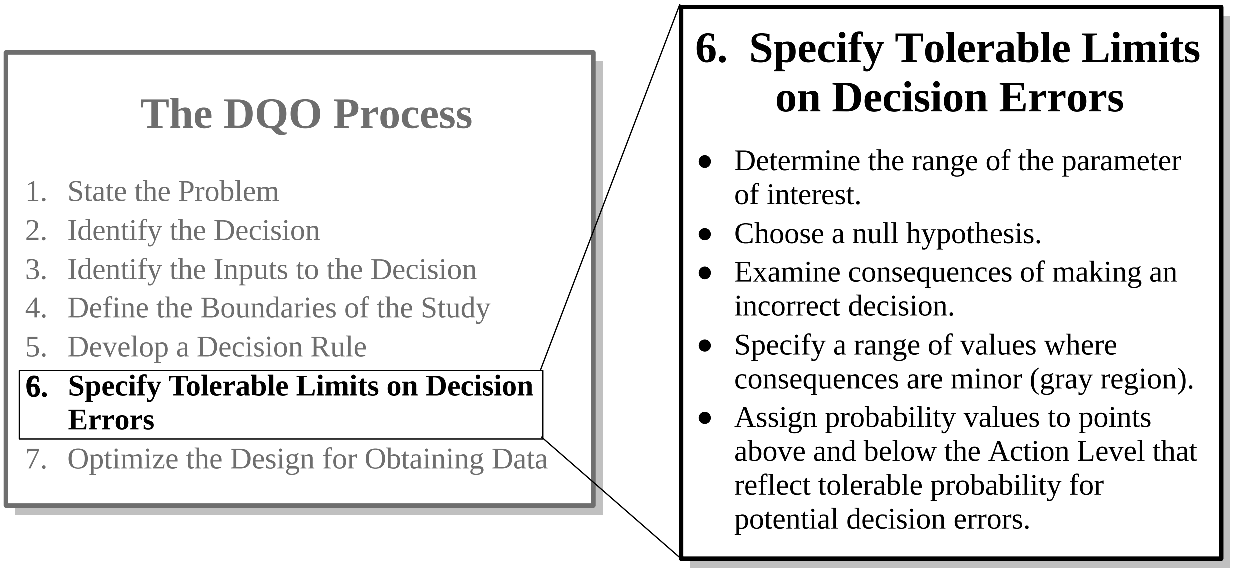
What was the decision rule and Action Level? *The population parameter of interest that characterizes $PM_{2.5}$ air quality was the true long-run proportion of daily concentrations falling below the 24-hr $PM_{2.5}$ federal standard of 65 µg/m^3. If the true proportion of daily concentrations less than or equal to 65 µg/m^3 was greater than or equal to 0.98, then the local region was considered in attainment for $PM_{2.5}$, so monitoring was continued, but no other action was taken. If the true proportion of daily concentrations less than or equal to 65 µg/m^3 was less than 0.98, then the local region was considered in nonattainment for $PM_{2.5}$, so monitoring was continued and the $PM_{2.5}$ control strategies outlined in the State Implementation Plan were implemented.*

Looking ahead to other DQO steps:

- Step 6 provides key information that will be used with the outputs of this step to select the sampling and analysis methods.
- Step 6 addresses the questions of what risk of an incorrect decision can be tolerated.

CHAPTER 6

STEP 6. SPECIFY TOLERABLE LIMITS ON DECISION ERRORS



After reading this chapter you should understand why specifying tolerable limits on decision errors is required to continue the DQO Process and the meaning of the concepts and terms used in completing this task. You should be able to specify tolerable limits on decision errors for your problem.

6.1 Background

This step builds on the previous steps where you have:

- identified members of the planning team, including decision makers;
- concisely described the problem;
- developed a conceptual model of the environmental problem to be investigated;
- identified the decision that needs to be made;
- determined the type of information required, the Action Level, and probable measurement methods;
- decided on the spatial/temporal boundaries of the decision; and
- decided on the theoretical *"if ... then"* decision rule.

In Step 6 of the DQO Process you no longer imagine that perfect information on unlimited data will be available for making decisions as you did in Step 5. You now face the reality that you will not have perfect information upon which to base your decisions. Instead you will be making decisions based on a set of sample data subject to various errors which is only part of the much larger population of interest. Inherent in the use of sampled data for making decisions is the fact that those decisions can, and occasionally will, be wrong. In this step of the DQO Process, numerical values will be considered in an attempt to keep the possibility of a decision error to a minimum.

The purpose of Step 6 is to specify quantitative performance goals for choosing between the two alternative actions decision rule. These goals are expressed as probabilities of making errors in your decision at selected true values of the parameter of interest specified in Step 5. These decision performance goal probabilities are a statement of the amount of uncertainty you are willing to tolerate in your decisions at a few specific critical true values of the parameter of interest.

6.2 Activities

You should conduct the following activities in Step 6:

- determine the sources of error in the sample data set;
- establish a plausible range of values for the parameter of interest;
- define the two types of potential decision errors and the consequences of making those errors;
- determine how to manage potential decision errors;
- select the baseline condition of the environment that will be assumed to be true in the absence of overwhelming evidence to the contrary;
- specify a range of possible parameter values where the consequences of a false acceptance decision error are considered tolerable (gray region); and
- assign probability values at several true value points above and below the Action Level that reflect your tolerable probability for the occurrence of decision errors.

What are sources of error in the sample data set? A decision error occurs when the sample data set misleads you into making the wrong decision and, therefore, taking the wrong response action. The possibility of a decision error exists because your decision is based on sample data that are incomplete and never perfect. Even though the data collection method and analysis method may be unbiased, the sample data are subject to random and systematic errors at different stages of acquisition, from field collection to sample analysis. The combination of all these errors is called "total study error." There can be many contributors to total study error, but there are typically two main components:

- Sampling design error – This error is influenced by the inherent variability of the population over space and time, the sample collection design, and the number of samples. It is usually impractical to measure the entire decision unit, and limited sampling may miss some features of the natural variation of the measurement of interest. Sampling design error occurs when the data collection design does not capture the complete variability within the decision unit to the extent appropriate for the decision of interest. Sampling design error can lead to random error (i.e., variability or imprecision) and systematic error (bias) in estimates of population parameters.

- Measurement error – This error (variability) is influenced by imperfections in the measurement and analysis system. Random and systematic measurement errors are introduced in the measurement process during physical sample collection, sample handling, sample preparation, sample analysis, data reduction, transmission, and storage.

Total study error directly affects the probability of making decision errors. Therefore, it is essential for you to manage total study error by your choice of sample design and measurement system. This will enable you to control the possibility of making decision errors to acceptable levels. Figure 6-1 shows an example of how total study error (also known as Total Variability) can be broken down further into components that will relate to the data collection process.

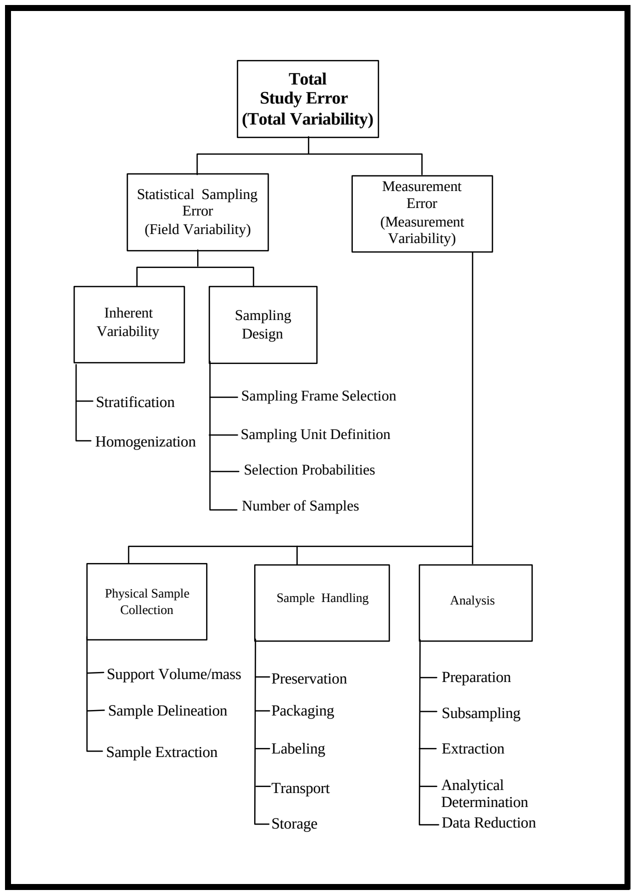


Figure 6-1. An Example of How Total Study Error Can Be Broken Down by Components

How do you establish a plausible range of values for the parameter of interest? You should establish a plausible range of values for the parameter of interest by approximating its upper and lower bounds based on currently available information, professional judgment, or historical data. This helps focus the process of defining probability limits on decision errors only on the relevant values of the parameter. For example, if the parameter of interest is a mean, the range might be defined using the lowest and highest concentrations at which the contaminant is thought to exist at the property. This range of values is useful when discussing the Decision Performance Goal Diagram (to be discussed later).

How are decision errors defined? If perfect knowledge of the true value of the parameter of interest in a decision unit were available to you, you could simply apply the theoretical decision rule from Step 5 to the known true value, make your decision, and not be concerned with decision errors. However, in real life you use sample data to make the decision and, consequently, the chance of a decision error becomes reality.

Due to the uncertainty inherent in decisions based on sample data, it is possible to get results that will not clearly tell you if the true value is below the Action Level or above the Action Level. It becomes necessary to label one of these two possibilities as the baseline condition so that a decision can still be made in these situations. The baseline condition then becomes the *de facto* decision outcome when there is insufficient evidence to refute it and the other condition then becomes the alternative decision. For example, in legal decisions on human behavior, the baseline condition is "innocent until proven guilty."

In environmental decisions affecting human health and the environment, the baseline condition is more flexible and may depend on your situation. In certain instances, the baseline condition for your problem may be prescribed for you in regulations. For example the baseline condition in RCRA facility monitoring is that the concentrations in ground water are less than or equal to the background concentrations. If the baseline condition is not specified for you, you must select it based on careful consideration of the consequences of making decision errors and taking the wrong actions. This selection may be based on your conceptual model for the decision unit, i.e., based on prior information, you have good cause to think that the true value for the decision unit is above the Action Level.

The probabilities of making decision errors with sample data can be quantified through the use of a statistical decision procedure known as hypothesis testing. When hypothesis testing is applied to decision making, the sample data are used to choose between a baseline condition of the environment and an alternative condition. The test can then be used to show either that there is insufficient evidence to indicate that the baseline condition is false (and therefore you accept the default that the baseline condition is presumed to be true), or that the baseline condition is probably false (and therefore the alternative condition is probably true). The burden of proof is placed on rejecting the baseline condition. This approach is taken because the test-of-hypothesis structure maintains the baseline condition as being true until overwhelming evidence is presented to indicate that the baseline condition is not true. It is *critical* to understand that selection of the baseline condition is important to the outcome of the decision process. The exact same set of sample data from a decision unit can lead to different decisions depending on which possibility was chosen as the baseline condition.

A false rejection decision error[1] occurs when the limited amount of sample data lead you to decide that the baseline condition is probably false when it is really true. In the reverse case, a

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[1]In previous editions of *Guidance for Data Quality Objectives Process (EPA QA/G-4)* (U.S. EPA, 1994a), false rejection was called "false positive" and false acceptance was called "false negative."

false acceptance decision occurs when the sample data lead you to decide that the baseline condition is probably true when it is really false. To understand these definitions you may find it helpful to note that an acceptance decision is to decide the baseline condition is true and a rejection decision is to decide the alternative condition is true. Hence, a false rejection decision incorrectly decides that the alternative is true, and a false acceptance decision incorrectly decides that the baseline is true (see Table 6-1). For example, suppose you strongly believe that the true value of the parameter of interest exceeds the Action Level (i.e., the baseline condition states that the true value of the parameter of interest exceeds the Action Level). If your baseline assumption is actually correct and the sample data, by chance, contain an abnormally large proportion of low values, you would conclude that the true value of the parameter of interest does not exceed the Action Level. In reality, the true value did exceed the Action Level; therefore, you would then be making a false rejection decision error.

