GUIDELINES FOR EVALUATING THE ADEQUACY OF SOIL RESOURCE INVENTORIES

by

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Preface

Knowledge of soil resources is necessary for sound planning for rural development. Most countries have institutions responsible for conducting soil surveys. Many reports and maps have been prepared which cover substantial parts, or even all, of these countries. Much of this information, however, is unused, either because communications between agencies is lacking, or because the surveys did not respond to the actual needs of development planners.

It has been the concern of the Agency for International Development of the United States to find ways to correct this situation. In 1976, a grant was awarded to Cornell University under the 211(d) section of the Foreign Assistance Act of 1966 to examine methods which would facilitate the interactions of soil scientists with development planners. To achieve this purpose, several approaches were pursued.

In the beginning of the grant, groups of specialists were convened to express their views on how to assure the utilization of soil resource inventories. Two workshops were held, at which participants addressed such problems as intensities of surveys, information content, cost effectiveness, methods for assessing adequacy of surveys, and communications with development planners. The papers presented at these meetings have been published (Soil Resource Inventory Group, 1981).

Simultaneously, a group of soil scientists in the Department of Agronomy at Cornell University (the "SRI group") began to develop a methodology for assessing objectively the adequacy of a soil resource inventory with respect to a specific use. Many approaches were suggested and tested, some of which have been described in separate journal articles, theses, and progress reports for the first part of the grant. A preliminary draft of what was called a "Handbook" was prepared and circulated for comments to a number of reviewers. Many suggestions were received. We are grateful for the contributions from T. Calhoun, R. Dudal, R. F. Isbell, A. A. Klingebiel, J. D. Nichols, A. C. Ordeval, R. W. Simonson, J. Schelling, A. J. Smyth, K. Valentine, E. P. Whiteside, and D. H. Yaalon.

Our commitment to conclude the project with a coherent set of procedures leading to a comprehensive evaluation of adequacy could only be fulfilled when the most promising procedures were included in a well defined framework. The development of the procedures and framework was the task of the "SRI group".

The results of this effort are now condensed in these "Guidelines". They are the product of the efforts of many individuals. It is not possible to list all of them and give an accurate account of their participation in the program. It would be a serious shortcoming, however, if the most important contributions were not duly acknowledged. An attempt is made here to do this, with the understanding that many contributors remain unnamed. Those who are named follow in alphabetical order.

Richard Arnold, who was Professor of Soil Science at Cornell University for the duration of the grant, was instrumental in the identification of the major research objectives. He designed the program's work plan, and was active in developing statistical approaches for measuring map unit composition. With his students, he brought many innovative ideas to the investigations.

Marlin Cline constantly guided the research by identifying the major requirements that soil surveys should meet to satisfy the demands of users. His two papers in the Proceedings (1981) place the adequacy problem in a much broader perspective than the methodology in the present publication could possibly address. His guidance was invaluable in keeping the direction of this study on the correct course.

Hari Eswaran, an active member of the SRI group for more than a year, worked out several indices for map texture, legibility standards, and information content of soil classification systems.

Terence Forbes coordinated all activities of the participants during the tenure of the grant. He cooperated with Hari Eswaran and Michiel Laker in developing methodologies for assessing the adequacy of map scales, the relevance of soil information, and the purity of map unit composition. He also developed checklists which tabulated the major characteristics of soil resource inventories. He prepared the first draft of the "Handbook" mentioned above, which provided substantial parts of the subject matter for these guidelines. He continued to participate in the revision of the present text.

Michiel Laker devised the method for measuring delineations on maps, and he established standards for the adequacy of map scales. He was a full-time member of the research team at Cornell for more than one year.

David Rossiter started his work on these guidelines only after the 211(d) grant was terminated. He accepted the assignment to prepare the final manuscript. He, almost alone, carried the burden of writing the complete text, following an outline into which the major research findings had been condensed. He did more than rewrite the contributions of others, however. He developed the chapter on the quality of base maps, taking as a starting point some ideas proposed in a M.S. thesis by J. Perez, one of R. Arnold's students. David also worked out, in detail, the statistics used in the various steps leading to ground truth evaluation, and devised the method for checking the composition of map units. He also typed and edited the entire manuscript, using Cornell's DECSYSTEM 20 computer.

The figures in this publication are original drawings by Tatyana Seredin. Thanks are also due to Barbara Gingras of the Graphic Arts service of Cornell University for help in computerized typesetting.

Several funding agencies, research institutions, and universities, from abroad as well as in the United States, made time available for staff and faculty to contribute to this study. Those most directly involved were with the Agency for International Development (AID). Dr. T. Gill at the Bureau of Science and Technology of AID was an active promoter of the investigation, and his support is gratefully acknowledged.

The Soil Management Support Services (SMSS) project of the Soil Conservation Service of the United States Department of Agriculture funded the preparation and publication of the final manuscript after the completion of the 211(d) grant, and by doing so greatly encouraged all of those involved to continue their efforts.

A. Van Wambeke

Introduction

A **soil resource inventory** (abbreviated SRI) is any document that describes the attributes and spatial distribution of soils. The best known type of SRI is the soil survey, but other resource inventories, such as land evaluations, capability surveys, or land inventories, may provide valuable information about soils. These guidelines are intended for SRI users who wish to evaluate the adequacy of existing SRIs for specific uses. The guidelines should be useful to planners, engineers, agronomists, and others who intend to use soil surveys to aid them in their work and who need to determine whether a given SRI will in fact meet their needs.

These guidelines are organized in four chapters, each covering a more or less independent aspect of SRI evaluation. Following the body of the text are several appendices that deal with specialized topics or with topics shared by more than one chapter. A glossary of all specialized terms used in the guidelines is included in the appendices.

The evaluation of the adequacy of a SRI can be summarized by four questions:

1. Is the soils map legible, and, in particular, can it legibly represent the smallest land area of interest to the SRI user?
2. Does the soils map convey sufficient information on the properties of the mapped land?
3. Can points and areas be accurately located on the ground or on the map?
4. How reliable is the map? Does the representation of the soilscape presented by the map accurately reflect the true soilscape?

These four questions are covered in chapters on 1) map scale and map texture, 2) map legend and SRI report , 3) base map quality, and 4) ground truth, respectively. These chapters are presented as a sequence of steps that may be followed when evaluating a SRI. Ground truth follows the other three points, because it is the most expensive operation, which can only be justified when the other components of SRI quality are satisfactory.

The four points summarized above are not comprehensive. There are many other questions that a user might ask concerning the quality of a soil survey. However, it is hoped that these points cover most of the important questions. These four points include most criteria relevant to SRI evaluation that were mentioned by contributors to the workshops on soil resource inventories and development planning, held at Cornell University in 1977 and 1978 (Soil Resource Inventory Group, 1981). In addition, these topics are reasonably independent, and therefore provide a good framework for discussion, with minimum duplication.

The methodology presented here is certainly not the only one which can be developed to evaluate the adequacy of SRIs. It was developed with the following requirements in mind. First, the evaluation criteria should be as quantitative as possible, and based on measurements that are reproducible within statistical norms. Second, the procedures for evaluation should be explained step-by-step, by giving the rationale for each procedure and by providing examples of calculations. Third, the emphasis should be placed on the evaluation of the SRI as a finished document, and not on the detection of the sources of inadequacies (which could lead to their correction). Thus, the objectives of the present methodology are rather limited in scope.

An important general concept in SRI evaluation is that of site specificity. A **site-specific** use of an SRI means that the SRI is used to appraise specific land areas (sites) for some purpose, for example, operational units such as fields, farms, or villages. In these cases, the user needs to locate areas that have certain attributes. In other cases, the SRI is used only to provide information without regard for exact location of land areas (for example, the proportion of soils suitable for a given use present in a survey area); such uses are **non-site-specific**.

These guidelines only give a method of evaluating soil surveys for single uses, or for a set of similar uses. To obtain a general measure of the overall quality of a soil survey, these guidelines could be applied in turn to several major land uses that have diverse land requirements. If the SRI is adequate for all of these, it will probably be adequate for many other uses.

Much of the methodology presented here has not been sufficiently tested in the field, and will certainly need amendments and improvements before it is suitable for routine application in soil survey operations. However, it provides a first attempt to solve this important problem of evaluating soil resource inventories.

Chapter 1

Map Scale and Map Texture

1.1 Introduction

A soil map must legibly represent the smallest land area of interest to the SRI user. Whether it can do so depends on the map scale and the size of the area of interest. In addition, the lines and symbols used to represent soil areas on the map must be legible. In this chapter, map scale, map texture, and related terms are defined, and three map parameters, the "minimum legible area", the "maximum location accuracy", and the "index of maximum reduction", are developed as criteria of the adequacy of a map's scale and texture.

An important general distinction is that between delineations on a map and land areas on the ground. A **delineation** on a map is the undivided portion of a map sheet inside a continuous boundary line. Areas of delineations are usually measured in square centimeters (cm^2) of map sheet surface. Map delineations represent **land areas** on the ground, which are usually measured in hectares (ha) or square kilometers (km^2) of the earth's surface. Delineations are separated by boundary lines on the map; land areas are separated by conceptual boundaries on the ground, which do not necessarily correspond with man-made boundaries, but rather with separations between soil bodies.

1.2 Map Scale and minimum legible area

The **map scale** is the ratio of distances shown on the map to the corresponding distances on the ground. The scale is usually written as the ratio of these two numbers, which is called the **representative fraction** (abbreviated RF). For example, a scale of 1:20,000 means that 1 cm on the map represents 20,000 cm (200 meters) on the ground. Appendix B gives conversion formulas between map and ground distances measured in various units.

The scale of a map is qualitatively described by the size of the map sheet that would be needed to represent a given land area. Thus, a "large scale" map would require a "larger" sheet of paper than a "small scale" map to represent the same land area. The terms "large" and "small" also refer to the numerical value of the representative fraction for the scale. The distinction between "large", "small", and "medium" scales is somewhat arbitrary; in the context of this publication, "large" scale refers to representative fractions greater than 1:30,000; "medium" scale from 1:30,000 to 1:100,000; and "small" scale less than 1:100,000. Note that as the map scale becomes smaller, the denominator of the representative fraction increases.

The **minimum legible delineation** (abbrevaited MLD) is the smallest legible map area. This area is independent of map scale. It is conventionally defined to be a roughly circular area of 0.4 cm^2; the diameter of a circle with this area is 7.2 mm. Smaller delineations are considered illegible for two reasons: 1) there is not enough room inside the delineation to legibly write the map unit symbol, and 2) the proportion of the delineation covered by the bounding line becomes significant. For example, using a #1 Mars-Staedtler pen (line width = 0.45 mm), the boundary of a circular 0.4 cm^2 delineation covers about 12% of its area; for a #00 pen (line width = 0.30 mm) this figure is still 8.2%.

The **minimum legible area** is the smallest land area that can be legibly represented on the map at a given scale, and is thus the land area represented by the minimum legible delineation. It may be calculated from the map scale by the formula:

$$\frac{\left(\frac{1}{RF}\right)^2}{2.5 \times 10^8} = \text{minimum legible area, ha}$$

In order for the map scale to be adequate for a given use, the minimum legible area must be less than or equal to the smallest area of interest for that use. In other words, the scale must not be so small that the size of a delineation representing the smallest area of interest is reduced below 0.4 cm^2, defined as the minimum legible delineation. Table 1.1 shows minimum legible areas corresponding to a MLD of 0.4 cm^2 for some common map scales.

Table 1.1 - Minimum legible areas for some common map scales

Map scale	Minimum legible area
1:5,000	0.1 ha
1:10,000	0.4 ha
1:15,000	0.9 ha
1:20,000	1.6 ha
1:25,000	2.5 ha
1:50,000	10 ha
1:100,000	40 ha
1:200,000	160 ha (1.6 km^2)
1:250,000	250 ha (2.5 km^2)
1:500,000	1,000 ha (10 km^2)
1:1,000,000	4,000 ha (40 km^2)

1.3 Map scale and maximum location accuracy

The map scale also directly affects the accuracy with which points on the ground may be represented. A well-defined ground point can be plotted to an accuracy of at best 0.25 mm on the map sheet (Davis et al. 1981); therefore, there is an inherent uncertainty in the ground position of the point, equal to this 0.25 mm scaled up to the ground distance (Appendix B). For example, on a map with scale 1:20,000, the inherent uncertainty in the ground position of well-defined map points is 5 m. The true uncertainty may be considerably higher, as shown in section 3.4; however, the maximum location accuracy gives the best possible accuracy, which depends entirely on the map scale, rather than on the accuracy of the methods used to make the map.

In order for the map scale to be adequate, the maximum location accuracy must be numerically smaller than the accuracy to which the user wishes to locate points on the ground. The desired accuracy depends on the intended uses of the survey. For general planning or inventory, point location is not important. If the map is to be used for preliminary siting of civil engineering works, point location should be accurate enough for this purpose. Table 1.2 shows the maximum location accuracy that is attainable at some common map scales.

Table 1.2 - Maximum location accuracy at some common map scales

Scale	Maximum location accuracy
1:5,000	1.25 m
1:10,000	2.5 m
1:15,000	3.75 m
1:20,000	5 m
1:25,000	6.25 m
1:50,000	12.5 m
1:100,000	25 m
1:200,000	50 m
1:250,000	62.5 m
1:500,000	125 m (0.125 km)
1:1,000,000	250 m (0.25 km)

1.4 Map Texture

The **texture** of a map refers to the sizes and pattern of delineations on the map, and determines the map's overall legibility. Assessment of map texture becomes very difficult when the pattern of delineations is taken into account, and for this reason map texture is usually measured only by the density or the size of delineations (average size delineation and index of maximum reduction, section 1.5).

The map of a survey area often contains portions with different map textures. This may result from varying landscape and soils patterns within the survey area. For example, the survey area may include a floodplain with a very intricate pattern of depositional forms and also a broad, homogeneous upland. Each soil surveyor has a unique scientific and esthetic concept of map texture, so that maps of areas mapped by different surveyors may have different texture for that reason alone. Different map textures can also result from the decision of the soil surveyor to use map units with different homogeneity for different portions of the survey area. For example, if some portions of the survey area (e.g. very steep slopes or rocklands) are so unsuitable for most land uses, they may be delineated without subdivision as undifferentiated areas. (Map units are more fully discussed in Chapter 2.) Different map textures can also result from a decision to map different parts of the survey area at different mapping intensities, for example, because of different current or anticipated land uses.

If a map contains portions with different textures, each portion should be evaluated separately for the average size delineation and index of maximum reduction (next section). The total soils map is divided into portions with different textures. This is most conveniently done by a visual estimate of the map texture, although there may be information in the survey report, such as map unit descriptions or a small-scale map showing the areas mapped by each soil surveyor, that may be helpful for this.

1.5 Average size delineation and index of maximum reduction

The **average size delineation** (abbreviated ASD) of a portion of map with uniform map texture is the arithmetic mean of the sizes of the delineations in that portion of the map. It may be measured in cm^2 of map sheet. The ASD may be estimated by sampling small areas of the map sheet, as explained in section 1.6. The ASD is compared to the minimum legible delineation (MLD, section 1.2), which also represents a map area, to obtain an index of the overall legibility of the map portion, the index of maximum reduction.

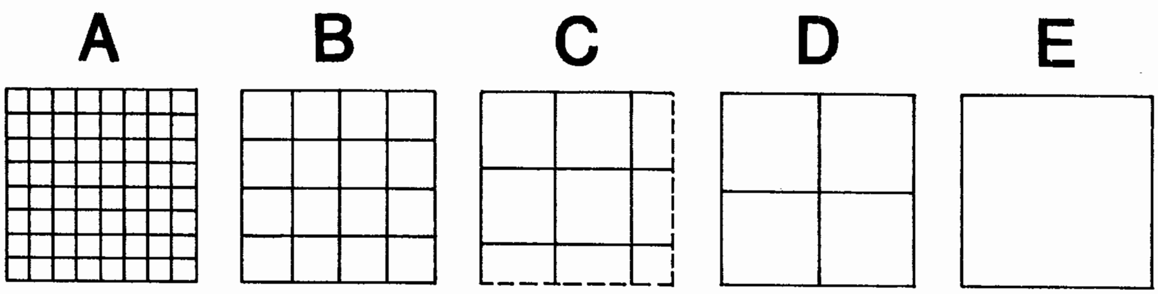
The **index of maximum reduction** (abbreviated IMR) is the factor by which the scale of the map could be reduced before the average size delineation would become equal to the minimum legible delineation, that is, before more than half of the map would become illegible. It is computed as the square root of the ratio of the ASD to the minimum legible delineation (0.4 cm^2) by the formula:

$$IMR = \sqrt{2.5 \times ASD}$$

An IMR of 2.0 is considered optimal. In this case, the ASD is 1.6 cm^2, or four times the size of the MLD. This delineation size of 1.6 cm^2 is called the **optimum legible delineation**. As the IMR decreases from the optimum of 2.0, the map texture becomes increasingly fine and the map becomes decreasingly legible. An IMR of 1.58 is considered the minimum acceptable; this value results when the ASD is 1.0 cm^2. An IMR greater than 2.0 implies that the map is very legible; indeed, the scale could be substantially reduced without impairing legibility. A large IMR implies that the survey area is represented on a map that is physically larger than necessary.

Figure 1.1 shows the relation between the average size delineation and index of maximum reduction for several values of the ASD, represented by square delineations of uniform size. This figure clearly shows the effect of the IMR on map legibility.

DELINEATION SIZE AND LEGIBILITY



ASD:	**0.1**	**0.4**	**1.0**	**1.6**	**6.4 CM2**
IMR:	**0.5**	**1.0**	**1.58**	**2.0**	**4.0**

Figure 1.1 Delineation size and legibility

(ASD = average size delineation)
(IMR = index of maximum reduction)

AREA A: ASD = ¼ of the minimum legible delineation
AREA B: ASD = minimum legible delineation
AREA C: minimum acceptable IMR
AREA D: ASD: = optimum legible delineation
(4 times the minimum legible delineation)
AREA E: ASD = 4 times the optimum legible delineation
(16 times the minimum legible delineation)

1.6 Procedure for estimating the average size delineation

The ASD may be estimated for portions of a map with a given map texture by randomly sampling the map area with circles or squares of known area, and converting the count of delineations in several of these areas, by an empirical formula (after Laker 1977), to the size of an average delineation. Worksheet 1.1 summarizes the procedure and calculations. A transparent overlay with the worksheet has circles with radii of 2.5 and 3.5 cm, and a square with 20 cm on a side, to be used in counting delineations.

The evaluator should start by using the smaller circle (radius of 2.5 cm). First, the circle is placed on the map sheet at a random position. (These positions may be selected by the procedure of Appendix C.) If the area that the circle falls on is not of uniform texture, the placement is repeated. The number of delineations or portions of delineations that are within the circle is then counted. If a delineation comes into the circle more than once, each of the occurrences should be counted separately; thus boundaries outside the circle need not be traced. This procedure is repeated for a total of five circle counts. The five counts are then added; if the sum is less than 30 the sample size was too small, and the procedure must be repeated using the larger circle (radius of 3.5 cm) instead. If the sum is still less than 30, the procedure must be repeated using the 20x20-cm^2 square, in this case taking only one count.

To obtain the ASD from the sample counts, one of the following formulas is used, depending on the overlay size used when sampling:

1) 2.5-cm radius circle: [(Sum of 5 counts)/142] - 0.1

2) 3.5-cm radius circle: [(Sum of 5 counts)/192] - 0.1

3) 20 x 20 cm square: (1 Count)/400

NOTE: See page 51 for template sheet.

1.7 Spot symbols

Spot symbols are figures placed on the map to indicate the presence of small areas of strongly contrasting soils or other relevant features within larger delineations; they are usually employed to show severely limiting conditions such as slope, erosion, wetness, or stoniness that occur within otherwise favorable land areas and that can not be legibly delineated at the map scale. They are very important for users who are appraising specific parcels of land for uses which might be limited by the conditions represented by the spot symbols. Spot symbols are also indicative of intensive mapping. Their presence on a soils map should be considered a definite "plus" for the map.

1.8 Summary

For the map scale and map texture of a soils map to be adequate:

1. The minimum legible area (section 1.2) should be less than or equal to the smallest area of interest for a given use.

2. The maximum location accuracy (section 1.3) should be less than or equal to the accuracy to which ground points must be located.

3. The index of maximum reduction (section 1.5) should be equal to or greater than 2.0 for each map texture area. Values between 1.6 and 2.0 are marginally adequate.

Worksheet 1.1 Map Scale and Map Texture

1) **Minimum Legible Area** (Section 1.2)

Read from the map sheet or report :

1.1) Representative Fraction = 1:________

1.2) (Line 1.1)^2 / (250,000,000) = ________ (ha)
(Minimum Legible Area)

2) **Average Size Delineation** (Section 1.5)
(See section 1.6 for the sampling procedure)

2.1) Sum of 5 circle counts or 1 square count = _____

2.2) Do ONE only of 2.2.1, 2.2.2, or 2.2.3 :

2.2.1) 5 counts with 2.5-cm radius circle :
[(Line 2.1)/142] - 0.1 = ________ delineations/cm^2

2.2.2) 5 counts with 3.5-cm radius circle :
[(Line 2.1)/192] - 0.1 = ________ delineations/cm^2

2.2.3) 1 count with 20x20 cm square :
[(Line 2.1)/400] = ________ delineations/cm^2

2.3) 1 / (Line 2.2) = ________ cm^2
(Average Size Delineation)

3) **Index of Maximum Reduction** (Section 1.4)

3.1) $\sqrt{(\text{Line 2.3}) \times 2.5}$ = ________
(Index of Maximum Reduction)

Chapter 2

Map Legend

2.1 Introduction

A soil survey must convey information to its users so that they may make accurate predictions about the performance of surveyed land areas for specific land uses. The information in a soils map is contained in the definition of its map units, which collectively comprise the map legend.

A **map unit** is a set of map delineations designated by the same name; the term "map unit" also refers to the land areas represented by these delineations. There are three types of map legends, which may in practice be combined. An **identification legend** lists the symbols by which the map units are identified on the map, along with the corresponding map unit name. The identification legend is often printed on the map sheet. A **descriptive legend** gives information, in either narrative or tabular form, about each map unit, such as the proportions, landscape patterns, and attributes of the soil bodies and non-soil areas making up the map unit. The descriptive legend usually forms the bulk of the written SRI report. An **interpretive legend** gives information about each map unit in terms of specific land uses or management systems. The interpretive legend is usually presented as tables or narratives for each land use; alternatively, the interpretations for each map unit may be included in the descriptive legend, with the description of the map unit.

Map unit names and definitions in the descriptive and interpretive legends determine the amount and usefulness of information about the land areas shown on the map. Soil surveyors construct map legends to divide the surveyed area into mappable land areas that have less variation within areas of the same map unit than between areas in different map units. There are many soil characteristics that are important for land use, but those that the map makers consider important or feasible to use when defining the map legend may not correspond to those that are most important for a certain use.

Map legends may be evaluated either in terms of a specific use of the SRI or in terms of a more general criterion, such as a soil classification system. The latter case is discussed in section 2.6; the rest of chapter 2 discusses legend evaluation with respect to specific land uses. Thus, the legend evaluation presented here is use-specific.

There are two components of map legend quality: the specificity and the homogeneity of the map units. The **specificity** of a map unit is the degree to which the map unit name, description, or interpretation give information which makes it possible to predict the performance of the land. The **homogeneity** of a map unit is the proportion of the land area mapped as delineations of the map unit that will perform uniformly as predicted. A map legend should be composed of map units that divide the surveyed area into partitions that are more homogeneous than the total area. In addition, the legend should provide sufficiently specific information about each map unit to enable accurate predictions of performance and specification of management systems for a land use.

Information about map units can be conveyed in three ways: 1) directly stated for a use (interpretive legend), 2) directly stated or implied in the description of attributes of the soils in a map unit (descriptive legend), or 3) implied by map unit names and their classification in a comprehensive soil classification system (identification legend and classification). Interpretations are presented in the form of tables or narratives, and are intended to be used directly by the SRI user. Descriptions are presented in the same forms, but are intended to be used by soil scientists to infer soil performance from the descriptions. If a map unit name is included in a soil classification system, the name may imply a great deal of information about soil characteristics; in this case, a soil scientist familiar with the classification system should be able to extract information from the map unit name. Conversely, a map unit name may be merely a label for the map unit, and imply no further information.

When evaluating a map legend at this stage of the SRI evaluation, the concern is only whether the information of interest to the user is included and clearly presented. The question of whether the information correctly reflects reality is determined while evaluating the ground truth of the survey.

2.2 Map unit specificity

In this methodology, specificity is evaluated in terms of one or more land uses. The concepts used in land suitability and capability classification are useful for evaluating map unit specificity. **Land suitability** has been defined as "the fitness of a given type of land for a specified kind of land use" (FAO 1976), and **land capability** as "the suitability of land for use without permanent damage" (SCSA 1976). In practice, land capability refers to broad types of land uses, such as intertilled crops or woodland. In contrast, land suitability refers to more narrowly defined land uses and management systems, such as dryland wheat production.

The attributes of a land area which make it less than completely suitable for a use are called **limitations**. Management systems and corrective practices may be specified to overcome limitations so that a land area is made more suitable for a use; thus land suitability depends on agronomic techniques and the economic environment, as well as intrinsic attributes of the land. Expert judgement by soil scientists, crop production and protection specialists, agricultural engineers, and economists is necessary to properly match soils with land uses and management systems; this process is referred to as **land evaluation**.

A land evaluation assigns each map unit to a **suitability group**. Each group consists of map units with the same general suitability (suitable or unsuitable) and specific limitations for the land use; in addition, management systems by which the areas in the map unit may be used are specified. Several procedures for making land evaluations are available (FAO 1976, Klingebiel and Montgomery 1961); these depend on soil surveys and other resource inventories to provide enough specific information about each map unit to allow the land evaluator to place it in a suitability group. Thus, a reasonable criterion for map unit specificity is whether the map unit's definition is specific enough to allow the map unit's suitability classification to be determined.

Ideally, the SRI report should include an interpretive legend which assigns each map unit to a clearly defined suitability group for the intended use. Or, each map unit definition may include a narrative description of the map unit's suitability, limitations, and management for the use. In either case, if the SRI user can understand and directly apply the information in the interpretive legend, the map legend is by definition sufficiently specific, and no further testing of legend specificity is necessary.

If the interpretive legend for a use is absent or inadequate, one may ask if enough information is present in the descriptive legend to allow an interpretive legend for the use to be constructed, should such a legend be desired. In other words, the SRI evaluator must decide if a land evaluation for the intended use could be performed on the basis of the land attributes that are listed in the SRI report.