Table 6-1. False Acceptance and False Rejection Decisions

Decision Based on Sample Data	**True Condition**	
	Baseline is True	Alternative is True
Decide baseline is true	Correct Decision	*Decision Error (False Acceptance)*
Decide alternative is true	*Decision Error (False Rejection)*	Correct Decision

Another example would be a regulatory situation in which an effluent discharge should not exceed the permitted level. Your baseline condition would be that the true parameter value of the effluent is less than or equal to the permitted level; your alternative would be that the true parameter exceeds the permitted level. If the baseline condition was actually correct, but your sample data happened to have a preponderance of high values, you could conclude the effluent exceeds the permitted level. This would be a false rejection decision error and is sometimes called a false positive decision error. The reverse (a false acceptance decision error) is sometimes called a false negative decision error.

In the statistical language of hypothesis testing, the baseline condition is called the null hypothesis (H_o) and the alternative condition is called the alternative hypothesis (H_a). A false rejection decision error occurs when the decision maker rejects the null hypothesis when it is really true; a false acceptance decision error occurs when the decision maker fails to reject the null hypothesis when it is really false. Statisticians label a false rejection decision error as a Type I error and the measure of the size of this error (probability) is labeled alpha (α), the hypothesis test's level of significance. Statisticians label a false acceptance decision error as a Type II error; the measure of the size of this error (probability) is labeled beta (β). Both alpha and beta are expressed numerically as probabilities. The statistical power of a test of hypothesis is equal to $1-\beta$.

How can you manage potential decision errors? Although the possibilities of making decision errors can never be eliminated totally, you can manage them. To manage the possibilities of decision errors, your planning team focuses mostly on the largest components of total study error. If the sampling design error is believed to be relatively large, you can manage the chance of making a decision error by collecting a larger number of samples or developing a better sampling design, i.e., a better way of deciding where and when to sample. If the analytical component of the measurement error is believed to be relatively large, you can manage it by analyzing multiple individual samples, or by using more precise and accurate analytical methods. In some instances your planning team will actually be able to address both components of total error.

In some cases, placing a stringent (i.e., very small) limit on the possibility of both types of decision errors is unnecessary for making a defensible decision. If the consequences of one decision error are relatively minor, it may be possible for you to make a defensible decision based on relatively imprecise data or on a small amount of data. For example, in the early phases of a hazardous site assessment, the consequences of deciding that an area of a site is hazardous, when in reality it is not, may be relatively minor. In this case, you may make a decision during this stage of the investigation by using a moderate amount of data, analyzed using a field screening analytical method, and only using a limited number of confirmatory analyses.

Conversely, if the consequences of decision errors are severe (i.e., human health effects), you will want to develop a data collection design that exercises more control over sampling design and measurement error. For example, in a waste discharge investigation, deciding that a discharge is not hazardous when it truly is hazardous may have serious consequences because the discharge may pose a risk to human health and to the environment. Therefore, the decision made during this phase of the investigation may need to be supported by a large amount of data and analyzed using very precise and accurate analytical methods.

You will need to balance the consequences of decision errors against the cost of limiting the possibility of these errors. It may be necessary to iterate between Step 6 and Step 7 several times before this balance between limits on decision errors and costs of data collection design is achieved. This is not an easy part of the DQO Process. The balancing of the risk of incorrect decisions with potential consequences should be explored fully by your planning team. Resorting to arbitrary values such as "false rejection = 0.05, false acceptance = 0.20" is not recommended. The circumstances of the investigation may allow for a less stringent option, or possibly a more stringent requirement. In the early stages of DQO development, it is recommended that a very stringent choice be made and the consequences of that choice be investigated by your planning team during their activities under Step 7 of the DQO Process.

Decision errors can also occur that are independent of the use of statistical hypothesis testing. An example could be that the data were manipulated prior to use in decision making by an outside agent censoring the reported values. This is sometimes found in the collection of screening data where insufficient training on the importance of adherence to QA protocol and practice has resulted in data being recorded in an erroneous fashion. If data has been manipulated prior to use in decision making, the assumed false rejection and false acceptance error rates become invalid.

How can you represent the quality of a decision process? There is a graphical construct called a Decision Performance Curve that represents the quality of a decision process. In statistical hypothesis testing usage, an operating characteristic curve or a power curve serve similar purposes. Figure 6-2 depicts an example Decision Performance Curve and shows the range of possible true values of the parameter of interest (including the Action Level) decided in Step 6, on the x-axis and the range of probabilities (0 to 1) of deciding that the parameter of interest exceeds the Action Level along the y-axis. Intuitively, the probability of deciding the parameter of interest exceeds the Action Level is small for low true values and increases as the true value increases. A full Decision Performance Curve is actually a continuous curve from the lowest true value to the highest true value. If you had perfect knowledge of the true value of the parameter of interest, a Decision Performance Curve would have a probability of 0 for any true value less than the Action Level and jump to a probability of 1 for any true value above the Action Level. Since you are dealing with sampled data (containing error), the probabilities will more realistically increase gradually from near 0 for true values far below the Action Level, to near 1 for true values far above the Action Level. The shape and steepness of this curve is a consequence of the sample design and number of samples taken.

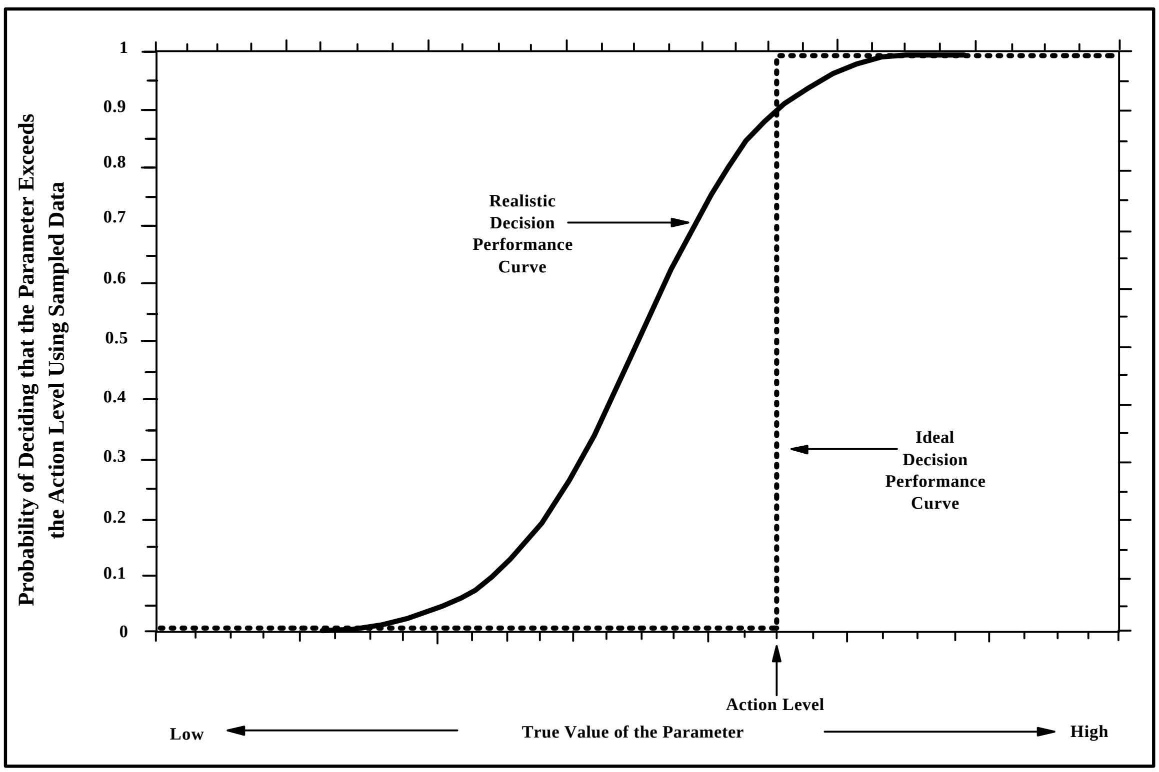

Figure 6-2. An Example of a Decision Performance Curve

The following subsections describe the process of selecting a baseline condition, defining a gray region, and establishing Decision Performance Goals (DPGs) by stating tolerable decision error probabilities at a few critical true values of the parameter of interest. The combined information from these activities can then be displayed graphically as a Decision Performance Goal Diagram (DPGD) that approximates the Decision Performance Curve. This DPGD stipulates your tolerable risks of decision errors and allows you to communicate them to others, including your sample design team and all stakeholders. The Decision Performance Curve is then the overlay on the diagram and can be used to assess performance.

How do you select the baseline condition? If your baseline is not established by regulatory considerations, your planning team should define the baseline condition based on the relative consequences of the decision errors.

The baseline condition is the one that will be kept until overwhelming evidence (in the form of data to be collected) is presented to make you reject the baseline condition in favor of the alternative. You should use your evaluation of the potential consequences of the decision errors to establish which decision error has the more severe consequences near the Action Level. For example, you would judge the threat to public health against spending unnecessary resources.

Define the baseline condition and the alternative condition and assign the terms "false rejection" and "false acceptance" to the appropriate decision error. An alternative name for "false rejection" is "false positive" or Type I Error (by statisticians principally). The alternative name for "false acceptance" is "false negative" or Type II Error. A false rejection decision error corresponds to the more severe decision error, and a false acceptance decision error corresponds to the less severe decision error.

You should designate the areas above and below the Action Level as the range where the two types of decision errors may occur. This activity has two steps:

1. Define both types of decision errors and establish the "true state of nature" for each decision error. The "true state of nature" is the actual condition of the parameter of interest in the decision unit which is unknown to the decision maker. You should state both decision errors in terms of the parameter of interest, the Action Level, and the alternative actions.

2. Specify and evaluate the potential consequences of each decision error. For example, the consequences of incorrectly deciding that the parameter is below the Action Level (when in fact it is above the Action Level) include potential threats to human health and to the environment. Conversely, the consequences of incorrectly deciding that the value of the parameter of interest is above the Action Level (when in fact it does not exceed the Action Level) include spending unnecessary resources for further study.

   You should evaluate the potential consequences of decision errors at several points within the false rejection and false acceptance ranges. For example, the consequences of a decision error when the true parameter value is only 10% above the Action Level may be minimal because it may cause only a moderate increase in the risk to human health. Conversely, the consequences of a decision error when the true parameter is an order of magnitude above the Action Level may be severe because it could significantly increase the risk to human health and threaten the local ecosystem.

How do you specify a range of possible true parameter values where the consequences of a false acceptance decision error are considered tolerable (gray region)? The gray region is one component of the quantitative decision performance criteria that is specifically used to limit impractical and nonfeasible number of samples. The gray region is a range of true parameter values within the alternative condition near the Action Level where it is "too close to call." This gray region is where sampled data may correctly reject the baseline condition, but the sampled data frequently do not provide sufficient evidence to be overwhelming. In essence, the gray region is an area where it is not considered feasible to control the false acceptance decision error limits to lower levels because the high costs of sampling and analysis outweigh the potential consequences of choosing the wrong course of action (see Figure 6-3 for example).