Land attributes may be divided into two main levels of abstraction (FAO 1976). On the more specific level, a **land characteristic** is any measurable attribute of the soil or its site in the landscape. These include internal physical attributes (e.g. cation exchange capacity, texture, and clay minerals), chemical attributes (e.g. reaction, base saturation, and organic matter), site attributes (e.g. slope, position in the landscape, and vegetation), and general environmental attributes (e.g. precipitation and temperature patterns). In practice, land characteristics are used when making soil surveys, since they are observable and measurable. On the more applied level, a **land quality** is a composite of several land characteristics which is more or less independent of other land qualities, and which has significant predictive value for land use. A land quality can not generally be used when making soil surveys, since identical land qualities may result from different combinations of soil characteristics. (These must be mapped separately, because their differences may be important for other land uses.)

For example, "erodibility" is a land quality that depends on the interaction of several land characteristics, including surface texture, coarse fragments, topographic position, slope gradient and length, and rainfall distribution and intensity. Erodibility of a site can be quantified, although this requires special experiments or interpretations that are not always part of the normal soil mapping procedure. In general, land qualities are quantified for special purposes, often on the basis of experiments, and values for land qualities of map units in a soil survey are estimated from values of several land characteristics.

Some land attributes may be either land characteristics or land qualities, depending on one's point of view, since there may be several levels of generality in defining either concept. The main point is that the descriptive legend is more accessible to the user (and thus more useful) if general attributes of the map unit (land qualities), rather than specific attributes (land characteristics), are presented. A descriptive legend with a wealth of detailed information about land characteristics, but with no information about the land qualities that can be inferred from these characteristics, is difficult for the non-specialist to use effectively.

The evaluation procedure to assess map unit specificity is presented in section 2.5.

2.3 Map unit homogeneity

For purposes of legend evaluation, map units may be assigned to one of three homogeneity classes: Uniform map units, Associations, or Non-homogeneous map units.

Uniform map units are those map units wherein the major proportion (e.g. 85%) of the land area is in the same suitability group and thus is expected to perform "uniformly" (i.e. within the limits of the group) for the land use. In addition, it is expected that the minor proportion (e.g. the remaining 15%) will not be strikingly different from the major proportion. (Small areas of strongly contrasting soils within a uniform map unit may be indicated by spot symbols, as explained in Chapter 1).

Map units that do not meet the requirements for uniformity are called **non-uniform**. Map units whose homogeneity can not be determined from the legend are assumed to be non-uniform. Non-uniform map units may result from poor definition, a complex landscape, or a small map scale. In the latter case, however, the map unit's composition may be described in such a way that the map unit may still be useful for certain planning purposes. If the following conditions are met, a non-uniform map unit on a small-scale map is called an **association of uniform land areas**:

1. Each of the constituents is uniform and could have been assigned to different map units at a larger map scale;

2. The **proportion** of each constituent is given; and

3. The **landscape pattern** of the constituents within the map unit is described. In addition, all constituents must occur in a regular pattern within each map unit.

The latter two requirements may not be necessary for some SRI uses. For example, it is possible to inventory the area covered by each soil if the proportions of each are given, without knowing the pattern of the soils on the landscape. In such cases, these non-uniform map units would not be called associations, but could still be adequately defined for the use.

Uniform map units are necessary for those users who want to site operational units directly from the map. Associations are adequate for users who intend to use a soils map to locate large land areas in which they expect to place operational units (e.g. farms or fields) by on-site inspection of the landscape or by more detailed surveys of the selected areas. Associations are also useful for those who want an overview of the soils of a large land area, for example, to identify land suitable for large operational units which utilize different kinds of land (e.g. cropland, grazing land) in specified proportions. Uniform map units are also adequate for these users; however, the user may have to generalize a large-scale map of uniform map units to a small-scale map of associations in order to better understand the general pattern of land areas. Other non-uniform map units are not adequate for any purpose.

Note that there is a difference between the concept of map unit homogeneity for a specific use (as presented in these guidelines) and the concept of a homogeneous soil body (as usually presented in detailed soil surveys). A map unit consisting of a single soil body is only uniform for the differentiating characteristics used in the classification, but may contain sufficient variation so that it is not homogeneous for the intended land use. Conversely, a map unit that contains a mixture of different soil bodies will be homogeneous for a given land use if all its constituents are assigned to the same suitability group. (This is the concept of the "undifferentiated group" type of map unit in the SCS soil surveys.) An additional complication is that different survey organizations may have very diverse ideas about the range of variability that is allowed in the soil bodies that they delimit as map units. Therefore, in most cases it will be necessary to check uniformity of map units by careful examination of the descriptions given in the legend and the soil survey report.

There are several sources of information about map unit homogeneity in a soil survey. First, the homogeneity of each map unit may be stated in its description. General information concerning the homogeneity of all map units in a map legend may be presented in an introductory section of the SRI report, and not repeated with each map unit's description. In addition, organizations that publish soil surveys may have homogeneity standards that are implied in the map unit names, but which are not explicitly presented in each SRI report. In this case, the report should contain a reference to the published standards. Note, however, that these standards usually apply to homogeneity of soil bodies (described in terms of taxonomic classes), not suitability groups.

The evaluation procedure to asses map unit homogeneity is presented in section 2.5.

2.4 Information from map unit names

The map unit name may be examined for specific information. This is of two types. First, some attributes may be listed as part of the name, e.g. "Rhinebeck silty clay loam, 10–20% slopes, moderately eroded" says something about surface texture, slopes, and erosion. These attributes may be assumed to apply as if they were stated in the description. Second, the name may be part of a classification system (e.g. "clayey, kaolinitic, thermic Typic Hapludults") or it may be correlated to such a system (e.g. "Cecil", whose classification is the example just given (Soil Conservation Service 1979)). To extract information from the classification, the published classification system must be consulted. The more specific the name (i.e. the lower its category), and the more quantitative the classification system, the more specific the information that can be inferred from it. Examples of comprehensive, quantitative classification systems from which much specific information may be inferred are the USDA Soil Taxonomy (Soil Survey Staff 1975) and the system used in the Soil Map of the World (FAO 1974).

Map unit homogeneity may also be implied by the map unit name. However, different survey organizations use different names for the same homogeneity concept, or even the same name for different concepts, so that only general guidelines can be given for inferring map unit homogeneity from the map unit name.

Map unit names may consist of one, two, or three elements. Usually, each map unit is given a proper name, which is either 1) a place name (e.g. "Rhinebeck"), or 2) the name of a higher category in a classification system (e.g. "Ochrepts"), or 3) a descriptive term (e.g. "rockland"). Proper names may be combined in any way (e.g. "Tioga-Saprists-marshland"). In addition, the name may include a word or phrase that is intended to convey the homogeneity of the map unit in relation to the soil bodies on the landscape, for example "series", "phase", or "complex". Finally, the name may end with a short list of soil attributes that apply to the entire map unit, for example, "silty clay loam, 0–3% slopes, shallow variant". Various combinations of these three parts of the name have different implications for the homogeneity of the named map unit.

Certain map unit names imply heterogeneity. These are of three types: 1) names that contain words like "association", "complex", "juxtaposition", "undifferentiated area", or plural nouns like "areas", "lands", or "soils"; 2) names that contain more than one proper name with a connective symbol or word, for example, "Tioga-Middlebury" or "Bath and Valois"; and 3) names with a general term (i.e. not a place name) for the proper name (e.g. "Torrifluvents"). One or more of these in a name suggests that the map unit may contain several soils; however, the map unit may be uniform for the use if each constituent listed in the name is in the same suitability group for the use. If this is not the case, the map unit may meet all the criteria for an association. Otherwise, the map unit is non-uniform.

Other map unit names imply homogeneity. These consist of single place names, followed by words such as "series" or "phase" that do not imply a mixture of soils, and possibly followed by some specific qualifiers that further limit the range of certain attributes of the map unit (e.g. "shallow phase" or "3–8% slopes"). These are probably homogeneous for most land uses.

2.5 Method for evaluating a legend

This section describes and illustrates a method for estimating a single map unit's specificity and homogeneity. This method has three steps: 1) selection of the land attributes to be used as legend evaluation criteria (section 2.5.1); 2) subdivision of each of these criteria into classes, so that map unit homogeneity may be checked (section 2.5.2); and 3) examination of the map unit's legend description for a) the presence of information (specificity) and b) the homogeneity of the map unit (section 2.5.3). The objective is to determine whether the map unit's description gives sufficiently specific information on each selected land attribute (specificity), and whether their ranges are within prescribed class limits (homogeneity).

2.5.1 Selection of land attributes

The first step in legend evaluation is to select those land attributes that are important for the intended use of the survey. Therefore, familiarity with the development objectives is necessary. Reference works about the intended land use may be consulted, and published lists of important land attributes may exist (for example, Sys 1976). If possible, an agronomist or crop production specialist who is familiar with the development problems of the region and the land use should assist in the preparation of the list, as well as the classes (next section).

It is preferable to use land qualities, rather than land characteristics, for land evaluation. However, SRI legends seldom include land qualities, so that often land characteristics must be used. In this case, the soil resource inventory is by definition less directly useful than one which also gives values for those land qualities that are important for the intended land use.

Example:

Leveque (1978) gives the following list of land attributes that are important in making a general-purpose agronomic classification of soils in Togo, considering the following crops: corn, sugar cane, banana, oil palm, fruit trees, cotton, manioc, cacao, coffee, beans, yam, sorghum, pasture, upland and paddy rice, peanut, millet, and kitchen gardens. Given the values of each of these attributes for a map unit, an agronomist familiar with the area of West Africa should be able to assign each map unit to a suitability group.

1. Rooting depth
2. Percentage of coarse fragments
3. Textural profile: texture of each horizon; contrasts between horizons
4. Structure
5. Drainage (surface and internal)
6. Available water holding capacity
7. Organic matter
8. Natural chemical fertility

In this list, rooting depth, available water holding capacity, and natural chemical fertility are land qualities, and the other attributes are land characteristics. If, for example, a map unit description does not include information on "available water holding capacity", a land evaluator would have to infer this land quality from land characteristics such as textural profile, stoniness, restrictive horizons, and clay mineralogy.

2.5.2 Definition of classes

For each land attribute selected for legend evaluation, **critical limits** must be determined. These limits separate the total range of the land attribute into two or more classes. The number of classes to form depends on the level of precision that would be desired in a land evaluation. If one is only interested in evaluating land as "suitable" or "unsuitable" for a use, only one limit is necessary to separate these two classes. Intermediate classes, such as "suitable with slight limitations", may be used to further refine the land evaluation, in which case more limits are necessary. The classes should correspond to groupings that would be managed alike in practice.

Example:

Sys (1976) gives tables of land characteristics and critical limits for several important land uses in the tropics. The following table (Table 2.1), for the land use of paddy rice with water control and use of fertilizers, is adapted from his Table 29. Five classes, based on degrees of limitation, are specified. Each attribute is considered independently for the purposes of legend evaluation; if a land evaluation were actually to be performed, their interaction would also be considered. Land in class 1 is completely suitable for the land use, with no limitations, and the yield potential is not limited by soil conditions. Land in classes 2 and 3 has slight and moderate limitations, respectively, and is therefore suitable for the land use, although these areas may require more careful management or their final yields may be somewhat lower than areas in class 1. Land in class 4 has severe limitations for paddy, but the land use is still physically possible. Class 5 contains that land which can not be used for paddy rice, because of severe physical limitations to paddy rice culture, such as very coarse soil texture or moderately sloping land, that can not feasibly be corrected or managed.

Table 2.1 — Evaluation classes for paddy (after Sys 1976)

Characteristic	Degree of Limitation 1	2	3	4	5
TOPOGRAPHY					
Slope, %	<1	1-2	2-3	3-5	>5
WETNESS LIMITATIONS					
Drainage	Poor, Very poor	Poor	Somewhat Poor	Moderately Well	Well
Flooding	Severe	Very severe	Moderate	Slight	——
PHYSICAL SOIL CONDITIONS					
Texture	C,SiC,SC, SiCL,CL	SCL,L,SiL, SiL,Si	SL	LS	S
Stoniness, % by vol.	none	<3%	3-15%	>15%	——
Depth, cm	>90	50-90	25-50	10-25	<10
Calcium carbonate, percent	<25	25-50	50-75	>75	——
Gypsum, %	<3	3-10	10-25	>25	——
SOIL FERTILITY, NOT READILY CORRECTED					
Cation exchange capacity, meq/100g soil	>24	16-24	0-16	pos. charge	——
Base saturation, % of CEC	A: >50	>50	35-50	<35	——
	B: >80	50-80	50-80	<50	——
Organic matter, % wt. in A	>1.5	>1.5	0.8-1.5	<0.8	——
SALINITY AND ALKALINITY					
Salinity, mmhos/cm	<1.5	1.5-2.5	1.5-2.5	2.5-4.0	<4.0
Alkalinity, exchangable sodium percentage (ESP), %	<15	15-25	25-35	>35	——

To interpret this table, each land characteristic is considered separately. For example, if a map unit were defined to have slopes less than 1%, the map unit would be in class I (completely suitable) for paddy, with respect to the "slope" land characteristic.

In this table, some characteristics are divided into less than five classes. For example, "stoniness" has no class worse than class 4. This is because, according to this table, paddy culture is still possible no matter what the stoniness, so that no class 5 can be specified for this characteristic. According to this table, the only characteristics that absolutely limit paddy production are slope (too steep), drainage (too well drained), depth (too shallow), and salinity (too salty).

If fewer classes are used for each land attribute, the evaluation is less stringent, and it is more likely that the legend will be accepted. The evaluation is simpler, since there are fewer class limits to check.