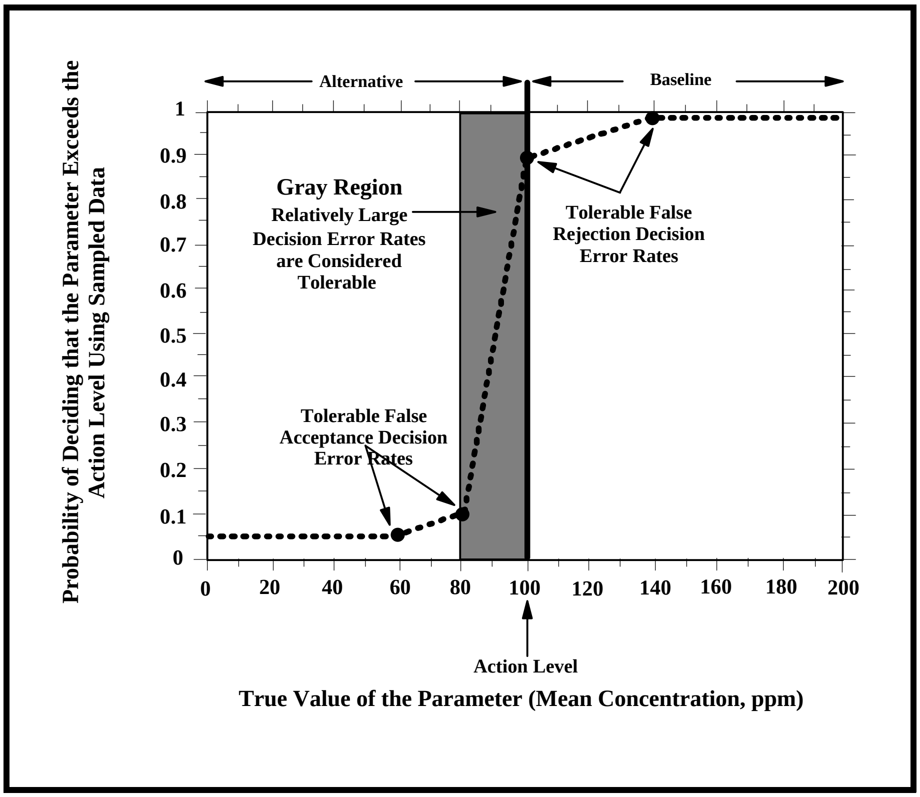

Figure 6-3. An Example of a Decision Performance Goal Diagram (Baseline Condition: Parameter Exceeds the Action Level)

The first boundary of the gray region is the Action Level itself. Your planning team establishes the other boundary of the gray region by evaluating the consequences of a false acceptance decision error over the range of possible parameter values in which this error may occur. This boundary corresponds to the parameter value at which the consequences of a false acceptance decision error are significant enough to have to set a low limit on the probability of this decision error occurring.

For example, suppose the baseline condition is that the true mean level of contaminant does not exceed 1.0 mg/L and the result of a sample of five observations reveals a sample mean of 1.05 mg/L. Is this sufficient evidence to reject the baseline condition? If the natural variability of the contaminant was low, then probably this would be enough evidence. If the natural variability was quite high (i.e., a coefficient of variation of 50%), then the evidence would not be overwhelming, as a result of this happening quite naturally. On the other hand, if the sample mean had been 1.50 mg/L, even high variability could not hide the fact that the baseline condition had been exceeded. The second boundary of the gray region is that value that you decide represents overwhelming evidence to reject the baseline condition.

In general, the narrower the gray region, the greater the number of samples needed to meet the criteria because the area of uncertainty has been reduced. The width of the gray region may be wide during early phases of the study process, but narrowed at later stages to determine if the parameter of interest is only slightly different than the Action Level.

In statistical hypothesis testing language, the width of the gray region is called the "minimum detectable difference" and is often expressed as the Greek letter delta (Δ). This value is an essential part of many calculations for determining the number of samples that need to be collected so that you will have your stated confidence in decisions made based on the data collected.

How do you assign probability values to points above and below the action level that reflect the tolerable probability for the occurrence of decision errors? A decision error limit is the probability that a decision error may occur for a specific value of the parameter of interest when making the decision using sampled data. This probability is an expression of the decision maker's tolerance for uncertainty but does not imply that a decision error will occur. Instead it is only a measure of the risk a decision maker is willing to assume of making an incorrect decision.

At a minimum, you should specify a false rejection decision error limit at the Action Level and a false acceptance decision error limit at the other end of the gray region based on the consequences of the respective errors. Severe consequences (such as extreme risks to human health) should have stringent limits (small probabilities), whereas moderate consequences may have less stringent limits (large probabilities). In general, the tolerable limits for making a decision error should decrease as the consequences of a decision error become more severe farther away from the Action Level.

The most stringent limits on decision errors that are typically encountered for environmental data are 0.01 (1%) for both the false rejection and false acceptance decision errors.

This guidance recommends using 0.01 as the starting point for setting decision error rates. If the consequences of a decision error are not severe enough to warrant this stringent decision error limit, this value may be relaxed (a larger probability may be selected). However, if this limit is relaxed from a value of 0.01 for either the decision error rate at the Action Level or the other bound of the gray region, your planning team should document the rationale for relaxing the decision error rate. This rationale may include regulatory guidelines; potential impacts on cost, human health, and ecological conditions; and sociopolitical consequences.

The value of 0.01 should not be considered a prescriptive value for setting decision error rates, nor should it be considered EPA policy to encourage the use of any particular decision error rate. Some programs, for example Superfund, give guidance on alternative values for starting points. In the *Soil Screening Guidance: User's Guide* (U.S. EPA, 1996), the starting value for false rejection is 0.05, and for false acceptance, 0.20. The actual values finally selected by the planning team will depend on the specific characteristics of the problem being investigated.

Figures 6-3 and 6-4 illustrate some key outputs of Step 6 of the DQO Process for an example, but with opposite baseline conditions and different project specific-considerations. The DPGD is a special schematic representation of a Decision Performance Curve. While the Decision Performance Curve is a continuous curve, the schematic DPGD depicts only a few critical points on that curve. These few points represent your tolerable error limits, or DPGs, at a few critical values. Your sampling design team will use this as the criteria for any sampling plan they design. As the explanation progresses, it may be helpful to keep in mind that the DPGD represents a set of "what if?" conditions in the following sense. You are answering the question at several selected true values of the parameter of interest:

> If the true value of the parameter of interest were at this level, how strong of an aversion would I have if the data misled me into making the wrong decision and taking action?

Figure 6-3 shows the case where a decision maker considers the more severe decision error to occur above the Action Level and has labeled that as baseline. Figure 6-4 shows the reverse, the case where the decision maker considers the more severe decision error to occur below the Action Level.

Consider Figure 6-3 where the baseline condition is that the parameter exceeds the Action Level (in statistical terms, H_0: the parameter equals or exceeds the Action Level and H_A: the parameter is less than the Action Level). The plausible range of values based on professional judgment was from the Detection Limit (as the Detection Limit was 0.01, it is essentially zero for purposes of the DPGD) to 200 ppm. The Action Level was 100 ppm (from the permit for this investigation). A false rejection would be saying the parameter is less than the Action Level, when, in fact, it is really greater. A false acceptance would be saying the parameter level is above the Action Level, when, in reality, it is below the Action Level. The gray region is the area where you consider it is tolerable to make a decision error as it is "too close to call." For example, suppose you decided the true parameter level was above the Action Level (100 ppm) when in reality it was 99 ppm. Although an error has occurred (false acceptance), it is not particularly severe because the difference of 1 ppm on human health and financial resources is minimal. On the other hand, suppose you decided the true parameter level was above the Action Level (100 ppm) when in reality it was 80 ppm. Again, an error has occurred (false acceptance), but it is severe because a difference of 20 ppm is quite considerable. In this particular case the planning team chose 80 ppm as the edge of their gray region because it represented the case where errors in decision making have a great impact on resources. The planning team then assigned risk probabilities to the chance of making decision errors for various true values of the parameter. They agreed that, if the true value was 80 ppm and they decided (from the data yet to be collected) that the true value exceeded 100 ppm, they were only willing to accept a 10% risk of this happening. The team then considered the implications of what adverse effect would occur if the true value was 60 ppm, but they decided the parameter was greater than 100 ppm. The analysis showed a huge expenditure of resources, so the planning team elected to take only a 5% risk of this happening. They did a similar exercise with the tolerable false rejection error rates.

Now consider Figure 6-4 where the baseline condition is that the parameter is less than the Action Level (in statistical terms, H_0: the parameter is less than or equal to the Action Level and H_A: the parameter is greater than the Action Level). Notice how the DPGD looks very similar to that of Figure 6-3, except that the gray region is on the other side of the Action Level, and false rejection and false acceptance have now been switched. In statistical terms, this is because a false rejection is defined as rejecting H_0 when H_0 is really true, and false acceptance to be accepting H_0 when H_0 is really false.

Figure 6-4 shows that at the Action Level the decision maker will tolerate a 10% chance of deciding that the true value is below the Action Level when it is really above the Action Level. If the true value is 140 ppm, the decision maker will tolerate only a 1% chance of deciding the true value is below the Action Level when it is really above the Action Level. At the edge of the gray region, 120 ppm, the decision maker is willing to tolerate a 10% risk of saying it is above the Action Level when it is really below the Action Level. At 60 ppm, the decision maker is only willing to tolerate a 5% risk of a decision error. These probabilities represent the risk to the decision maker of making an incorrect decision for the selected true values.

6.3 Outputs

The outputs from this step are your baseline condition, your gray region, and your set of tolerable decision error limits at selected true values of the parameter of interest. These selections are based on a consideration of the consequences of making incorrect decisions. The baseline condition, the gray region, and your tolerable limits on decision errors are summarized in a Decision Performance Goal Diagram.

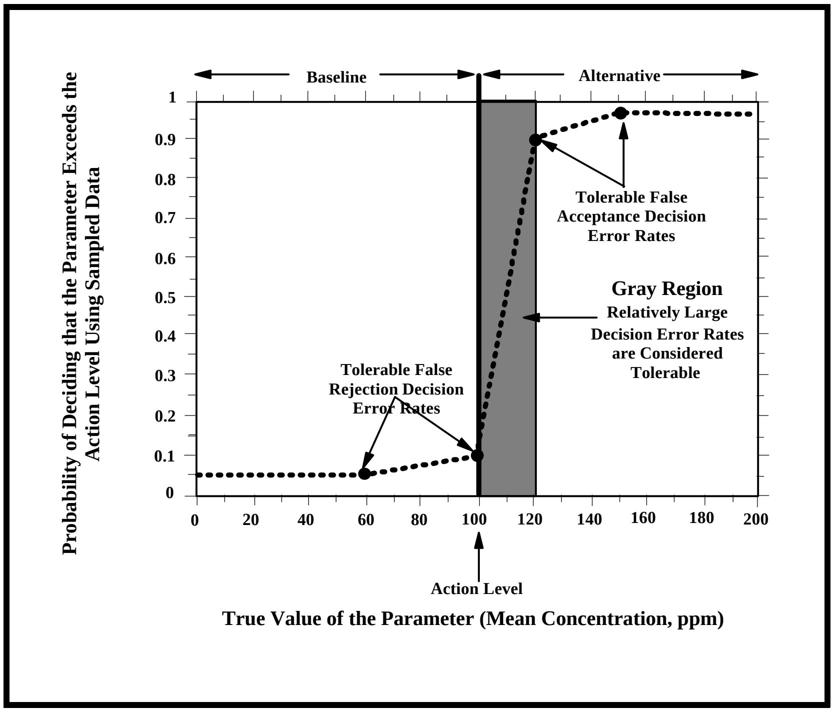

Figure 6-4. An Example of a Decision Performance Goal Diagram (Baseline Condition: Parameter is less than the Action Level)

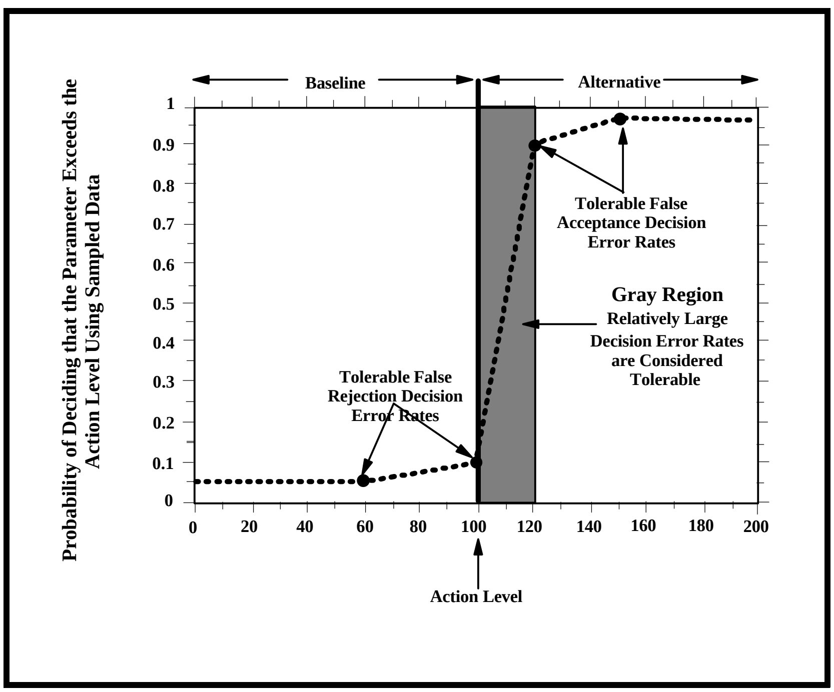

Figure 6-5. Decision Performance Goal Diagram for Example 1

6.4 Examples

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

How was the baseline condition set? *The baseline condition [i.e., the null hypothesis (H_o)] was established as "the waste is hazardous." The consequences of deciding that the waste was not hazardous when it truly was hazardous were that the incinerator company disposed of the waste in a sanitary landfill, possibly endangering human health and the environment. In this situation, the incinerator company could be held liable for future damages and environmental cleanup costs. Additionally, the consequences of this decision error were to compromise the reputation of the incinerator company, jeopardizing its future profitability. The planning team concluded that this decision error (false rejection) had the more severe consequences near the Action Level since the risk of jeopardizing human health outweighed the consequences of having to pay more for disposal.*

How was the gray region specified? *The gray region was designated as that area adjacent to the Action Level where the planning team considered that the consequences of a false acceptance decision error were minimal. The planning team specified a width of 0.25 mg/L for this gray region based on their preferences to guard against false acceptance decision errors at a concentration of 0.75 mg/L (the lower bound of the gray region).*

How were tolerable decision error limits set? *RCRA regulations specify a 5% decision error rate at the Action Level. Below the Action Level, the planning team set the maximum tolerable probability of making a false acceptance error at 20% when the true parameter was from 0.25 to 0.75 mg/L and 10% when it was below 0.25 mg/L. These limits were based on both experience and an economic analysis that showed that these decision error rates reasonably balanced the cost of sampling versus the consequence of sending clean ash to the RCRA facility.*

Example 2. Making Decisions About Urban Air Quality Compliance

How was the baseline condition set? *In most applications of the DQO Process, when, where, and how many samples to collect is not determined until Step 7. However, given that the monitoring network and sampling frequency were already established, the DQO Process in this case was conducted to establish the quality and quantity of data needed for making attainment decisions and to determine if the present network design achieved those quality and quantity specifications. As the planning team was most concerned about protecting public health, the baseline condition in this case was that the 98^{th} percentile of daily concentrations was above 65 µg/m^3 (i.e., less than 98% of daily concentrations are below 65 µg/m^3). That is, the null hypothesis was set as the state of nature the planning team found evidence against, and, to protect public health, carefully guarded against the false rejection decision error of incorrectly rejecting the baseline condition.*

How was the gray region specified? *The gray region, in this case, was specified in terms of proportions. The planning team decided that the gray region should be from 0.98 to 0.995.*

How were tolerable decision error limits set? *The planning team determined that the tolerable false rejection decision error rate should be 10% or less. While lowering the tolerable bound on such error was desirable, the planning team, based on observed $PM_{2.5}$ daily concentration variability in other parts of the country, believed that significantly smaller false rejection error rates were unobtainable for all but the most extensive and costly network designs. The team also wished to protect against implementing* unnecessary and costly control strategies (i.e., incorrectly failing to reject the baseline condition), but was willing to tolerate a somewhat larger probability of making this false acceptance decision error. The planning team decided that the false acceptance decision error rate should be not larger than 30%. These are shown in Figure 6.6.

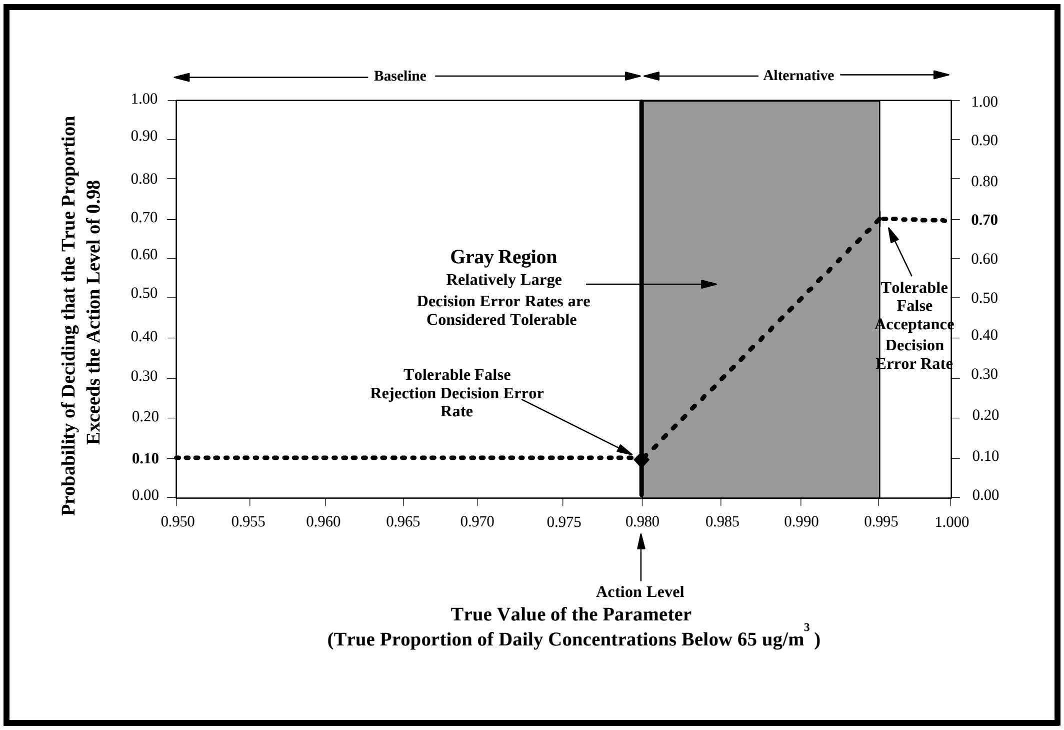

Figure 6-6. Decision Performance Goal Diagram for Example 2

Looking ahead to other DQO steps:

- The information developed in Step 6 is then translated into the requirements for a sampling plan in Step 7.

CHAPTER 7

STEP 7. OPTIMIZE THE DESIGN FOR OBTAINING DATA

The DQO Process

1. State the Problem
2. Identify the Decision
3. Identify the Inputs to the Decision
4. Define the Boundaries of the Study
5. Develop a Decision Rule
6. Specify Tolerable Limits on Decision Errors
7. **Optimize the Design for Obtaining Data**

7. Optimize the Design for Obtaining Data

- Review the DQO outputs.
- Develop data collection design alternatives.
- Formulate mathematical expressions for each design.
- Select the sample size that satisfies the DQOs.
- Decide on the most resource-effective design, or agreed alternative.
- Document details in the QA Project Plan.

After reading this chapter you should have a broad understanding of the steps that are needed to develop a sampling and analysis design to generate data that meet the Data Quality Objectives and Decision Performance Goals developed in Steps 1 through 6 of the DQO Process.

7.1 Background

This step builds on the previous steps where you have:

- identified members of the planning team, including decision makers;
- concisely described the problem;
- developed a conceptual model of the environmental problem to be investigated;
- identified the decision that needs to be made;
- determined the type of information required, the Action Level, and probable measurement methods;
- decided on the spatial/temporal boundaries of the decision and the scale of the decision making;
- decided on the theoretical "*if...then*" decision rule; and
- specified tolerable limits on decision errors.

The purpose of Step 7 is to develop a resource-effective sampling and analysis design for generating data that are expected to satisfy the DQOs and DPGs developed in Steps 1 through 6 of the DQO Process.

7.2 Activities

In this final step you should:

- review existing environmental data;
- evaluate operational decision rules;
- develop general data collection design alternatives;
- calculate the number of samples to be taken; and
- select the most resource-effective data collection design.

Why should you review existing environmental data? Review existing data in more detail if it appears that they can be used to support the data collection design (e.g., analyze the variability in existing data if they appear to provide good information about the variance for the new data). If no existing data are available, it may be cost-effective to conduct a limited field investigation to acquire preliminary estimates of variability for determining the number of samples. If existing data are going to be combined with new data to support the decision, then determine if there are any gaps that can be filled or deficiencies that might be mitigated by including appropriate features in the new data collection design. The existing data should also be reviewed for indications of analytical problems, such as detection limits, that may rule out using certain statistical techniques. Prior knowledge of the probability distribution (characteristics) exhibited by the data may also have an effect on the choice of statistical tests.

How do you evaluate operational decision rules? The theoretical decision rule you developed in Step 5 was based on the assumption that you knew the true value of the parameter of interest (e.g., the true mean or median). Since you will be using measurements made on samples to make your decision, an operational decision rule will be needed to replace the theoretical decision rule. This operational decision rule will most likely be in the form of a statistical hypothesis test which may involve some form of a statistical interval such as a confidence interval or tolerance interval. The design team should evaluate the possible operational decision rules and choose one that best matches the intent of the theoretical decision rule with the statistical assumptions. Each operational decision rule will have a different formula for determining the number of samples needed to meet your DPGs.

Some common statistical hypothesis tests and their sample size formulas are described in detail in *Guidance for Data Quality Assessment*: *Practical Methods for Data Analysis (EPA QA/G-9),* (U.S. EPA, 1997a). Most tests applied to environmental data can be broadly classified as one-sample (single-site) tests or two-sample (two-site) tests. In one-sample cases, data from a site are compared with an absolute criterion such as a regulatory threshold or an Applicable or Relevant and Appropriate Requirement. In the two-sample cases, data from a site are compared with data from another site or background (reference) area or from another time period at the same site. In this case, the parameter of interest is usually the difference between the two means, two medians, two proportions, or two percentiles, and the Action Level is often zero (i.e., no difference).

How do you develop data collection design alternatives? A full explanation of the procedures for developing a data collection design is beyond the scope of this guidance document. This document provides a broad overview of the steps that need to be accomplished to reach a final sampling plan. This section provides a general description of the activities necessary to generate sampling design options and select the one that optimally satisfies the DPGs defined in Step 6. In addition, it contains information about how outputs from the previous six steps of the DQO Process are used in developing the most resource-effective sampling and analysis design.

The design team should develop alternative data collection and analysis designs based on the DQO outputs and other relevant information, such as historical patterns of contaminant deposition, estimates of variance, and technical characteristics of the contaminants and media. The most important element of this step is to reduce the total variability through judicious choice of a spatial and temporal sampling design and analytical measurement technique (see also Figure 6-1). If the total variability can be reduced to a value less than that specified in Step 6, the result will be either a reduction in decision error rates (given a fixed number of samples) or reduction in the number of samples (and, hence, resource expenditure) for a given set of decision error rates. In general, the more complex the sampling design, the lower the total variability of the sample will be.