Example:

The following table is a simplification of table 2.1. Classes 1, 2, and 3 have been combined into the "suitable" class, and classes 4 and 5 have been combined into the "unsuitable" class. There is only one class limit per land attribute, so that the table is most conveniently written as a list of these critical limits.

Table 2.2 - Critical limits for paddy

Characteristic	Critical limit for "suitable" class
TOPOGRAPHY	
Slope, %	<5
WETNESS LIMITATIONS	
Drainage	Worse than moderately well drained
Flooding	Greater than slight
PHYSICAL SOIL CONDITIONS	
Texture	Finer than Loamy sand
Stoniness,% by vol.	<15
Depth, cm	>25
Calcium carbonate,%	<75
Gypsum, %	<25
SOIL FERTILITY, NOT READILY CORRECTED	
Cation exchange capacity, meq/100g soil	any negative charge
Base saturation, % of CEC	A: >35; B: >50
Organic matter, % wt. in A	>0.8
SALINITY AND ALKALINITY	
Salinity, mmhos/cm	<2.5
Alkalinity, exchangeable sodium percentage (ESP), %	<35

2.5.3 Checking a map unit description

To check whether a map unit is adequately defined, both for specificity and homogeneity, it is sufficient to determine whether the map unit can be unambiguously placed in one of the classes defined in the previous section (2.5.2), for each land attribute determined in section 2.5.1. The description of each map unit in the legend must provide information on all selected land attributes, and in addition, a range of values must be given for each of these land attributes, so that homogeneity may be evaluated by determining whether the range crosses a class limit.

(If the map unit consists of more than one soil or land type, the description of each constituent is evaluated separately. If all constituents are well-defined, so is the map unit. Therefore, the required information must be given for each map unit constituent.)

If the range of any one land attribute in the list of attributes to check falls entirely on the "unsuitable" side of the critical limit, there is no need to check any other land attributes for this map unit. From this one attribute, it is clear that the map unit is uniformly unsuitable for the intended land use; therefore, it is adequately defined with respect to that use.

Two problems often occur in practice. First, many map unit descriptions do not give ranges of values; a value from only a single sample site may be presented. The value given is presumably typical of the map unit, but there is no way to determine how much variability exists between different sites in the map unit. In this case, the SRI evaluator can only determine whether the map unit description is specific enough; homogeneity can not be determined. Second, many map unit descriptions consist of general or vague discussions, and do not directly address the land attributes of interest. For example, a map unit description may say "These soils are coarse-textured", rather than presenting the actual texture class name or particle-size distribution. Any land evaluation based on such descriptions would therefore also be vague; the map unit description is not specific enough.

Example:

The following hypothetical map unit descriptions illustrate the evalution of map units. Table 2.1 is used as the evaluation table. Table 2.2 could have been used instead, if a less stringent evaluation was required.

Map Unit A: "Soils less than 10 cm to bedrock."

This map unit is adequately defined, even though only one of the 13 land attributes listed in the evaluation table is given. This is because this one attribute places the map unit in class 5 (completely unsuitable).

Map Unit B: "Poorly drained soils on level terraces subject to moderate annual flooding, with texture of silt or silt loam and no coarse fragments."

This map unit is not adequately defined, because only 5 of the 13 attributes are mentioned; the description is not specific enough. None of the 5 attributes given would place the map unit in class 5 (as in Map Unit A).

Map Unit C: "Poorly drained soils on level terraces subject to moderate annual flooding, with texture of silt or silt loam and no coarse fragments; depth to coarse gravel ranges from 40 cm to 150 cm; calcium carbonate 15%, no appreciable gypsum, salinity, or alkalinity; organic matter 2% in the surface horizon; cation exchange capacity ranges from 8 to 20 meq/100g; base saturation ranges from 40-70% of CEC in the A horizon and 50-80% in the B horizon."

This map unit is not adequately defined. Although values are given for all 13 evaluation attributes (i.e. the description is specific enough), three attributes (depth, cation exchange capacity, and base saturation) have ranges that cross at least one class limit. Therefore, the map unit is not sufficiently homogeneous in terms of the intended land use. For example, management of the shallow soils in this map unit (class 3, 40-50 cm depth) would be quite different from management of the very deep soils in the same map unit (class 1, 90-150 cm depth). Note that if table 2.2 were used for the evaluation, no class limits would be crossed, so that the map unit would be adequately defined by the less stringent homogeneity criteria of that table.

Map Unit D: "Poorly drained soils on level terraces subject to moderate annual flooding, with texture of silt or silt loam and no coarse fragments; depth to coarse gravel ranges from 100 cm to 150 cm; calcium carbonate 15%, no appreciable gypsum, salinity, or alkalinity; organic matter 2% in the surface horizon; cation exchange capacity ranges from 16 to 20 meq/100g; base saturation ranges from 50-70% of CEC in the A horizon and 50-80% in the B horizon."

This map unit is adequately defined. All 13 attributes are given, and all ranges are within a single class.

Map Unit E: "A typical profile of this map unit is located in ... district, on the lands of the state experiment station. The site is on a nearly level terrace subject to moderate annual flooding. The texture is silt loam with 2% coarse fragments by volume. There is 3% free calcium carbonate (etc.)."

This map unit is not adequately defined. It is defined in terms of one site, which may or may not be typical of the map unit as a whole. No ranges are given for the land attributes, only the single values found at this test site. Thus, there is no way to judge the homogeneity of this map unit.

2.6 Evaluation by more general criteria

In the preceding section, map units were evaluated for specificity and homogeneity in terms of a land use. It is also possible to evaluate map unit definitions by more general criteria, in particular, in terms of a soil classification system. In this case, the aim is to see whether the map units are well-defined in terms of the classification, rather than in terms of any particular land use. In place of the suitability groupings of the preceding three sections, the concept of **taxonomic classes** is used. The land attributes and critical limits to be used in the evaluation are already defined as the diagnostic criteria of the classification system. A well-defined map unit is one which can be unambiguously placed in a taxonomic class.

If the classification system is hierarchical, as in the USDA Soil Taxonomy (Soil Survey Staff, 1975), it may be possible to classify the map unit at a higher (more general) level in the system, but not at a lower (more specific) level.

2.7 Overall information quality of the soil survey

The method of section 2.5 only evaluates a single map unit description. To evaluate the legend as a whole, it is necessary to develop a composite measure, based on the evaluations of all the map units in the legend.

A simple but informative measure is the proportion of map units that are evaluated as "adequate" in both specificity and homogeneity. This figure may range from 0% to 100%. Any proportion can be specified as "acceptable" overall; for example,a value of 80% seems reasonable.

A more meaningful measure of the overall legend quality is the proportion of the land area surveyed that is covered by adequately defined map units. This can be computed, if the land area covered by each map unit is given in the SRI report, by multiplying each map unit's result (0 = "not adequate", 1 = "adequate") by its land area and then dividing the result by the total land area surveyed. This measure would be appropriate if the different map units cover considerably different amounts of land.

Example:

Consider the following hypothetical evaluation:

Map unit	Land area (ha)	Adequately defined?	Well-defined land area (ha)
Alpha	11,000	Y	11,000
Beta	1,500	N	0
Gamma	1,250	N	0
Delta	15,000	Y	15,000
Epsilon	4,750	N	0

total area: 32,000 total well-defined: 26,000

In this example, only 2 of the 5 map units (40%) are adequately defined; however, 26,000 of the 32,000 ha in the survey area (81.25%) are contained in adequately defined map units.

2.8 Summary

A map legend is adequately defined, relative to a given land use or other objective if an acceptable proportion (e.g. 80%) of the land area surveyed of interest to the user and considered suitable for the use is contained in map units that:

1. provide sufficiently specific information relevant to the land use so that the map unit's suitability group may be determined, and

2. are uniform in their suitability for the land use, that is, 85% of their total area will perform similarly for the use.

Chapter 3

Base Map Quality

3.1 Introduction

A **base map** for a soil resource inventory is any cartographic material on which soil information is shown. It is a representation of the landscape, cultural features, and abstractions (such as political divisions) by which points or areas may be located in the field, and on which planning or interpretive maps may be prepared. The SRI user generally does not have access to, and thus can not evaluate, the base map that was used by the soil surveyor in the field. This map is often different from that used in the published survey.

Many different types of base maps have been used for soil surveys. These may be divided into two main classes: **photographic** and **schematic**. Photographic base maps are photographs, usually modified after exposure, of the survey area. These are usually panchromatic black-and-white aerial photographs, but may be color or false-color (infrared) air or space imagery. By contrast, schematic base maps use lines, symbols, and colors to represent land areas and cultural features. Most schematic maps are compiled from a photographic base, but the user does not see the photographs. In practice, photographic base maps also present some information, such as political boundaries, place names, and roads, in schematic form.

The principal advantage of photographic base maps to the SRI user is the amount of ground detail that may be shown. Many features are visible on a good air photo that aid in field location and orientation, including natural features (e.g. vegetative cover, streams, rock outcrops), cultural features (e.g. roads, buildings, farm ponds, drainageways), and land use features (e.g. field and woodland patterns). The principal advantage of schematic maps is that selected information can be more clearly presented, and extraneous or confusing information can be eliminated. Topographic information, in the form of contour lines or shading, may be shown on a schematic map, or on a special type of photographic map (an orthophotomap).

Eight components of base map quality are considered in these guidelines: 1) physical quality, 2) resolution, 3) point accuracy, 4) area measurement accuracy, 5) date, 6) location of points, 7) location of areas, and 8) clarity of soils information. These are discussed in the following eight sections (3.2–3.9).

3.2 Physical quality

The **physical quality** of a base map refers to those qualities that are independent of the map's information content. These include the paper grade and finish, the size and format of the map sheets, and the reproduction quality. A map's physical quality is a major factor in its overall utility. Evaluation of physical quality is largely subjective. The central question is: "Are the physical features of the map adequate for its envisioned uses?" The following paragraphs list some important components of physical quality, and suggest some criteria for their evaluation.

The base map should be printed on good-quality, heavy paper, especially if it will be used in the field or as a base for interpretive or planning maps. Cloth-backed maps are ideal for field use. The sizing and finish of the paper should allow sharp lines to be clearly represented (printing should be sharp), and the finished surface should be glare-free. If additional information will be drawn on the map by the user, the paper and finish should take the drawing ink or pencil well, and any drawing should erase cleanly without erasing any of the original printing or image.

The map sheet should be easy to handle and store. Large formats are suitable for wall displays but are difficult to use in the field or office. On the other hand, such maps can convey general information about a large area very well. Except for wall displays, map sheets should not exceed the dimensions of a medium-sized drafting table (about 75 x 100 cm) for office work; even smaller sheets (about 30 x 50 cm) are most useful in the field. Large-scale maps may be split into several sheets, each of usable dimensions, although it is difficult to visualize information about large areas on split maps. An excellent format for field work and for farm planning is that used by the USDA, in which a series of 28 x 42 cm sheets, with one fold, are bound with the SRI report, as in an atlas. Folding maps should be easy to unfold and fold; the "concertina" folding method is easiest to use. Maps whose folds alternate direction are unwieldy in the field. It should be possible to read both the map and the identification legend at the same time; a particularly inconvenient placement of the legend is on the back of the map sheet.

Map reproduction refers to the actual printing, photography, or other means of placing information on the map sheet. Any printed information, such as lines, symbols, or text, should have sharp edges with no blurring or running of ink on the paper. Lines of a given type (e.g. soil boundaries) should be of uniform width and darkness. If overprinting was used (e.g. for color separation or to represented different types of information), the overlays should be in perfect registration, that is, corresponding lines and points on the different overlays should be printed on top of each other in the finished map. If colors are not in registration, there will be strips of colors, not represented in the legend, near boundary lines. If air photos are overprinted with line information (such as roads), the line information and the photograph should show the lines in the same place.

Reproduction quality of photographic base maps (or the photographic component of composite photographic-schematic maps) may be evaluated in the same way that photographs are evaluated. The advantage of a photo base map to the user is that the photograph can show ground detail; the quality of the photograph determines how much detail can be clearly seen on it. The main components of photograph quality are **value range** and **resolution**. Resolution is discussed in the next section (3.3).

In the context of photographic reproduction, **value** refers to the amount of light reflected from an area of a photo. It is measured on a scale of 0 to 9, with the lowest value (0) being pure black (no reflectance) and the highest value (10) being pure white (complete reflectance). Value is one of the three attributes of color in the Munsell system (Munsell 1977). The other two attributes are **hue** (spectral quality of the light) and **chroma** (color saturation). In monochromatic (e.g. black and white) photographs, the hue and chroma are constant, so that adjacent objects are differentiated by their values. The most detail is obtained when the photograph contains the full range of values, in other words, all shades of grey from black to white. Value should not be confused with **contrast**, which refers to the maximum difference of values in the photograph, rather than the range of intermediate values. A photograph with maximum contrast may consist only of black or white areas, with no intermediate greys; such a photo is difficult to interpret.

The value range of a photo may be evaluated with a photographer's grey scale or with a Munsell color book (Munsell 1977). In the Munsell system, true greys have a hue of N (neutral) and a chroma of 0. For example, dark grey is Munsell color N3/0. (If the N hue chart is not available, the value range of any hue at chroma 1 may be used to approximate the neutral hue.) If the photo is monochromatic in another spectral quality (e.g. "green and white"), the evaluator should find the hue and chroma that represent the spectral quality, and use that value series instead of N-/0. With the correct hue and chroma in hand, the photograph should then be examined for areas of each value in the series. A satisfactory photograph should have areas of all values from 2 through 8. A "muddy" photograph will only have the middle values (e.g. 4 through 7), and a "contrasty" photograph will only have the extreme values (e.g. 1.5 through 3 and 8 through 9).

3.3 Resolution of air photos and digital imagery

In the context of photographic reproduction, **resolution** refers to the size of detail that can be discriminated in the photograph. This definition of reproduction also applies to digital remote sensing imagery. Since the SRI user is concerned with objects on the ground, resolution should be measured in terms of ground distances, rather than distances on the image. The smallest object in the image that can be clearly identified thus defines the **ground resolution**. For example, if a road that is known to be 10 meters wide can be clearly discriminated on the photo, the ground resolution is 10 meters or less (better). If an airport runway number that is made of 2-meter wide reflecting strips can not be read, the ground resolution is greater (poorer) than 2 meters.

The better the ground resolution, the more ground detail that can be used for location of points or areas. Although there are no standards for ground resolution, one could reasonably expect that well-defined objects and ground control points (section 3.4) should be resolvable on the photograph. Ground control points are by definition plottable to within 0.25 mm on the map. This suggests that "sharp" lines in nature, such as road edges or stream banks, should be no wider than 0.25 mm on the photograph.

The map resolution is limited by the resolution of the original imagery from which the base map was compiled. In the case of photo imagery, the resolution is limited by the camera's optics, the emulsion of the photosensitive paper, and the chemistry used to develop the picture. Except with photographs from very high altitudes (e.g. U-2 or spacecraft), the original air photographs are capable of resolving very fine ground detail, so that the original resolution is not a problem.

By contrast, if digitized remote sensing imagery (e.g. LANDSAT) is used, the resolution is limited by the ground area that each point in the image represents. These points are called **pixels** (an abbreviation of "picture elements"), and each of these usually represents an area of 1600 or 6400 square meters (40 × 40 or 80 × 80 meters), depending on the resolution of the remote sensing equipment on the spacecraft. These dimensions limit the maximum map scale that may legitimately be produced from digital imagery. The minimum legible delineation (MLD) on a map is specified as 0.4 cm^2 (section 1.2), and so the maximum acceptable map scale may be computed by the formula:

$$\text{Maximum Scale} = 1 : \sqrt{(\text{pixel area} \times (\text{pixels/MLD}) \times 25{,}000)}$$

For example, with the 80 × 80 pixel size and at least 64 pixels per minimum legibile delineation, the maximum acceptable scale would be 1:101,192, or approximately 1:100,000. (The corresponding scale for the 40 × 40 pixel size would be 1:50,596, or approximately 1:50,000.) Maps with larger scales (for example, 1:25,000) would be attempting to represent finer ground detail than the resolution of the imagery.

3.4 Point accuracy

Map accuracy is the agreement between the map and the area that it represents. In this section, the accuracy of individual point locations is discussed; the next section (3.5) deals with accuracy of areas. Point accuracy may be either **relative** or **absolute**, in either the **horizontal** (plan) or **vertical** (elevation) dimension.

Absolute accuracy is the relation of points as represented on the map to their geodetic positions, referred to some known horizontal and vertical coordinate systems. An example of a horizontal control system is the Universal Transmercator (UTM) Grid; another is the system of latitude and longitude. An example of a vertical control system is the 1927 North American datum of mean sea level. Absolute accuracy is not important for most SRI users, although a horizontal grid may be used as a convenient and unambiguous means of referring to points in the field. However, for extremely remote areas with practically no visible ground control points (for example, in a dense rainforest with uniform topography and ground cover), absolute position with respect to an astronomic reference system may be required to locate points in the field.

Relative accuracy is the relation between horizontal or vertical distances between points represented on the map and the distances as actually existing on the ground. For example, if a map states that points A and B are 3200 meters apart and their elevation difference is 25 meters, and these are in fact true (to a specified accuracy), the map would be relatively accurate for these two points. If a map states that point A is located in UTM Zone 18, grid reference 379550E, 4697075N at an elevation of 183 meters above the 1927 North American datum, and this is in fact its true geodetic position, the map would be absolutely accurate for point A.

Vertical accuracy, either relative or absolute, is rarely important for SRI applications, although for some engineering or hydrologic interpretations of the soils map, vertical accuracy may be necessary. On the other hand, **relative horizontal accuracy** is usually important to SRI users for two applications: locating points or areas in the field or on the map, and measuring land areas and distances from the map.

The need for base map accuracy, the type of accuracy needed, and the level of accuracy, must be specified by the SRI user when evaluating the soil survey. The main consideration is the uses for which the map is intended, and the required ground accuracy for these uses. For example, a general soils map of a region at a small scale could well be a sketch, with the major features exaggerated for legibility. On the other hand, a large scale map to be used in planning civil engineering works, such as roads or irrigation systems, would have to be very accurate, in both the relative vertical and relative horizontal dimensions. If the map legend consists primarily of general mapping units such as associations (Chapter 2) or if the map scale is too small to permit detailed planning (Chapter 1), accuracy of the base map is not very important. The level of accuracy specified by the SRI evaluator should be comparable to the ground accuracy that is necessary and possible in the actual ground operations for which the soil survey may be used.

Horizontal accuracy can only be determined for **ground control points**. These are any points on a map that are easily visible or recoverable in the field. These include surveyor's monuments and benchmarks, but more generally are any well-defined locations such as crossroads, bridges, buildings, or railway crossings. If great accuracy is required, a precise position within a well-defined location may be specified, for example, the point of intersection of the center lines of two railways, or the northeast corner of a house. A well-defined ground control point may be plotted to an accuracy of 0.25 mm on a map sheet. Therefore, the point on the ground must be locatable with an uncertainty of at most 0.25 mm, scaled up to ground distance (see Appendix B). For example, a ground control point on a map with a scale of 1:20,000 must be locatable within 5 meters in the field; other sample field tolerances are 2.5 m at 1:10,000, 6.25 m at 1:25,000, 12.5 m at 1:50,000, and 25 m at 1:100,000.

3.4.1 Map accuracy standards

Direct evaluation of the relative horizontal accuracy of a map is not feasible for most SRI users. In this process, commonly performed by a cartographic or survey organization, positions of well-defined points on the map are compared with those on an existing map or survey, or on a re-survey, of known accuracy greater than or equal to the desired accuracy, and a composite accuracy value for the map as a whole is calculated by some form of least-squares estimation (Merchant 1982).

Fortunately, many maps are published to specified accuracy standards, implying that the map has already been tested for compliance with these standards. For example, most topographic maps published in the U.S.A. have the following statement printed in the map margin: "This map complies with the National Map Accuracy Standards requirements". These standards (Davis et al. 1981) state that 90% or more of the well-defined points on a map of scale 1:20,000 or smaller are plotted on the map sheet within 0.51 mm (1/50 inch) of their true location; for maps of scales larger than 1:20,000 the tolerance is 0.85 mm (1/30 inch). Other nations and surveying organizations have their own published accuracy standards. If a map contains a reference to such standards, the SRI evaluator should accept that the map does indeed meet these standards, unless there is evidence to the contrary.

A map which is a reproduction of an accurate map may be considerably less accurate than its original, since the reproduction process usually introduces distortions. First, if the scale was enlarged when the map was copied, any errors in the original would be exaggerated in the copy. Furthermore, the optics used in ordinary reproduction are inferior to those used in making original maps, and the reproductions may be considerably less accurate, particularly towards the edges of the map.

If accuracy standards are not presented with or referenced by the map, some inference may be made about the probable relative horizontal accuracy of the map if the method of map compilation is stated on the map or in the report. For example, a recently published soil survey (Goodwin 1979) contains the following statement on each map sheet: "This map was compiled by the U.S. Department of Agriculture, Soil Conservation Service ... on 1974 orthophotography obtained from the U.S. Department of Interior, Geological Survey." The source of the base map (USGS), the compiling agency (SCS), and the base map material (orthophotography) all suggest high accuracy.

3.4.2 Point accuracy of aerial photographs

Aerial photographs have a major advantage as a base for soil maps, in that if the soil boundaries were drawn directly on them, these boundaries are accurate with respect to the details shown on the photo, even if the photogaphic image is distorted. Thus, when attempting to locate the mapped boundaries in the field (by the method of location by interpolation, explained in section 3.7.2), point location accuracy may not be necessary. However, point location accuracy is necessary for many other uses of the survey.

Maps compiled from aerial photography become more accurate as the original air photos are **rectified** (distortions due to camera tilt and variable flying height are removed) and **controlled** (known ground points are placed in true relation to each other). The most accurate photographic maps are **orthophotomaps**, which also have horizontal errors due to **relief displacement** removed. All other aerial photographs contain two types of inherent horizontal errors due to relief. First, the map scale varies inversely with ground elevation, since the camera was closer to the higher elevations when the photographs were taken. Second, points are displaced radially from the center of the photograph by an amount depending on their elevation and their distance from the center of the photograph. This effect is not important in areas of low relief or if the photos were taken from a sufficiently high altitude relative to the amount of **local relief** (the elevation difference shown on a single map sheet or photograph). For maps of standard accuracy, the ratio of local relief to flying height above the lowest point in the photograph must be less than 0.63%, for maps at a scale of 1:20,000 or smaller, in order that all points within 8 cm of the center of the photograph not be excessively displaced. This ratio is 1.05% for scales larger than 1:20,000. (The radius of 8 cm is the maximum distance from the center of the useable area of a standard 22.86 x 22.86 cm (9 x 9 inch) air photo with 60% overlap in the flight line.) For example, if the flying height was 4000 m above the local minimum elevation, the maximum allowable local relief would be 25 m for maps at a scale of 1:20,000 or smaller, or 42 m for scales larger than 1:20,000. The ground displacement (horizontal location error) at this standard accuracy level would be less than 10 m at all points on the ground represented by a photo at a scale of 1:20,000. Some other displacements would be 12.5 m at 1:15,000 , or 51 m at 1:100,000. Thus, if there is any significant local relief, uncontrolled air photos will have unacceptable horizontal accuracy.

3.5 Area accuracy

For some uses of a soil survey, it is important that land areas be accurately represented. For example, one may wish to measure the portion of the survey area covered by each map unit. An area is determined by its boundary, which may be thought of as a polygon connecting a series of points, which are the vertices of the boundary. Thus, the point accuracy of each of these vertices sets an upper limit on the accuracy of the area. However, the relation between the points on the (two-dimensional) map sheet also depends on the **map projection** from their original (three-dimensional) geodetic position. For large-scale maps, the effect of projection may be neglected, but on small-scale maps (e.g., of a region or nation), areas may be seriously misrepresented by some projections. There are "equal area" projections, but these are not common; the most common projections (Mercator, trans-Mercator, and polyconic) do not always represent equal ground areas by equal map areas. Thus, accurate area measurement is not generally possible on small-scale maps. Note, however, that the uncertainty in the area of map delineations that results from the uncertainty associated with soil boundaries is usually much greater than the distortion of areas introduced by the map projection.

3.6 Base Map Date

All land areas change with time; the changes vary in velocity, quantity, and extent, and result from natural events, human activities, and their interaction. If, as a result of changes since the compilation of the map, it no longer correctly represents the corresponding land area, the map is less useful for location. For example, if an area were to be extensively altered for a water management project (e.g. land smoothed and terraced, ditches cut, ponds and embankments built, streams channelized), any existing map, no matter how recent, would become entirely obsolete. On the other hand, there are maps compiled 40 years ago which are still substantially up-to-date. The SRI evaluator should first decide what an acceptable base map date would be for the survey area, and then determine if the base map was in fact compiled since that date. As a minimum, all important linear features that would be used for location, such as roads, railways, canals, or streams, should be represented correctly; thus the compilation date should postdate the most recent important change to such features.

The best way to check the currency of a base map is to compare it directly to maps or imagery of a known, acceptable, date. For example, if an older base map is being evaluated, the representation of the land areas on the older map in which changes were most likely to occur (e.g. near towns) could be compared to a more recent map or aerial photgraph. If there are substantial changes that would make the map unacceptably obsolete, they should be evident on inspection.

If a more recent map is not available, the SRI evaluator should determine the date when the most recent substantial changes to the mapped area occurred, and then determine if the map was compiled after that date. Sometimes there may be a definite date, for example, the date that an irrigation scheme or a new town was completed. More often, however, changes in an area are gradual, and the evaluator must use an arbitrary date, for example, post-World War, that is accepted as an important date in the area's land use history.

The compilation date of any map should be given on the map sheet; unfortunately this is not always the case with soils maps. The date that the soil survey was completed may be later than the base map date, and the date that the soil survey was published will certainly be later than the base map date. Therefore, one must use the survey date or publication date with caution.

The amount of change in different land areas varies widely, even within the area covered by a single soil survey. For example, the base map may be current in rural areas, but obsolete in a recently-developed suburb. In this case, the SRI evaluator should estimate the proportion of the mapped area for which the base map is obsolete, and indicate those areas for which the map is still current.

3.7 Location of points

The user of a soil survey often wants to find a known ground point on the soils map, for example, to determine in what map unit the point is found (i.e., what kind of soil should be found at that point). Conversely, a SRI user may want to locate a point shown on the map in the field. These are two aspects of **point location**.

Two point location methods are discussed in these guidelines: **location by ground control points**, and **location by interpolation**. The utility of base maps for location can be estimated by tests based on either of these methods.

In the method of location by control points, angles and distances are measured from well-defined points to the point of interest (or vice-versa), and the point is located geometrically. Measurement methods vary in precision; in general, only pacing (for distances) and hand compass (for angles) are available to most SRI users.