Generally, the goal is to find cost-effective design alternatives that balance the number of samples and the measurement performance, given the feasible choices for spatial and temporal sample designs and measurement methods. In cases where there is relatively high spatial or temporal variability, it may be more cost-effective to use less expensive and less precise analytical methods so that a relatively large number of samples over space and time can be taken, thereby controlling the sampling design error component of total study error. In other cases, where the contaminant distribution over space and time is relatively homogeneous, or the Action Level is very near the method detection limit, it may be more cost-effective to use more expensive more precise and/or more sensitive analytical methods and collect fewer samples, thereby reducing the analytical measurement error component of total study error. These alternatives should, at a minimum, include the sample selection technique, the sample type, the number of samples, and the number of analyses per sample. To generate alternative designs, the planning team may vary the number and spatial/temporal locations of samples, the type of samples collected, the field sampling or analytical methods used, or the number of replicate analyses performed on samples. It should be remembered that the objective of the design is to estimate the parameter (mean, median, percentile) with as much precision as possible such that the DPGs can be achieved.

How do you calculate the number of samples that satisfy the DPGs for each design alternative and determine the cost for each design? You should use the formulas identified in the previous activity to calculate the number of samples needed to meet the DPGs for each data collection design alternative. You should then determine the associated cost for each design alternative.

To assist the design team in their development of alternative designs and evaluation of costs for a few select sampling designs and operational decision rules, EPA has developed the software, *Data Quality Objectives Decision Error Feasibility Trials (DEFT) Software (EPA QA/G-4D),* (U.S. EPA, 1994b). DEFT is a personal computer software package developed to assist your planning team in evaluating whether the DQOs are feasible (i.e., can be achieved within resource constraints) before the development of the final data collection design is started. DEFT uses the outputs generated in Steps 1 through 6 of the DQO Process to evaluate several basic data collection designs and determines the associated cost. DEFT presents the results in the form of a Decision Performance Goal Diagram that overlays the desired Decision Performance Curve of the sampling design.

If the DQOs are not feasible or not achievable within resource constraints, the DEFT software allows you to relax some of the DQOs and DPGs until a feasible alternative is achieved. The software allows the user to change the action level, the baseline condition, the width of the gray region, the decision error rates, the estimate of the standard deviation, and the sample collection and analysis costs. For each change, the software computes a new sample size and total cost and shows the corresponding Decision Performance Curve in the Decision Performance Goal Diagram.

How do you select the most resource-effective data collection design that satisfies all of the DQOs?   You should evaluate the design options based on cost and ability to meet the DQO constraints and DPGs. The design that provides the best balance between cost (or expected cost) and ability to meet the DQOs, given the non-technical, economic, and health factors imposed on the project, is the most resource-effective (or the optimum design) .

The statistical concept of a power function is extremely useful in investigating the performance of alternative designs. The power function is the probability of rejecting the null hypothesis (H_0) when the null hypothesis is false (i.e., the alternative condition is true). If there was no error associated with a decision, the ideal power function would be 0 if H_0 were true, and 1 if H_0 were false. Since decisions are based on imperfect data, however, it is impossible to achieve this ideal power function. Instead, the power function will most likely yield values that are small when H_0 is true and large when H_0 is false. A performance curve is based on the graph of the power function.[2] The performance curve can be overlaid into the Decision Performance Goal Diagram to assess how well a test performs or to compare competing test. A design that produces a very steep performance curve is preferred over one that is relatively flat.

[2]In this guidance, the performance curve is based on either the power curve or the complement of the power curve. This ensures that the performance curve always rises from left to right.

One simple method to improve the power of the statistical design is the use of stratification to reduce the total variability in the data. Stratification is done by dividing the target population into strata that are relatively homogeneous. The planning team may have made an initial attempt at this in Step 4, Define the Boundaries of the Study. The strata may be physically based (areas proximal to an incinerator, septic tanks, receptor wells, underground storage tanks) or based on other factors (potential exposure, activity patterns, residences, ecological habitats, agricultural sectors, historical or future use).

The advantages of stratification are:

- reducing the complexity of the problem by dividing it into manageable segments;
- reducing the variability in subsets; and
- improving the efficiency of sampling.

Disadvantages of stratification include:

- difficulty in determining the basis for selecting strata (prior estimates of variability, estimates of strata area may be needed);
- overstratifying may require more samples so increasing costs; and
- stratifying areas that are not approximately homogeneous may result in developing a design for collecting data that is inefficient or does not accurately reflect the characteristics of the population.

If none of the data collection designs satisfies all of the DQOs and DPGs within the resource constraints of the project, the planning team will need to review the outputs from the entire DQO Process and alter one or more of the steps. Examples of adjustments that could be made are:

- increasing the tolerable limits on decision errors;
- increasing the width of the gray region;
- increasing the funding for sampling and analysis;
- changing the boundaries (it may be possible to reduce sampling and analysis costs by changing or eliminating subgroups that will require separate decisions); and
- relaxing other project constraints.

For other sampling designs and/or operational decision rules, it will be necessary for the design team to evaluate the design alternatives by other methods (perhaps computer simulation) and possibly involve a statistical expert on sampling design and analysis.

Application of the DQO Process to remediation problems and integration with geostratistical approaches to the analysis of soil contamination scenarios may be found in Myers (1997). Once the final data collection design has been selected, it is important to ensure the design and operational decision rule are properly documented. This improves efficiency and effectiveness of later stages of the data collection and analysis process, such as the development of field sampling procedures, QC procedures, and statistical procedures for data analysis. The key to successful design documentation is in drawing the link between the statistical assumptions on which the design and operational decision rule are based and the practical activities that ensure these assumptions generally hold true.

For EPA programs, the operational requirements for implementing the data collection design are documented in the Field Sampling Plan, Sampling and Analysis Plan, QA Project Plan or other required document. Design elements that should be documented include:

- number of samples,
- sample type (e.g., composite vs. grab samples),
- general collection techniques (e.g., split spoon vs. core drill, or activated charcoal media vs. evacuated canister),
- physical sample (i.e., the amount of material to be collected for each sample),
- sample support (i.e., the area, volume, or quantity that each individual sample represents),
- sample locations (surface coordinates and depth) and how locations were selected,
- timing issues for sample collection, handling, and analysis,
- analytical methods (or performance-based measurement standards), and
- statistical sampling scheme.

Note that proper documentation of the model, operational decision rule, and associated assumptions used for collecting and statistically analyzing data is essential to maintain the overall validity of the study in the face of unavoidable deviations from the original design. Additionally, the documentation will serve as a valuable resource for Data Quality Assessment (DQA) activities after the data have actually been collected and the subsequent decision making process has been completed.

7.3 Outputs

The outputs from this step are the full documentation of the final sampling design and discussion of the key assumptions supporting the sampling design.

7.4 Examples

The examples presented here represent the initial final output of the DQO Process.

Example 1. Making Decisions About Incinerator Fly Ash for RCRA Waste Disposal

What was the selected sampling design? *The planning team's statistician performed an initial cost/benefit analysis that indicated a composite sample design was the best sampling option to use to determine whether a container of ash should be sent to a RCRA landfill or to a municipal landfill. Eight composite samples, each consisting of* *eight grab samples, were taken from each container; and two subsamples from each composite were sent to the laboratory for analysis. To form the composite samples, the containers were divided into eight equal size areas and grab samples were taken randomly within each area and composited. Each grab sample was a core that was extracted, then mixed together to form the composite sample. From this composite sample, two subsamples were sent to the laboratory for analysis.*

What were the key assumptions supporting the selected design? *The cost of this design was based on the cost of collecting ($10) and analyzing ($150) a sample. Eight grab samples were collected for each composite sample, for a sampling cost of $80; two subsamples were analyzed from each composite sample for a cost of $300. Therefore, each composite sample cost $380. The total cost of collecting and analyzing the eight composite samples in one container was eight times the cost of one composite, for a total of $3,040. The assumption that composite measurements were normally distributed was made. This assumption was evaluated after the measurements were obtained. If the assumption was not viable, then the planning team would recommend that additional grab samples per composite be taken, or that a revised compositing process be used to achieve normally distributed data. Based on the pilot study, the incineration company determined that each load of waste fly ash was fairly homogeneous and estimated the standard deviation in the concentration of cadmium among grab samples within loads of ash to be 0.6 mg/L. It was assumed that the variability among sub-samples within a composite sample was negligible. Data from the subsamples was used to test this assumption and to collect additional subsamples, if necessary.*

Example 2. Making Decisions about Urban Air Quality Compliance

What was the selected sampling design? *Information from Step 6 indicated that sampling everyday, regardless of the false rejection decision error rate tolerated, was probably an inefficient use of resources and was unnecessary. This conclusion was reached because sampling daily resulted in false acceptance decision error rates that were far below those required in Step 6. In contrast, 1-in-6-day or 1-in-3-day sampling could not satisfy the false acceptance decision error rate of 30% when the rather restrictive constraint of a 1% false rejection decision error rate was used. The current sampling scheme (1 in 3 days) performed at a satisfactory level as long as the false rejection decision error rate allowed was in the range of 5% to 10%. If the planning team decided that up to 10% false rejection decision error truly could be tolerated, then information in Table 7-1 indicated it was possible to reduce sampling frequency from the current rate to 1-in-6-day sampling, thereby reducing costs while maintaining an acceptable false acceptance decision error rate around 23%.*

What were the key assumptions supporting the selected design? *The monitoring network was already in place, so the goal at this stage was to determine the performance of the existing design, and to change the design, if needed, to achieve better performance. Information in Table 7-1 showed the design performance (false acceptance decision error rate) as a function of different false rejection error rate allowances and alternative sampling frequencies (sample sizes) over a 3-year period of data collection. In general, data in Table 7-1 indicated that the false acceptance* *decision error rate decreased when a higher false rejection decision error rate was tolerated. Similarly, false acceptance decision error rates decreased when sampling intensity was increased from one-in-six-days sampling to every-day sampling.*

Table 7-1. False Acceptance Decision Error Rates and Alternative Sampling Frequencies

		Sampling Frequency At Each Of Three Monitors		
		1 in 6 Days	1 in 3 Days (Current)	Every Day
Tolerable False Rejection Decision Error Rates	1%	>50%	>50%	1%
	5%	>50%	28%	<1%
	10%	23%	11%	<1%

CHAPTER 8

BEYOND THE DATA QUALITY OBJECTIVES PROCESS

After reading this chapter you should understand the kinds of information that will be necessary to develop a QA Project Plan and the role of Data Quality Assessment.

A project's life cycle consists of three principal phases: planning, implementation, and assessment (described in Chapter 0 as the project tier of EPA's Quality System). Quality assurance activities that are associated with each of these phases are illustrated in Figure 0-1. Systematic planning (e.g., the DQO Process) and developing the sampling design comprises the planning phase; the actual data collection process is the implementation phase; and an evaluation (Data Quality Assessment) that the collected data met the performance criteria specified in the DQOs is the final phase of a project.

8.1 Planning

During the planning stage, investigators specify the intended use of the data to be collected and plan the management and technical activities (such as sampling) that are needed to generate the data. Systematic planning and the DQO Process are the foundation for the planning stage and lead to a sampling design, the generation of appropriate data quality indicators, and standard operating procedures, which are all finally documented in the Agency's mandatory QA Project Plan or similar document.

Environmental data for EPA programs may not be collected without having an approved QA Project Plan in place (EPA Order 5360.1 A2). The mandatory QA Project Plan (EPA, 1998) documents four main groups – project management, data generation and acquisition, assessment/oversight, and data validation and usability (shown in Table 8-1).