In the method of location by interpolation, any features that are visible on both the map and the ground are used to interpolate an approximate position. These **interpolation features** may be points, lines, or areas. The approximate distance from each of a set of points or lines, the approximate bearing to several points or the difference in bearing between the line of sight to a linear feature and the bearing of the feature, and the position within a topographic or cultural area (e.g. a field) can be used in combination to provide a very accurate location. In fact, this method is widely used, both in making and using soil surveys, because, given a sufficient density of features, it can be as accurate as low-precision surveying. This method also has the advantage of flexibility, since the user can refer to whatever features are most convenient, and is well-suited to photographic base maps, which can show a wealth of ground detail.

In certain survey areas, for example tropical rainforest, sufficient ground control points or interpolation features for accurate point location may not exist in the field. Clearly, the cartographer is not responsible for this situation. In these cases, astronomic or geodetic grids should be overprinted on the map, so that land surveying methods may be used for point location.

3.7.1 Location by ground control points

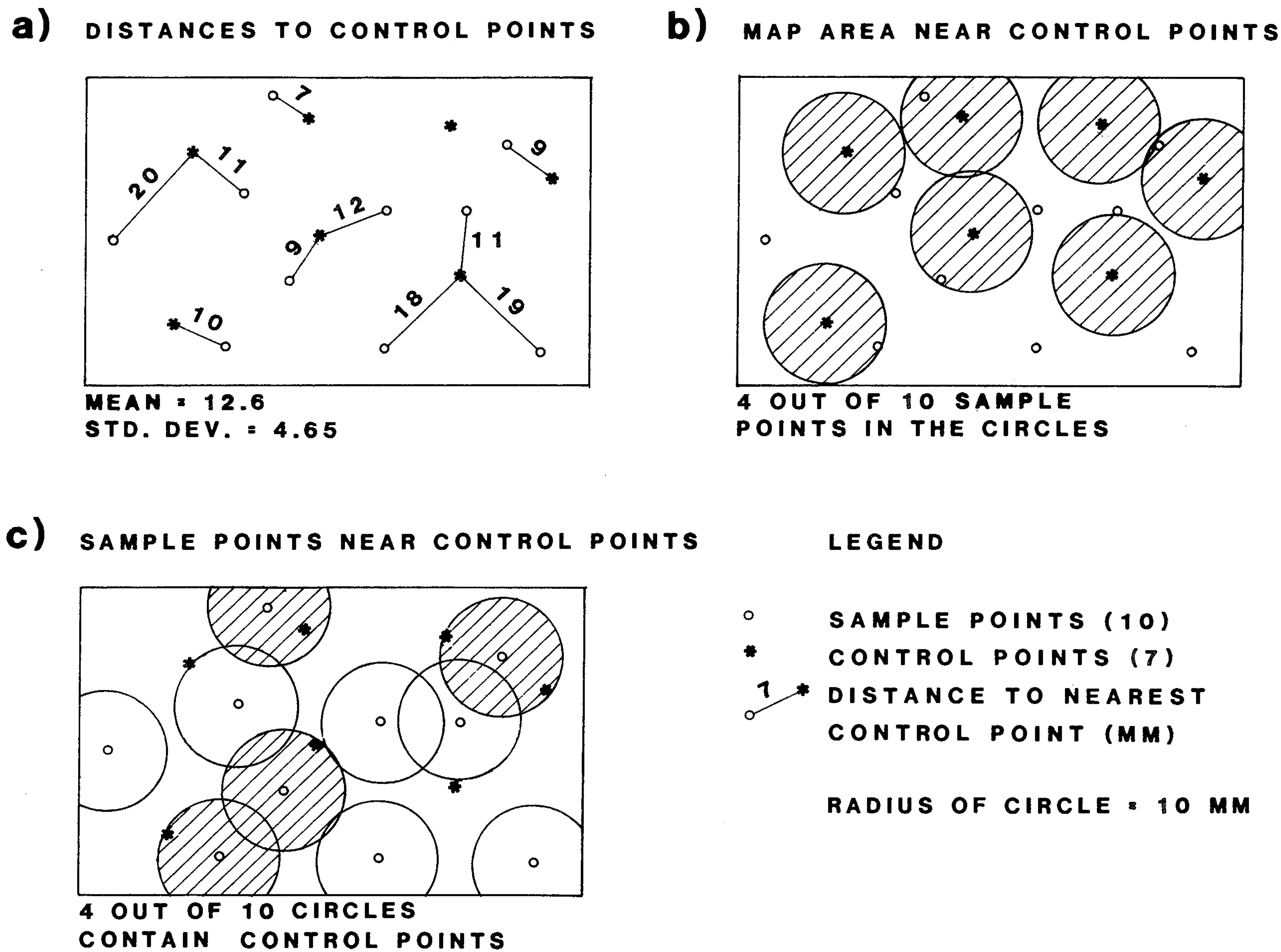
The location of any point on a map or on the ground can be geometrically determined by its distance and bearing from another point whose location is known. The accuracy with which a point may be located depends on the precision with which distances and angles may be measured, both on the map and in the field. With a high quality scale and protractor, map distances and angles may be measured to the precision with which the map itself was drafted. The absolute precision of measurements on a map does not depend on the distance between map points; by contrast, the absolute precision with which distances may be measured in the field depends directly on the distance to be measured, and errors in measuring and following bearings in the field are magnified as longer distances are measured. Therefore, the distance of a point from the nearest control point (a point that is well-defined both on the map and on the ground, Section 3.4) is a measure of the absolute precision with which it may be located.

Several methods can be used to evaluate the utility of a base map for point location in the field. The basic idea is to estimate the proportion of the map area that is close enough to control points so that any point in the area may be accurately located from a control point. Three methods are discussed in the following paragraphs, and one is described in detail in section 3.7.1.3. Figure 3.1 (pg. 17) illustrates the three methods.

The simplest estimate is the statistical distribution of the distances of a random sample of map points from the nearest control point. This is illustrated in Figure 3.1A. A random sample of map points is selected, possibly using the method of Appendix C. The control point nearest each sample point is found by inspection, and the map distance between each sample point and its nearest control point is measured. These distances may be assumed to follow the normal (Gaussian) distribution, so that simple statistical measures may be applied (Steel and Torrie, 1980). An appropriate statistic is the "90% confidence distance", that is, the distance from the nearest control point within which 90% of the map points are expected to lie. This is determined by the upper confidence limit of the t-distribution, at 95% confidence (two-tailed), based on the mean, standard deviation, and size of the random sample of points. This distance may be compared against a pre-determined standard. Figure 3.1A illustrates a sample of 10 points, and shows the derived statistic. The difficulties with this method are: 1) it requires some statistical calculations, and 2) there may be inaccuracy in finding the nearest control point for a sample point.

A simpler method is to first determine the maximum distance from a control point that a sample point may lie, and then determine the portion of the map that is farther than that distance from the nearest control point. One way to do this requires that test circles, with radius equal to the specified maximum distance, be drawn around each control point on the map. The circles will cover a certain portion of the total map, as shown in Figure 3.1B. This portion may be determined directly, using an area measurement device such as a planimeter, digitizing planimeter, or map analyzer. It may also be estimated by selecting a random sample of map points, and determining the portion of these that fall inside the test circles. This is a binomial test, since the point is either inside the circle or not, and so the binomial distribution may be used in the same manner as explained in the next paragraph. This method is the best if area measurement devices are available, since there is no statistical uncertainty in the result. Its disadvantage is that test circles

Figure 3.1 **Methods of Estimating Point Locatability**



must be drawn around all control points. Since there are typically many control points on a map, this could be very time-consuming.

An equivalent, but quicker, method is illustrated in Figure 3.1C. In this method, a random sample of test points is selected, and test circles are drawn around each of the test points. Whether or not each test circle contains at least one control point is a binomial test that is equivalent to that described in the preceding paragraph. This method is more fully discussed in section 3.7.1.3.

The maximum distance, to be used as the radius of the test circle, depends on two parameters that must be specified by the SRI user: 1) the accuracy to which ground points must be located, and 2) the relative precision of the location method in the field. These two parameters are discussed in the following two sub-sections (3.7.1.1, 3.7.1.2). A final sub-section (3.7.1.3) gives the methodology for estimating a map's utility for point location by the method of test circles at sample points.

3.7.1.1 Specifying the accuracy of point location

The desired accuracy of point location depends on the anticipated uses of the survey. If the survey will not be used to locate points, the point location accuracy of the base map is not important. By contrast, if the map is to be used for site evaluation for civil engineering works, one might require, for example, that points be locatable with an uncertainty of at most 2 meters. The SRI user specifies the desired ground location accuracy, subject to the constraint that it can not exceed the accuracy of the base map. Typical map accuracy standards (section 3.4) state that 90% of all points must be located within 0.85 mm of their true position on the map, for map scales of 1:20,000 or larger (0.51 mm for map scales smaller than 1:20,000). This accuracy can be converted to a ground distance (see Appendix B); for example, on a map with scale 1:15,000, the best ground accuracy that could be specified is 12.75 meters.

Values for the desired ground location accuracy can also be based on the delineation sizes on the map (Chapter 1). It would at least be desirable for one to be able to determine whether one is inside a delineation of minimum acceptable size (the minimum legible delineation), which was defined as having an area of 0.4 cm^2. Assuming a circular delineation, one would thus need a location accuracy on the map equal to the radius of this delineation, or 3.57 mm. This map distance can also be converted to a ground distance (Appendix B). For example, on a 1:15,000 map, the corresponding ground location accuracy should be at least 53.5 meters, and on a 1:100,000 map, it should be at least 357 meters. Intuitively, these distances seem like large uncertainties at these map scales. Basing the desired ground location accuracy on the minimum legible delineation (and thus on the map scale) thus provides a reasonable upper limit (worst case) for a ground location accuracy figure. If even this accuracy is not attainable with the base map, one should conclude that the base map does not contain location information commensurate with its scale.

3.7.1.2 Precision of a location method

The **precision** of the location method is expressed as the ratio of the standard deviation of distance measurements to the mean value of the distances measured. Thus, the smaller the relative precision ratio (i.e. the larger its denominator), the more precise the measurement. For example, distances measured by pacing over open country may be measured with a relative precision of 1/100 (Davis et al. 1981), that is, if a 100 meter line is paced, there is a standard deviation of 1 meter associated with this measurement, so that 90% of the time, one could expect the distance paced to be within 1.645 meters of the true distance of 100 meters. Measurement of angles and the precision with which bearings may be followed in the field may be compared to the precision of distance measurement; table 3.1 shows the correspondence between distance and angle measurement precisions. For example, to attain the same precision as 1/100 distance measurement, one would have to measure and follow angles within 1 degree on either side of the true bearing 90% of the time. (To obtain angular precisions for other distance precisions, convert the distance precision ratio, in which the angles are expressed in radians, to degrees, and multiply by 1.645. When calculating this table, it was assumed that angle and distance measurements are uncorrelated.)

Table 3.1 Precision of distance and angle measurements

Precision of distance measurement	90% of angles must be measured within ± this value
1/20	4 2/3 degrees
1/25	3 5/6 degrees
1/50	1 5/6 degrees
1/100	1 degree
1/200	1/2 degree

The SRI evaluator should use the precision corresponding to the worse of the two measurements, depending on the measurement methods available. If the terrain in the survey area is generally wooded or rough, a lower precision should be used. Given the precision ratio and the desired ground accuracy, the maximum distance from the nearest control point for which points may be adequately located is found by the formula (after Davis et al. 1981):

$$\text{Distance} = (0.466) \times (\text{Ground Accuracy}) \,/\, (\text{Precision ratio})$$

For example, with a desired ground accuracy of 10 meters and a precision ratio of 1/50, the maximum ground distance is 233 meters. The ground distance may then be converted to a map distance, as shown in Appendix B. In this example, if the map scale is 1:15,000, the ground distance of 233 meters is equivalent to a map distance of 15.5 mm.

3.7.1.3 Estimation of point location utility

The utility of the map for point location is measured by estimating the proportion of the map that is within the specified maximum map distance from the nearest control point. This is accomplished by randomly placing test circles, with radius equal to the maximum map distance calculated in the previous section (3.7.1.2), on the map, and noting whether a control point occurs within the area covered by each circle. (The test circles may be placed by their centers, using the method of reference coordinates given in Appendix C.) This is a binomial sampling test (Steel and Torrie, 1980). If the circle is placed N times, and P of these result in successes (i.e., a control point lies within the circle), an estimate of the percentage of the map area that is close enough to a control point for accurate location is (N/Px100). For example, if the test circle is randomly placed on the map 30 times, and in 25 of these placements there is at least one control point within the circle, the estimate of the portion of the map which is locatable is 25/30, or 83.3%, of the map area. Note, however, that this statement has no statistical validity.

Figure 3.2 (pg. 20) shows a simple example of this method. Seven test circles have been randomly placed on the map; the test circle radius was determined to be 11.9 mm on the map, using the calculations in the previous section, assuming a map accuracy standard of 0.51 mm, and a relative precision of ground measurements of 1/50. Test circles 2,5 and 6 have no control points contained in them; thus, the points at their centers are too far from the nearest control point to be accurately locatable, under the assumptions just stated. Circles 3,4, and 7 each have one control point within them, and the points at their centers are accurately locatable. Circle 1 has four control points within the circle, but only one is necessary; the extras do not add to the locatability of the point at the center of this circle. The estimate of the portion of the map area that is accurately locatable is then 4/7, or 57%.

A statistically valid, and more conservative, estimate of a map's point location utility is the minimum portion of the map area that is locatable to the specified accuracy, with 90% confidence in this statement; this estimate will be somewhat lower than the estimate obtained directly from the success rate of the circle test. Table 3.2 shows the relationship between the number of successes out of 30 trials (test circle placements) and the minimum percentage of the map sheet that the evaluator can confidently assert to be adequately locatable, for both the 90% (Table 3.2A) and 80% (Table 3.2B) confidence levels. For example, if the circle is randomly placed on the map 30 times, and in 28 of these placements there was at least one control point within the radius of the circle, one can assert with 90% confidence that at least 87.5% of the map area is adequately locatable. The converse of this statement is also true, that is, that at most 12.5% of the map area is not adequately locatable. At the 80% confidence level, the corresponding percentage is 90.4% locatable, or 9.6% not locatable.

Table 3.2 - Estimating a map's locatable area

Left column of each double column gives the number of successes observed in a sample of 30 test circles.

Right column of each double column gives the minimum area of the map sheet, in percent, that is locatable.

A) 90% confidence

Successes (number)	Area (percent)	Successes (number)	Area (percent)	Successes (number)	Area (percent)
xxx 30	95.8	x 20	57.0	10	24.6
xxx 29	92.6	x 19	53.1	9	21.9
xx 28	87.5	x 18	50.0	8	19.1
xx 27	83.2	17	46.9	7	16.2
xx 26	78.9	16	43.4	6	13.5
xx 25	75.0	15	40.2	5	10.9
x 24	71.1	14	37.1	4	8.4
x 23	67.6	13	34.0	3	5.9
x 22	64.1	12	30.9	2	3.8
x 21	60.2	11	27.7	1	1.8

B) 80% confidence

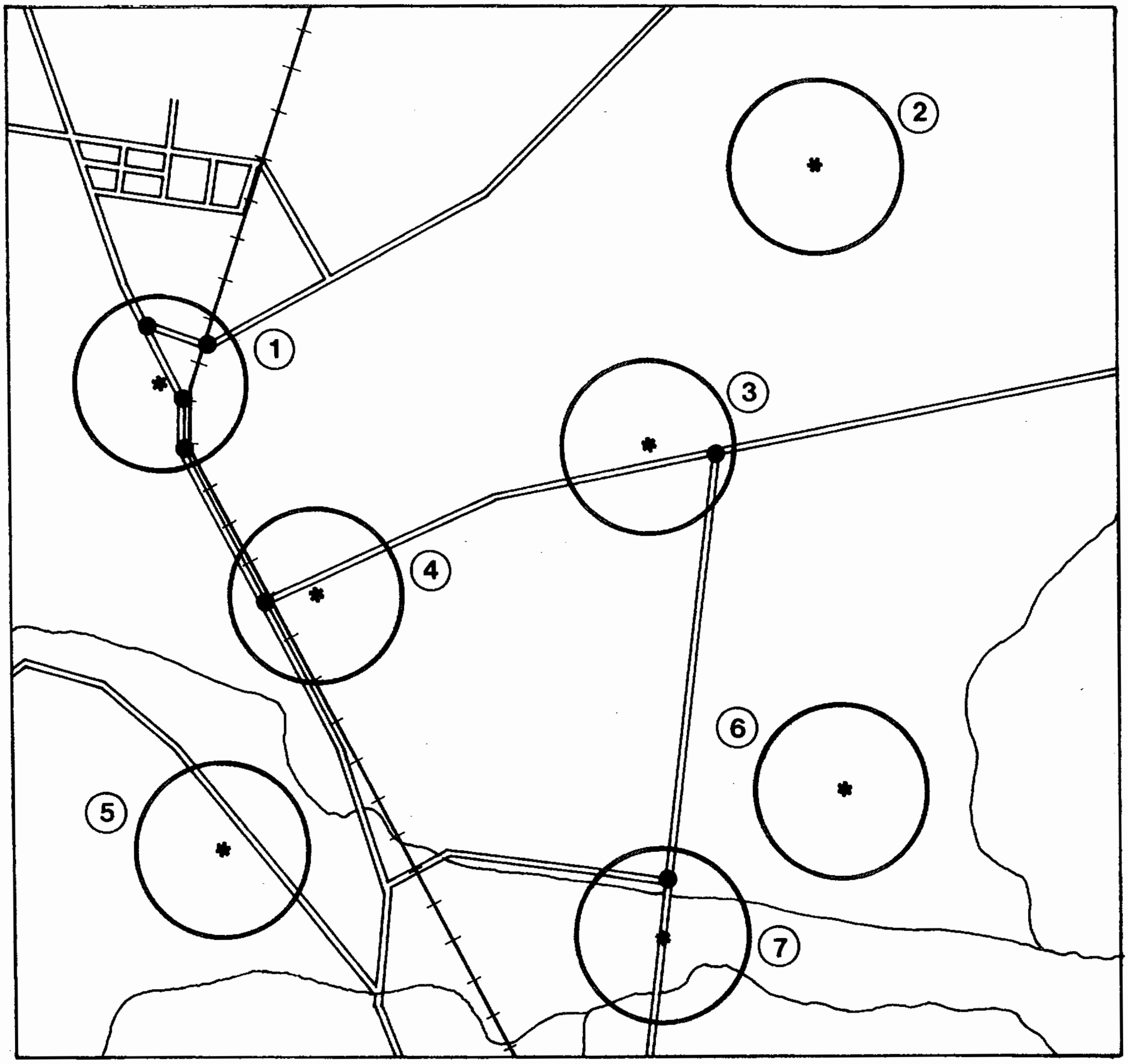
Successes (number)	Area (percent)	Successes (number)	Area (percent)	Successes (number)	Area (percent)
xxx 30	99.8	x 20	60.9	10	28.1
xxx 29	94.7	x 19	57.4	9	25.0
xxx 28	90.4	x 18	53.9	8	22.1
xx 27	86.3	x 17	50.8	7	19.1
xx 26	82.4	16	47.3	6	16.2
xx 25	78.5	15	44.1	5	13.3
xx 24	75.0	14	40.8	4	10.6
x 23	71.3	13	37.5	3	7.8
x 22	67.8	12	34.4	2	5.2
x 21	64.3	11	31.3	1	2.7

xxx HIGH location utility (>90%)
xx MEDIUM location utility (75–90%)
x LOW location utility (50–75%)

The SRI evaluator must decide on a minimum acceptable percentage of point-locatable area for the map. Some possible percentages are 90% (marked as "high" point location utility in table 3.2), 75% ("medium"), and 50% ("low"), at either 80% or 90% confidence in the estimate. Table 3.2A shows that a success rate of at least 29, 25, or 18 out of a sample of 30 test circles will meet the criteria of 90%, 75%, or 50%, respectively, at 90% confidence. The corresponding success rates at 80% confidence are 28, 24, and 17, as shown in Table 3.2B.

Figure 3.2

ESTIMATING POINT LOCATION UTILITY (LOCATION BY GROUND CONTROL POINTS)



SCALE 1:31680 MAP ACCURACY STANDARD = 0.51 MM

RELATIVE PRECISION OF GROUND MEASUREMENTS = 1/50

RADIUS OF TEST CIRCLES = 376.5 M ON GROUND = 11.9 MM ON MAP

LEGEND

RAILWAY

STREAM

ROAD

① TEST CIRCLE

● CONTROL POINT

* SAMPLE POINT

If there are sections of the mapped area within which accuracy of point location is not important (e.g. rough, stony land where no intensive land use is planned), the SRI evaluator may eliminate these from consideration by rejecting any test circle placements in which the center of the circle falls within such sections. In this way, the estimate of the area in which point location will be accurate refers only to the land in which such location is desired.

3.7.2 Location by interpolation

The utility of a map for location by interpolation depends on the density and texture of interpolation features. There is no precise relation between a given texture of interpolation features and location accuracy; however, the density of interpolation features on the map may be estimated in order to obtain some idea of the map's utility for location by interpolation.

To estimate the density of interpolation features, a line of fixed length is placed on the map, with both its origin and another point (which determines the direction of the line) selected randomly. The method of reference coordinates, given in Appendix C, may be used to select both points. The number of interpolation features that the line crosses is counted, and this number is divided by the length of the line to give a count of features/mm of line. This test is repeated a number of times, and the mean and standard deviation of the count is computed. The number of samples depends on the confidence desired; sampling continues until the standard error (standard deviation of the mean) is less than some pre-determined value, for example, 1 feature/mm. The mean thus obtained is an estimate of the number of interpolation features per linear mm of traverse on the map. Finally, this estimate is converted to a measure of the density of features on the ground, by the formula:

$$\text{Features/km} = \frac{\text{Features/map mm} \times 1{,}000{,}000}{\text{RF}}$$

This is the number of interpolation features one would expect to cross while traversing one kilometer in a straight line in the mapped area. The higher this number, the more accurate will be location by interpolation in a given environment.

A simpler method of obtaining the number of features traversed in one kilometer is to use a line length that represents one km on the map. For example, on a 1:20,000 map, the required line length would be 50 mm. For maps with scales smaller than 1:50,000, the line length would be less than 20 mm, and errors in marking the beginning and end of the line would become important; for these maps, a fixed length of at least 20 mm should be used.

The inverse (reciprocal) of the number of features traversed in a given distance is the average distance between features; this may be a more intuitive way of expressing density of interpolation features. For example, if 5 features are traversed per kilometer, there are an average of 200 meters between features. In this measure, the lower value is more desirable.

Figure 3.3 shows a portion of a base map, with two 1-km transects, scaled to map distance, drawn on it. The intersections of the transects and interpolation features are shown. Note that if the transect crosses more than one interpolation feature in a very short distance, only one feature is counted, since the others would not add to the location accuracy. In this example, both transects cross seven features. The estimate of location accuracy is thus 7 features/km, or 142.8 m between interpolation features. Several more transects would be necessary to make a statistically valid estimate.

An acceptable value of this measure must be specified by the SRI evaluator, based on the site (landscape and vegetation), the experience of the map users, and the desired accuracy of point location. The same considerations used in determining the radius of the test circle for location by control points (section 3.7.1) can be applied to this problem. If the average distance between interpolation features is greater than the calculated radius of the test circle, location by interpolation will probably be insufficiently accurate.

3.8 Location of areas

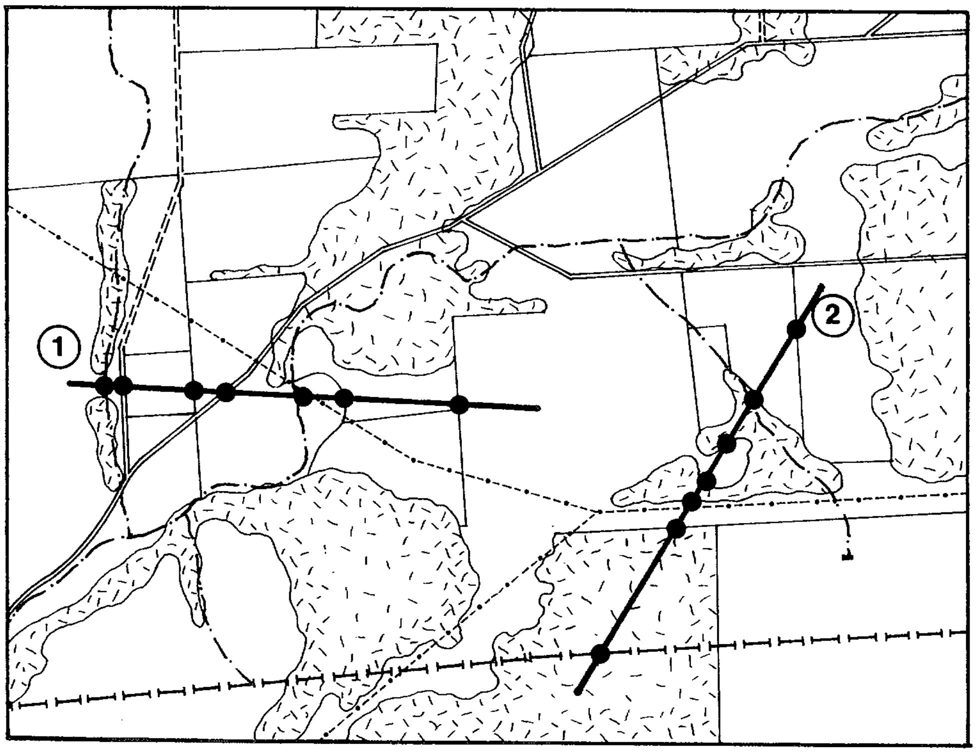
Soil maps show land areas that an SRI user may want to locate on the ground for planning or operational purposes. Conversely, a user may want to find on a map sheet the area corresponding to an identifiable ground area, for example, a field or a watershed, in order to determine the pattern and types of soils in that land area. These are the two aspects of **area location**. (A related problem, that of finding the location of soil delineations in the field, is not primarily a function of the base map, but rather of the soilscape.) Since an area is defined as the interior of a geometric figure which is determined by its boundaries, the area location problem is equivalently a boundary location problem. Area location may be considerably more difficult than point location (section 3.7), since two-dimensional geometric figures, rather than zero-dimensional points, must be transferred from map to field, or vice-versa.

Often the SRI user wants to find on a map sheet the area that corresponds to a land area of interest. The area's boundaries are either shown on the base map or they are not. In the first case, the user just identifies the boundary features on the ground and then finds the corresponding representation of that boundary on the map and outlines it; the interior of the outlined figure is the required area. Photographic base maps usually have a decided advantage over schematic base maps, because most boundaries that can be identified in the field, such as fence or field lines, streams, roads, or escarpments, can be easily identified on a good-quality air photo, whereas these features must be specifically drawn on a schematic map in order to be identifiable. Note, however, that older air photos may lose considerable value for identifying boundaries if the photographed area has substantially changed since the photos were taken (section 3.6).