Group A – Project Management
These elements address project management, project history and objectives, and roles and responsibilities of the participants. These elements help ensure that project goals are clearly stated, that all participants understand the project goals and approach, and that the planning process is documented.

Group B – Data Generation and Acquisition
These elements cover all aspects of the project design and implementation (including the key parameters to be estimated, the number and type of samples expected, and a description of where, when, and how samples will be collected). They ensure that appropriate methods for sampling, analysis, data handling, and QC activities are employed and documented.

Table 8-1. Elements of a Quality Assurance Project Plan

QA Project Plan Elements	
A. Project Management	
A1 Title and Approval Sheet	A6 Project/Task Description
A2 Table of Contents	A7 Quality Objectives and Criteria
A3 Distribution List	A8 Special Training /Certification
A4 Project/Task Organization	A9 Documents and Records
A5 Problem Definition/Background	
B. Data Generation and Acquisition	
B1 Sampling Process Design (Experimental Design)	B7 Instrument/Equipment Calibration and Frequency
B2 Sampling Methods	B8 Inspection/Acceptance of Supplies and Consumables
B3 Sample Handling and Custody	B9 Nondirect Measurements
B4 Analytical Methods	B10Data Management
B5 Quality Control	
B6 Instrument/Equipment Testing, Inspection, and Maintenance	
C. Assessment and Oversight	
C1 Assessments and Response Actions	C2 Reports to Management
D. Data Validation and Usability	
D1 Data Review, Verification, and Validation	D2 Verification and Validation Methods
	D3 Reconciliation with User Requirements

Group C – Assessment and Oversight
These elements address activities for assessing the effectiveness of project implementation and associated QA and QC requirements; they help to ensure that the QA Project Plan is implemented as prescribed.

Group D – Data Validation and Usability
These elements address QA activities that occur after data collection or generation is complete; they help to ensure that data meet the specified criteria.

Additional information on the preparation of QA Project Plans is provided in EPA's guidance document, *Guidance on Quality Assurance Project Plans (EPA QA/G-5)* (U.S. EPA, 1998).

8.2 Implementation

During the implementation phase of the project, data are collected and samples are analyzed according to the specifications of the QA Project Plan or the Sampling and Analysis Plan depending on specific program requirements. These provide detailed specific objectives, QA and QC specifications, and procedures for conducting a successful field investigation that is intended to produce data of the quality needed to satisfy the performance criteria. QA and QC activities (e.g., technical systems audits and performance evaluations) are conducted to ensure that data collection activities are conducted correctly and in accordance with the QA Project Plan.

8.3 Assessment

During the final phase (assessment) of a project, data are verified and validated in accordance with the QA Project Plan, and DQA is performed to determine if the performance criteria have been satisfied.

DQA is built on a fundamental premise: data quality, as a concept, is meaningful only when it relates to the intended use of the data. Data quality does not exist without some frame of reference; you really should know the context in which the data will be used in order to establish a yardstick for judging whether or not the data set is adequate. DQA is the scientific and statistical process that determines whether environmental data are of the right type, quality, and quantity to support a specific decision. DQA consists of five steps that parallel the activities of a statistician analyzing a data set; and include the use of statistical and graphical tools that nonstatisticians can apply to data sets (see Figure 8-1).

DQA involves the application of statistical tools to determine whether the data are of appropriate quality to support the decision with acceptable confidence. To conclude the assessment phase, it is necessary to document all the relevant information collected over all phases of the project's life cycle. The conclusion from a DQA must be presented in a fashion that facilitates the comprehension of the important points. Care should be taken to explain statistical nomenclature and avoid the use of statistical jargon whenever possible. For more information on Data Quality Assessment, see EPA's guidance document, *Guidance for Data Quality Assessment: Practical Methods for Data Analysis (EPA QA/G-9)*, (U.S. EPA, 1997a) and the associated software Data Quality Assessment Statistical Toolbox (DataQUEST) (*EPA QA/G-9D*), (U.S. EPA, 1997b).

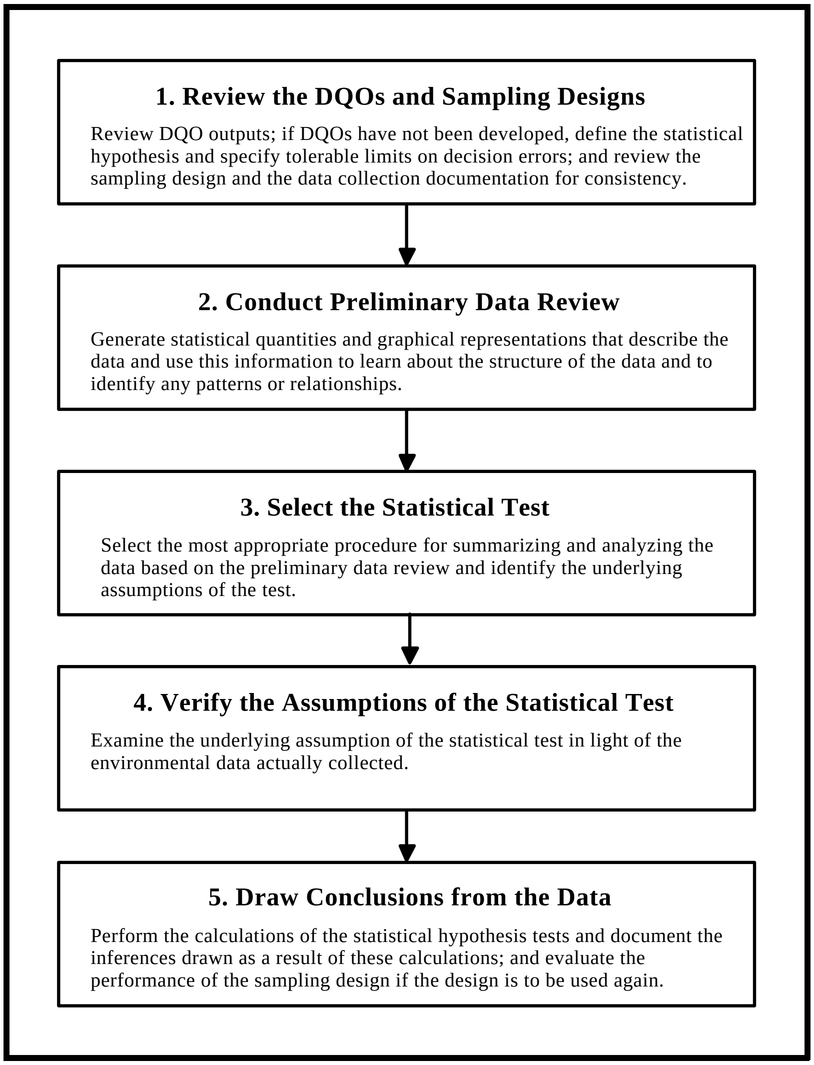

Figure 8-1. Data Quality Assessment Process

APPENDIX A

DERIVATION OF SAMPLE SIZE FORMULA FOR TESTING MEAN OF NORMAL DISTRIBUTION VERSUS AN ACTION LEVEL

This appendix presents a mathematical derivation of the sample size formula used in the DQO Example 1.

Let $X_1, X_2, ..., X_n$ denote a random sample from a normal distribution with unknown mean μ and known standard deviation σ. The decision maker wishes to test the null hypothesis H_0: μ = AL versus the alternative H_A: μ > AL, where AL, the action level, is some prescribed constant; the false positive (Type I) error rate is α (i.e., probability of rejecting H_0 when μ = AL is α); and for some fixed constant U > AL (where U is the other bound of the gray region), the false negative (Type II) error rate is β (i.e., probability of rejecting H_0 when μ = U is 1-β). Let X denote the sample mean of the Xs. It will have a normal distribution with mean μ and variance σ^2/n. Hence the random variable Z, defined by

$$Z = \frac{(\bar{X} - \mu)\sqrt{n}}{\sigma} \quad , \qquad \text{(A - 1)}$$

will have a standard normal distribution (mean 0, variance 1). Let z_p denote the p^{th} percentile of the standard normal distribution (available in most statistics books). Recall that the symmetry of the standard normal distribution implies that $z_p = -z_{1-p}$.

Case 1: Standard Deviation Known

The test of H_0 versus H_A is performed by calculating the test statistic.

$$T = \frac{(\bar{X} - AL)\sqrt{n}}{\sigma}. \qquad \text{(A - 2)}$$

If $T > z_{1-\alpha}$, the null hypothesis is rejected.

Note that

$$T = \frac{[(\bar{X} - \mu) + (\mu - AL)]\sqrt{n}}{\sigma} = Z + \epsilon(\mu) \qquad \text{(A - 3)}$$

where

$$\epsilon(\mu) = \frac{(\mu - AL)\sqrt{n}}{\sigma}. \qquad \text{(A - 4)}$$

Thus T has a normal distribution with mean $\epsilon(\mu)$ and variance 1, and, in particular, $\epsilon(AL) = 0$. Hence the Type I error rate is

$$Pr[rejecting\ H_0|H_0] = Pr[T > z_{1-\alpha}|\mu = AL] = Pr[Z + \epsilon(AL) > z_{1-\alpha}] = \alpha \qquad \text{(A - 5)}$$

Achieving the desired power 1-β when μ = U requires that

$$Pr[reject\ H_0|\mu = U] = 1 - \beta.$$

Therefore,

$$Pr[T \le z_{1-\alpha}|\mu = U] = Pr[Z + \epsilon(U) \le z_{1-\alpha}] = Pr[Z \le z_{1-a} - \epsilon(U)] = \beta. \qquad \text{(A - 6)}$$

This implies

$$z_{1-\alpha} - \epsilon(U) = z_\beta,$$

or

$$z_{1-\alpha} - \frac{(U - AL)\sqrt{n}}{\sigma} = -z_{1-\beta}.$$

Let Δ = U-AL, then rearrange terms to obtain

$$(z_{1-\alpha} + z_{1-\beta})\sigma = \Delta\sqrt{n},$$

or

$$n = \frac{(z_{1-\alpha} + z_{1-\beta})^2\sigma^2}{\Delta^2}. \qquad \text{(A - 7)}$$

Case 2: Standard Deviation Unknown

If the standard deviation σ is unknown, then a test statistic such as Equation A - 2 is used except that σ is replaced by S, an estimate of the standard deviation calculated from the observed Xs. Such a statistic has a noncentral t distribution rather than a normal distribution, and the n computed by the above formula will be too small, although for large n (say n>40), the approximation is good. The particular noncentral t distribution involved in the calculation depends on the sample size n. Thus, determining the exact minimum n that will satisfy the Type I and Type II error rate conditions requires an iterative approach in which the noncentral t probabilities are calculated for various n values until the desired properties are achieved. With the aid of a computer routine for calculating such probabilities, this is not difficult; however, a simple and direct approach for approximating n is available. This approach, whose derivation is described in the paragraphs below, leads to the following approximate but very accurate formula for n:

$$n = \frac{(z_{1-\alpha} + z_{1-\beta})^2\sigma^2}{\Delta^2} + \frac{1}{2} z_{1-\alpha}^2. \qquad \text{(A - 8)}$$

In practice, since σ is unknown, a prior estimate of it must be used in Equation A - 8.

The approach is based on the assumption that, for a given constant k, the statistic $\bar{X} - kS$ is approximately normal with mean μ-kσ and variance $(\sigma^2/n)(1+k^2/2)$ (Guenther, 1977 and 1981).

The classical t-test rejects H_0 when, $T = [(\bar{X} - AL)/S\sqrt{n})] > D$ where the critical value D is chosen to achieve the desired Type I error rate α. The inequality can be rearranged as $\bar{X} - kS > AL,\ where\ k = D\sqrt{n}.$ Subtracting the mean (assuming H_0) and dividing by the standard deviation of $\bar{X} - kS$ on both sides of the inequality leads to

$$\frac{\bar{X} - kS - (AL - k\sigma)}{(\sigma/\sqrt{n})\sqrt{1+k^2/2}} > \frac{AL - (AL - k\sigma)}{(\sigma/\sqrt{n})\sqrt{1+k^2/2}} = \frac{k\sqrt{n}}{\sqrt{1+k^2/2}}. \qquad \text{(A - 9)}$$

By the distributional assumption on $\bar{X} - kS$, the left side of Equation A - 9 is approximately standard normal when μ = AL, and the condition that the Type I error rate is α becomes

$$Pr[Z > k\sqrt{n}/\sqrt{1+k^2/2}] = \alpha, \qquad \text{(A - 10)}$$

$$i.e.,\ z_{1-\alpha} = k\sqrt{n}/\sqrt{1+k^2/2}. \qquad \text{(A - 11)}$$

One can show that Equation A - 11 is equivalent to

$$1/[1+k^2/2] = 1 - z_{1-\alpha}^2/2n. \qquad \text{(A - 12)}$$

The condition that the Type II error rate is β (or that power is 1-β) when μ = U means that the event of incorrectly accepting H_0 given $\bar{X} - kS \le AL$ should have probability β. Subtracting the mean (U - kσ) and dividing by the standard deviation of $\bar{X} - kS$ on both sides of this inequality yields

$$\frac{\bar{X} - kS - (U - k\sigma)}{(\sigma/\sqrt{n})\sqrt{1 + k^2/2}} \le \frac{AL - (U - k\sigma)}{(\sigma/\sqrt{n})\sqrt{1 + k^2/2}}. \quad \text{(A - 13)}$$

Again, the left side is approximately standard normal and the Type II error rate condition becomes

$$Pr[Z \le [AL - (U - k\sigma)]/[(\sigma/\sqrt{n})/\sqrt{1 + k^2/2}]] = \beta,$$

which implies

$$-z_{1-\beta} = z_\beta = \frac{(AL - U) + k\sigma}{(\sigma/\sqrt{n})\sqrt{1 + k^2/2}}. \quad \text{(A - 14)}$$

Subtracting Equation A - 14 from Equation A - 11 yields

$$z_{1-\alpha} + z_{1-\beta} = \frac{(U - AL)}{(\sigma/\sqrt{n})\sqrt{1 + k^2/2}}, \quad \text{(A - 15)}$$

or

$$\frac{(z_{1-\alpha} + z_{1-\beta})\sigma}{(U - AL)} = \frac{\sqrt{n}}{\sqrt{1 + k^2/2}}. \quad \text{(A - 16)}$$

Substituting Equation A - 12 into the denominator on the right side of Equation A - 16 yields

$$\frac{(z_{1-\alpha} + z_{1-\beta})\sigma}{(U - AL)} = \sqrt{n}\sqrt{1 - z_{1-\alpha}^2/2n}. \quad \text{(A - 17)}$$

Squaring both sides of Equation A - 17 and solving for n yields Equation A - 8.

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APPENDIX B

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APPENDIX C

Data Quality Objectives; Household Dust Lead Hazard Assessment

This example concerns the use of the median in planning for environmental decision making. The example is presented in a continuous format to show the seven-step DQO Process in its entirety.

0. Background

The adverse health effects resulting from exposure to lead hazards (paint, dust, and soil) have received increasing attention because chronic exposure to low levels of lead can cause impairment of the central nervous system, mental retardation, and behavioral disorders. Young children (below the age of six) are at a particularly high risk for these adverse effects. Concern about the exposure to lead hazards in residential housing has led federal agencies, including the EPA and Department of Housing and Urban Development, to develop programs to evaluate, and ultimately control, lead hazards in housing.

A critical pathway for exposure to lead by a child is through the ingestion of household dust because dust collects on hands, toys, and food and is easily transferred by hand-to-mouth activities. As a result of the concern about the dust-to-mouth pathway, an important component of risk assessment is dust sampling. Dust sampling offers a way of characterizing dust lead levels at a property and determining if intervention is warranted. One of the preferred methods for sampling residential dust is using baby wipes to wipe a specified surface area. A single area may be sampled using an individual wipe; or multiple areas of a room may be sampled with individual wipes, and the individual wipes combined, or composited, then submitted to the laboratory as a single sample (40 CFR 745). The distribution of dust lead levels is such that normality cannot be assumed and a 50th percentile (the median) is the appropriate risk assessment level. This example demonstrates use of the median (i.e., 50th percentile) as the primary population parameter of concern

1. State the Problem

How were the planning team members selected? The planning team included the property owners, a certified risk assessor (to collect and handle dust samples and serve as a liaison with the laboratory), a statistician, and a quality assurance specialist. The decision makers were the property owners.

How was the problem described and a conceptual model of the potential hazard developed? The problem was described as evaluating potential hazards associated with lead in dust in a single-family residence because other residences in the neighborhood had shown levels of lead in dust that might pose potential hazards.

The conceptual model described a single-family residence in a neighborhood where hazardous levels of lead had been detected in other residences. Interior sources of lead in dust were identified as lead-based paint on doors, walls, and trim, which deteriorated to form, or attach to, dust particles. Exterior sources included lead in exterior painted surfaces that had deteriorated and leached into the dripline soil, or lead deposited from gasoline combustion fumes that accumulated in soil. In these cases, soil could be tracked into the house, and collected as dust on floors, window sills, toys, etc. Because this dust could be easily ingested through hand-to-mouth activities, dust was considered to be a significant exposure route. Levels of lead in floor dust were to be used as an indicator of the potential hazard.

What were the available resources and relevant deadlines? The property owners were willing to commit up to $1,000 for the study. To minimize inconvenience to the family, all sampling would be conducted during one calendar day.

2. Identify the Decision

What was the Decision Statement? The decision statement was determining if there were significant levels of lead in floor dust at the residence.

What were the alternative actions? If there were significant levels of lead in floor dust at the residence, the team planned follow-up testing to determine whether immediately dangerous contamination exists and the location of the contamination in the property. If not, the team decided there was not a potential lead hazard, and testing was discontinued.

3. Identify the Inputs to the Decision

Identify the kind of information. The assessment of a dust lead hazard was evaluated by measuring dust lead loadings by individual dust wipe sampling.

Identify the source of information. The EPA proposed standard stated that if dust lead levels were above 50 $\mu g/ft^2$ on bare floors, a lead health hazard was possible and follow-up testing and/or intervention should be undertaken (40 CFR 745).

What sampling and analytical methods were appropriate? Wipe samples were collected according to ASTM standard practice E1728. These samples were digested in accordance with ASTM standard practice E1644 and the sample extracts were chemically analyzed by ASTM standard test method E1613. The results of these analyses provided information on lead loading (i.e., µg of lead per square foot of wipe area) for each dust sample. The detection limit was well below the Action Level.

4. Define the Boundaries of the Study

What population was sampled? Dust contained in 1 ft^2 area of floors of the residence was sampled and sent to a laboratory for analysis.

What were the spatial boundaries? The spatial boundaries of the study area were defined as all floor areas within the dwelling that were reasonably accessible to young children who lived at, or visited, the property.

What was an appropriate time frame for sampling? The test results were considered to appropriately characterize the current and future hazards. It was possible that lead contained in soil could be tracked into the residence and collect on surfaces, but no significant airborne sources of lead deposition were known in the region. The dust was not expected to be transported away from the property; therefore, provided the exterior paint was maintained in intact condition, lead concentrations measured in the dust were not expected to change significantly over time.

What were the practical constraints for collecting data? Permission from the residents was required before risk assessors could enter the residence to collect dust wipe samples. Sampling was completed within 1 calendar day to minimize the inconvenience to the residents.

What was the scale of the decision making? The decision unit was the interior floor surface (approximately 1,700 ft^2) of the residence at the time of sampling and in the near future.

5. Develop a Decision Rule

What was the decision rule and Action Level? From 40 CFR 745, the median was selected as the appropriate parameter to characterize the population under study. The median dust lead loading was defined to be that level, measured in $\mu g/ft^2$, above and below which 50% of all possible dust lead loadings at the property were expected to fall. If the true median dust loading in the residence was greater than 50 $\mu g/ft^2$, then the planning team required followup testing. Otherwise, they decided that a dust lead hazard was not present and discontinued testing.

6. Specify Tolerable Limits on Decision Errors

How was the baseline condition set? The baseline condition adopted by the property owners was that the true median dust lead loading was above the EPA hazard level of 50 $\mu g/ft^2$ due to the seriousness of a potential hazard. The planning team decided that the most serious decision error would be to decide that the true median dust lead loading was below the EPA hazard level of 50 $\mu g/ft^2$, when in truth the median dust lead loading was above the hazard level. This incorrect decision would result in significant exposure to dust lead and potential adverse health effects.

How was the gray region specified? The edge of the gray region was designated by considering that a false acceptance decision error would result in the unnecessary expenditure of scarce resources for follow-up testing and/or intervention associated with a presumed hazard that did not exist. The planning team decided that this decision error should be adequately controlled for true dust lead loadings of 40 µg/ft^2 and below.

How were tolerable decision error limits set? Since human exposure to lead dust hazards causes serious health effects, the planning team decided to limit the false rejection error rate to 5%. This meant that if this dwelling's true median dust lead loading was greater than 50 µg/ft^2, the baseline condition would be correctly rejected 19 out of 20 times. The false acceptance decision, which would result in unnecessary use of testing and intervention resources, was allowed to occur more frequently (i.e., 20% of the time when the true dust-lead loading is 40 µg/ft^2 or less). These are shown in Figure C-1.

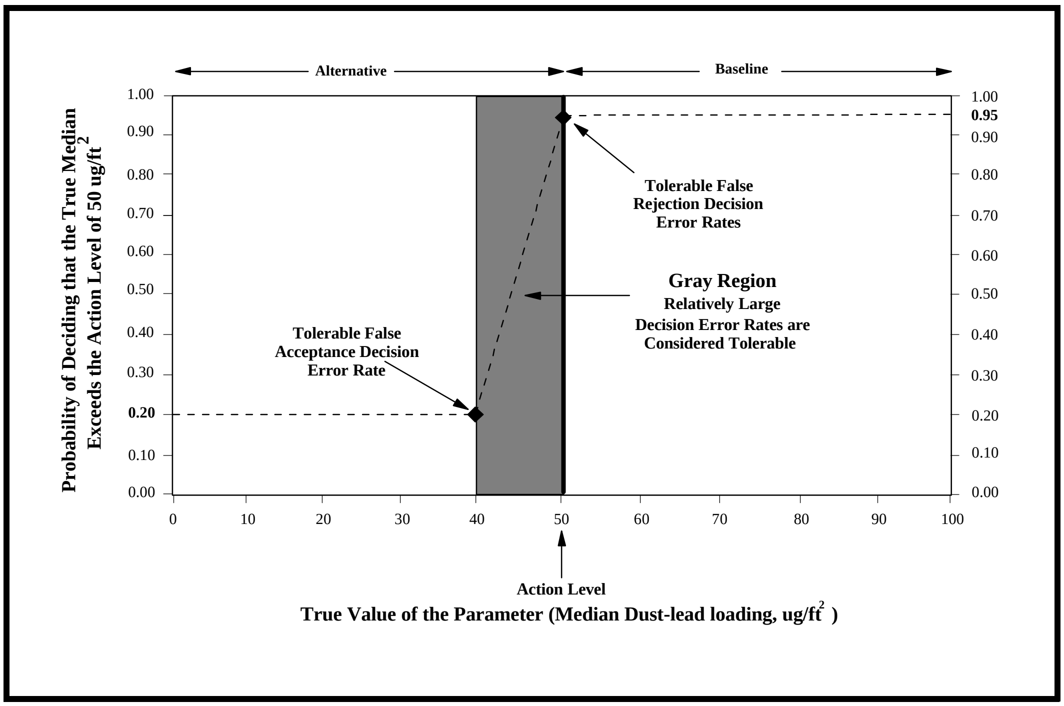

Figure C-1. Decision Performance Goal Diagram for Dust Lead Loading

7. Optimize the Design for Obtaining Data

What was the selected sampling design? The planning team determined that the cost of sending a certified risk assessor to the property for collecting and handling dust wipe samples was about $400. Also, an NLLAP-recognized laboratory was selected to analyze the collected wipe samples at a cost of $10 per sample. Thus, a maximum of 60 samples could be obtained within the study's cost constraint of $1,000. From Step 6 the initial gray region lower bound for the study was set at 40 µg/ft^2, but, the team found that this requirement could not be met given the specified decision errors (i.e., false rejection rate of 5% and false acceptance rate of 20%), assumed standard deviation (of the natural logarithms), range, and cost constraints of the study (i.e., a maximum of 60 samples). The planning team decided they were unwilling to relax the decision error rate requirements and elected to expand the width of the gray region from the original 40 to 50 µg/ft^2 to the less restrictive range of 35 to 50 µg/ft^2. Further, the planning team decided that a standard deviation (of the natural logarithms) value of σ=1.0 was probably more realistic than the more conservative estimate of σ=1.5.

The planning team used the upper variability bound to develop Table C-1 which presented statistical sample size requirements across various assumed dust lead loading standard deviations (of the natural logarithms) and various lower bounds of the gray region. This table indicated that sample size requirements increased rather dramatically as variability increased and/or as the gray region was made more narrow.

Therefore, based on Table C-1, the planning team decided that a total of 50 samples should be collected by a certified risk assessor (all within 1 calendar day) using simple random sampling throughout the residence. Samples were sent to the selected NLLAP-recognized laboratory for analysis. The total study cost was approximately $900 to the property owners.

What were the key assumptions supporting the selected design? The dust lead loading data was assumed to be log-normally distributed. The geometric mean was computed using the data because the true median and true geometric mean are the same when log-normality is assumed. The true variability in dust lead loadings was not known, but past data was used to estimate a reasonable upper bound on variability.

Table C-1. Number of Samples Required for Determining If the True Median Dust Lead Loading is Above the Standard

Gray Region (µg/ft^2)	**Standard Deviation of Natural Logarithms**		
	σ=0.5	**σ=1.0**	**σ=1.5**
20-50	6	9	13
25-50	8	15	21
30-50	14	26	37
35-50	26	50	75
40-50	64	126	188
45-50	280	559	837

APPENDIX D

GLOSSARY OF TERMS

acceptance criteria - specific limits placed on characteristics of an item, process, or service defined in requirements documents.

action level - the numerical value that causes a decision maker to choose one of the alternative actions (e.g., compliance or noncompliance). It may be a regulatory threshold standard, such as a maximum contaminant level for drinking water; a risk-based concentration level; a technology limitation; or a reference-based standard. Note that the action level defined here is specified during the planning phase of a data collection activity; it is not calculated from the sampling data.

alternative condition - a tentative assumption to be proven either rue or false. When hypothesis testing is applied to site assessment decisions, the data are used to choose between a presumed baseline condition of the environment and an alternative condition. The alternative condition is accepted only when there is overwhelming proof that the baseline condition is false. This is often called the alternative hypothesis in statistical tests.

alternative hypothesis - see alternative condition.

baseline condition - a tentative assumption to be proven either true or false. When hypothesis testing is applied to site assessment decision, the data are used to choose between a presumed baseline condition of the environment and an alternative condition. The baseline condition is retained until overwhelming evidence indicates that the baseline condition is false. This is often called the null hypothesis in statistical tests.

bias - the systematic or persistent distortion of a measurement process that causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value.

boundaries - the spatial and temporal conditions and practical constraints under which environmental data are collected. Boundaries specify the area of volume (spatial boundary) and the time period (temporal boundary) to which a decision will apply.

confidence interval - the numerical interval constructed around a point estimate of a population parameter, combined with a probability statement (the confidence coefficient) linking to the population's true parameter value. If the same confidence interval construction technique and assumptions are used to calculate future intervals, they will include the unknown population parameter with the same specified probability.

data collection design - see sampling design.

data quality assessment (DQA) - a statistical and scientific evaluation of the data set to determine the validity and performance of the data collection design and statistical test, and to determine the adequacy of the data set for its intended use.

data quality objectives (DQOs) - qualitative and quantitative statements derived from the DQO Process that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

data quality objectives process - a systematic planning tool to facilitate the planning of environmental data collection activities. Data quality objectives are the qualitative and quantitative outputs from the DQO Process.

decision error - the error that occurs when the dat mislead the site manager into choosing the wrong response action, in the sense that a different response action wold have been chosen if the site manager had access to unlimited "perfect data" or absolute truth. In statistical test, decision errors are labeled as false rejection or false acceptance depending on the concerns of the decision maker and the baseline condition chosen.

decision performance curve - a graphical representation of the quality of a decision process. In statistical terms it is know as a power curve (or a reverse power curve depending on the hypotheses being tested).

decision performance goal diagram (DPGD) - a graphical representation of the tolerable risks of decision errors. It is used in conjunction with the decision performance curve.

defensible - the ability to withstand any reasonable challenge related to the veracity or integrity of project and laboratory documents and derived data.

detection limit (DL) - a measure of the capability of an analytical method of distinguish samples that do not contain a specific analyte from sample that contain low concentrations of the analyte; the lower concentration or among of the target analyte that can be determine to be different from zero by a single measurement at a stated level of probability. DLs are analyte- and matrix-specific and may be laboratory dependent.

distribution - (1) the appointment of an environmental contaminant at a point over time, over an area, or within a volume; (2) a probability function (density function, mass function, or distribution function) used to describe a set of observations (statistical sample) or a population from which the observations are generated.

environmental conditions - the description of a physical medium (e.g., air, water, soil, sediment) or a biological system expressed in terms of its physical, chemical, radiological, or biological characteristics.

environmental data -any measurements or information that describe environmental processes, location, or conditions; ecological or health effects and consequences; or the performance of environmental technology. For EPA, environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as data bases or the literature.

environmental processes - manufactured or natural processes that produce discharges to, or that impact, the ambient environment.

environmental programs - work or activities involving the environment, including but not limited to: characterization of environmental processes and conditions; environmental monitoring; environmental research and development; and the design, construction, and operation of environmental technologies; and laboratory operations on environmental samples.

environmental technology - an all-inclusive term used to describe pollution control devices and systems, waste treatment processes and storage facilities, and site remediation technologies and their components that may be utilized to remove pollutants or contaminants from, or to prevent them from entering, the environment. Examples include wet scrubbers (air), soil washing (soils), granulated activated carbon unit (water), and filtration (air, water). Usually, this term applies to hardware-based systems; however, it can also apply to methods or techniques used for pollution prevention, pollutant reduction, or containment of contamination to prevent further movement of the contaminants, such as capping, solidification or vitrification, and biological treatment.

estimate - a characteristic from the sample from which inferences on parameters can be made.

false acceptance decision error - the error that occurs when a decision maker accepts the baseline condition when it is actually false. Statisticians usually refer to the limit on the possibility of a false acceptance decision error as beta (β) and it is related to the power of the statistical test used in decision making. An alternative name is false negative decision error.

false negative decision error - see false acceptance decision error.

false positive decision error - see false rejection decision error.

false rejection decision error - the error that occurs when a decision maker rejects the baseline condition (null hypothesis) when it actually is true. Statisticians usually refer to the limit on the possibility of a false rejection decision error as alpha (α), the level of significance, or the size of the critical region, and it is expressed numerically as a probability. An alternative name is false positive decision error.

field variability - see sampling design error.

gray region - the range of possible parameter values near the action level where the cost of determining that the alterative condition is true outweighs the expected consequences of a decision error. It is an area where it will not be feasible to control the false acceptance decision error limits to low levels because the high costs of sampling and analysis outweigh the potential consequences of choosing the wrong course of action. It is sometimes referred to as the region where it is "too close to call."

limits on decision errors - the acceptable decision error rates established by a decision maker. Economic, health, ecological, political, and social consequences should be considered when setting limits on decision errors.

mean - a measure of central tendency. A population mean is the expected value ("average" value) from a population. A sample mean is the sum of all the values of a set of measurements divided by the number of values in the set.

measurement error - the difference between the true or actual state and that which is reported from measurements. Also known as measurement variability.

median - a measure of central tendency, it is also the 50th percentile. The sample median is the middle value for an ordered set of n values; represented by the central value when n is odd or by the average of the two most central values when n is even.

medium - a substance (e.g., air, water, soil) that serves as a carrier of the analytes of interest.

natural variability - the variability that is inherent or natural to the media, objects, or people being studied.

null hypothesis - see baseline condition.

parameter - a description measure of a characteristic of a population. For example, the mean of a population (μ).

percentile - a value on a scale of 100 that indicates the percentage of a distribution that is equal to or below it. For example, if 100 ppm is the 25th percentile of a sample, then 25 percent of the dat are less than or equal to 10 ppm and 75 percent of the dat are greater than 10 ppm.

planning team - the group of people who perform the DQO Process. Members include the decision maker (senior manager), site manager, representatives of other data users, senior program and technical staff, someone with statistical expertise, and a quality assurance and quality control advisor (such as a QA Manager).

population - the total collection of objects or people to be studied and from which a sample is to be drawn.

precision - a measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions expressed generally in terms of the standard deviation.

quality assurance (QA) - an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the customer.

QA Project Plan - a document describing in comprehensive detail the necessary quality assurance, quality control, and other technical activities that should be implemented to ensure that the results of the work performed will satisfy the stated performance criteria.

quality control (QC) - the overall system of technical activities that measure the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality.

quality system - a structured and documented system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization or ensuring quality in its work processes, products (items), and services. The quality system provides the framework for planning, implementing, documenting, and assessing work performed by the organization and for carrying out required quality assurance and quality control.

range - the numerical difference between the minimum and maximum of a set of values.

sample - (a) a single item or specimen from a larger whole or group, such as any single sample of any medium (e.g., air, water, soil); or (b) a group of samples from a statistical population whose properties are studies to gain information about the whole. The definition is decided by context of usage.

sampling - the process of obtaining a subset of measurements from a population.

sampling design - a design that specifies the final configuration of the environmental monitoring effort to satisfy the DQOs. It includes what types of samples or monitoring information should be collected; where, when, and under what conditions they should be collected; what variables are to be measured; and what quality assurance and quality control components will ensure acceptable sampling error and measurement error to meet the decision error rates specified in the DQOs. The sampling design is the principal part of the QA Project Plan.

sampling design error - the error due to observing only a limited number of the total possible values that make up the population being studied. Sampling errors are distinct from those due to imperfect selection; bias in response; and mistakes in observation, measurement, or recording. Also known as field variability.

stakeholder - a person or organization having an interest in the development of the project.

standard deviation - a measure of the dispersion or imprecision of a sample or population distribution expressed as the positive square root of the variance and has the same unit of measurement as the mean.

statistic - a function of the sample measurements (e.g., the sample mean or sample variance).

standard operating procedure - a written document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps and that is officially approved as the method for performing certain routine or repetitive tasks.

total study error - the sum of all the errors incurred during the process of sample design through data reporting. This is usually conceived asa sum of individual variances at different stages of sample collection and analysis. Also known as total variability.

total variability - see total study error.

type I error - the statistical term for false rejection decision error.

type II error - the statistical term for false acceptance decision error.

variability - refers to observed difference attributable to heterogeneity or diversity in a population. Sources of variability are the results of natural random processes and stem from environmental differences among the elements of the population. Variability is not usually reducible by further measurement but can be better estimated by increased sampling.

variance - a measure of a the dispersion of a set of values. Small variance indicating a compact set of values; larger variance indicates a set of values that is far more spread out and variable.