If the boundary of the area to be located is not represented on the base map, the area location problem is insoluble without special methods. The area to be located would have to be surveyed with reference to ground points which are shown on the map, and the survey would have to be

Figure 3.3

ESTIMATING POINT LOCATION UTILITY (LOCATION BY INTERPOLATION)



SCALE 1:15840

1MM=15.840M

63.13MM=1KM

LEGEND

PIPELINE

POWER LINE

STREAM

ROAD

FENCE & FIELD LINE

WOODS

TRANSECT

scaled and transferred to the map. Some inaccuracy would be unavoidable in both the survey and transfer processes, so that the resulting map area would not be as accurate as one that was shown on the published base map.

Therefore, if the soil survey will be used to represent known land areas on the map, sufficient boundary lines must be shown on the base map, and these lines must be up-to-date. The SRI evaluator should determine the type of features that would commonly be used as ground boundaries of land areas (typically, roads, streams, field boundaries, ditches, and farm paths) and then see if these features are legibly represented on the base map.

The overall accuracy of a base map for area location can only be evaluated in general, non-quantitative terms. Assuming that the point location accuracy of the map is satisfactory (section 3.7), the degree of area location accuracy depends on the size and geometrical complexity of the area. If the area is rectilinear (e.g. a rectangular cultivated field), the figure may be determined almost as accurately as each of the points that define it (its vertices). However, if the area is non-rectilinear (e.g. an area bounded by streams), the figure is not determined by a few vertices, and the point location accuracy of the map affects the area location accuracy only indirectly, and in no exact relation. Photographic base maps or schematic base maps compiled by controlled photo methods may have area location accuracy approaching point location accuracy, because any point on a boundary of any shape may be plotted to nearly the same accuracy as a well-defined point. However, maps compiled by non-photo methods, or by uncontrolled photo methods, must be regarded as having only approximate area location accuracy, since irregular boundaries shown on such maps can only be more or less accurate interpolations from a finite number of known points.

3.9 Clarity of Soils Information

An important property of the soils map is the clarity of presentation of the soils information. There must be no confusion between soils information on the one hand, and base map information on the other. Boundary lines of soil areas must be of a different line width or boldness than other lines that might be confused with soil boundaries, such as roads or drainageways. Every soil delineation must be labelled with an unambiguous symbol.

The use of colored areas to represent soils information may be very helpful or very misleading to the SRI user. Colors should be light enough so that all printed base map information can be read. Colors should be different enough from each other so that areas of similar colors can not be confused, even if widely separated on the map. These two requirements imply that not too many different colors may be used; maps with more than about 16 colors will probably be confusing or illegible.

Another consideration suggests that only a few colors be used. The only reason for coloring a soils map is to convey information to the user in an easily visible form. Thus, the color pattern should be an abstraction of one or more important soil properties, and gradations of value (reflectance) and chroma (saturation) within a single hue (spectral quality) should correspond to commensurate changes in the soil properties. Hues should especially correspond to an important property. For example, purples may be used for mucks, blues for wet mineral soils, greens for humid soils, and yellows for droughty soils. Alternately, hues can be used to represent some important interpretation, such as suitability for general farming. Hues that are adjacent in the spectrum should represent interpretations that are adjacent in the ratings table. If colors are used to represent interpretations, the interpretation should be one of the most important to the SRI user. For example, a color scheme that shows the genetic classification of the soils may completely obscure the classification of map units for an important interpretation, such as upland crops; in this example the colors impress the soil scientist but are a hindrance to the agriculturalist's understanding.

Similar map units should have the same color. In a coloring style that was popular in the U.S.A. before the advent of photographic base maps, each map unit was given a distinct color, usually without regard to the relation between the map units, either as taxonomic units or for land use; indeed, the aim was often to provide maximum contrast between similar map units. This style results in beautiful wall displays; unfortunately the striking color patterns have nothing to do with the uses of the survey. Similar map units should be grouped and assigned the same color, and differentiated on the map by the printed map unit symbol.

Overprinted patterns may be used to provide additional information, particularly about important limitations to land use in map units. For example, thick dots overprinted on an area may signifiy that the area is sandy. These patterns may be a great help to the SRI user. They should not obscure other information, and they should correspond to land use factors, important to the user, that are not already inherent in any color pattern.

3.10 Summary

For the base map to be adequate:

1. The following physical qualities should be acceptable: paper grade and finish; printing; size and folding; and reproduction of colors (if any) (3.2);

2. For airphoto base maps, photographic resolution must be sufficient; for maps from digital imagery, the publication scale should not exceed the original resolution of the pixels (3.3);

3. The map must meet appropriate accuracy standards (3.4).

4. The map must be sufficiently recent (3.6).

5. The map must be adequate for point location (3.7), by either the control point (3.7.1) or interpolation feature (3.7.2) method.

6. The map must be adequate for area location (3.8).

7. Soils information and base map information must be clearly differentiated. If colors are used, they should clearly convey important soils or management information to the SRI user (3.9).

Clearly, some of these points are more critical than others. For example, poor physical quality (point 1) could be tolerated if the map were otherwise useful. Also, if the map will not be used for site-specific uses, accuracy standards are not as important.

Chapter 4

Ground Truth

4.1 Introduction

The **ground truth** of a soil resource inventory is the degree to which the map and legend accurately represent the soilscape. There are basically two ways to express the ground truth of an SRI. The first approach concentrates on the accuracy of the location of the soil boundaries on the map (the map delineations) with respect to the boundaries in the field; in contrast, the second approach concentrates on the reliability of the information given in the SRI about the soil at each map point. The first approach deals with **boundary errors** ("between" delineations), and the second with **classification errors** ("within" delineations). The methodology presented here uses the second approach, since the aim is to discover the amount of a map's area that is acceptably surveyed. Boundary errors will in fact be combined with classification errors, since, if a boundary is misrepresented, the classification of the land areas included in the "wrong" delineation will be incorrect. Another reason for emphasizing classification errors is that boundary errors are difficult to detect and quantify; usually their determination requires expert judgment by a soil surveyor. Within soil survey organizations, the emphasis may instead be on detecting and correcting boundary errors, in order to produce a higher-quality survey; however, the aim of the present methodology is the evaluation of existing surveys, not the improvement and correction of surveys in progress.

When thinking of ground truth in terms of the correct description of the soils at each map point, an intuitive measure of the overall ground truth of a map is the proportion of the map area in which the reported soils information is substantially correct. In particular, each point shown on the soil map is included in some map delineation; in turn each map delineation is part of a map unit which is described in the map legend. Thus the map and report together make assertions about the soil and associated landscape properties at each ground point. An assertion can be tested by examining the location in the field, and checking each statement of the assertion against what is actually found. An assertion about soils may be completely true, completely false, or, most commonly, some statements of the assertion may be true and others false. In addition, statements may be in error by different degrees, with correspondingly different effects on the overall truth level of the assertion. By combining the results of many such tests, a composite value for the ground truth of the SRI may be obtained. This value may be compared, by statistical methods, against pre-defined standards of ground truth, and the ground truth of the SRI may thus be judged acceptable or not.

There is no attempt in this methodology to discover errors in the base map, as opposed to the soil delineations. However, since the base map is used to locate ground truth sample sites, errors in the base map will probably result in apparent classification errors, which will lower the overall ground truth of the map. Note also that if there are typographical errors or mis-statements on the map or in the report, these will also lower the ground truth. For example, if a map delineation is incorrectly labeled with the wrong symbol, the apparent ground truth will be lowered, even though the error was committed by the map draftsman, not the soil surveyor. Thus, only a part of the ground truth error is attributable to soil surveyors.

The ground truth of an SRI can not be evaluated until it is judged to be adequate on the other three points of these guidelines, namely, scale, legend, and base map. The scale (Chapter 1) determines the minimum acceptable point location accuracy, while the base map (Chapter 3) determines the actual accuracy with which test points on the ground may be located. The assertions about the soils which are to be tested in this chapter are found in the map legend. Thus, the legend must have been judged adequate for the intended uses of the SRI (Chapter 2), in order that the ground truth be relevant to these uses. The legend must make sufficiently specific assertions about the soils contained in each map unit, and the map units about which the assertions are made must be sufficiently homogeneous so that the assertions apply over the entire area of each delineation.

In this chapter, a detailed method is presented for evaluating the overall ground truth of the SRI (section 4.3). In addition, a method of checking the composition of heterogeneous map units, such as associations or complexes, is presented (section 4.4). These methods involve considerable work, both in the office and in the field. At least 30 test sites must be located and examined in the field, and some ground truth criteria may require further laboratory testing. This method is designed primarily to objectively measure the ground truth of the map, not to allow mappers to correct errors and improve mapping techniques. By contrast, soil survey organizations commonly check ground truth (which is often referred to as "mapping quality") by spot checks or re-surveys of selected areas by senior surveyors or correlators. The areas selected are not random, but usually consist of samples of representative landscapes, and may especially include areas where difficulties in mapping might be expected (e.g. due to a poorly-understood landscape or difficult terrain). This process is a constructive one, by which the surveyor learns what sort of mistakes were made in the original mapping, and thus is a valuable learning tool as well as a check on map quality. This method is usually cheaper, faster, more informative, and more likely to catch subtle errors than the method presented in this chapter. However, map revision requires the services of experienced and unbiased soil surveyors, and does not usually provide a quantitative and objective measure of ground truth.

4.2 Establishing ground truth criteria

The ground truth of each sample location is evaluated in terms of several **ground truth criteria**, generally land characteristics or other attributes of interest to the user, derived from the map legend. The descriptive legend for a map unit gives values and ranges for a large number of attributes; only a suitable subset of these is necessary for an economical and rapid evaluation. The attributes chosen should be important for land use, and easily and unambiguously measurable, preferably by field methods. Attributes that are important for the land use but that can only be measured in the laboratory may also be included. The characteristics chosen may be the same as those used in evaluating the map legend (Chapter 2). Although land qualities are preferable when evaluating a map legend, by definition land qualities are composite attributes, not directly measurable by ordinary field methods. Therefore, land characteristics are preferred to land qualities as ground truth criteria.

It is also possible to evaluate ground truth in terms of a more general standard, such as a soil classification system. In this case, the SRI evaluator must use as ground truth criteria all land characteristics that are used as differentiating criteria in the classification system. This approach may be necessary if the legend consists of soil series or other taxonomic units which are assigned directly to suitability groups.

Example:

In evaluating the legend of the soil survey of Part Paparua Co., New Zealand (Cox 1978), for horticultural crops, the following land qualities were used: 1) natural drainage (internal and external); 2) available water storage capacity; 3) potential for subsidence if artificially drained; and 4) wind erosion hazard. None of these can be directly observed in the field, except by controlled experiment. Thus, they are not suitable for ground truth evaluation. However, these composite land qualities may be estimated from the following land characteristics.

1 Natural drainage

1.1 slope
1.2 mottling and other signs of wetness in the profile

2 Available water storage capacity

2.1 texture of mineral soil (particles < 2mm)
2.2 proportion of coarse fragments
2.3 depth to underlying gravel
2.4 proportion of peat

3 Potential for subsidence if artificially drained

3.1 proportion of peat

4 Wind erosion hazard

4.1 texture of mineral soil (particles < 2mm)
4.2 land form

All of these land characteristics are easily measured in the field. Note that two of the characteristics (texture of mineral soil and proportion of peat) are components in more than one land quality. Information on the values of all these characteristics is presented in the descriptive legend for each map unit. These characteristics, in combination, were in fact used to determine the overall horticultural suitability classes for this survey.

Most land characteristics vary continuously; "small" differences do not significantly affect land use, and thus "small" discrepancies between the reported and observed values of a land characteristic should not greatly affect the ground truth of the SRI. Conversely, "large" discrepancies should severely affect ground truth evaluation. The range of values that a characteristic may have is usually divided into **ground truth classes**, in order to emphasize larger differences in the continuous range of possible values. The classes have an explicit ranking in one or more dimensions, so that one may determine whether two classes are "adjacent" in terms of this ranking. The number of classes used depends on the characteristic and its total range in the survey area; typically three to seven classes are defined. For example, the land characteristic "site slope", which varies continuously from 0% (level) upwards, is divided into classes such as "Nearly level, 0–2%", "Gently sloping, 2–5%", "Sloping, 5–12%", and so forth. The class limits (the values which divide adjacent classes) depend on the characteristic itself, other characteristics, site conditions, and intended uses of the survey. In the example of site slope, the limits might depend on surface soil texture (another soil characteristic), rainfall amount and intensity (a site condition), and whether the area was suitable for pasture, woodland, or row crops (intended uses of the survey).

To evaluate ground truth, ranked classes are established by the user or taken from the legend for each ground truth criterion. These classes have the following attributes: 1) differences within the same class are not significant for the intended land uses; 2) differences between adjacent classes are significant for the intended land uses, but the classes could fairly be called "similar"; 3) differences between non-adjacent classes are very significant for the intended land uses, and the classes could fairly be called "dissimilar"; and 4) differences between adjacent classes must be reproducible in the field, in other words, class widths must be at least twice the standard error of the field measurement of the attribute in question.

In the example of site slope, differences within a class of several percent of slope are rarely important for land use, and the acceptable differences within a class become greater as the slope increases, partly because the possible land uses become more restricted. For general purposes, the classes might be set up as follows: A) "Nearly level, 0–2%"; B) "Gently sloping, 2–5%"; C) "Sloping, 5–12%", D) "Moderately steep, 12–25%"; E) "Steep, 25–45%"; and F) "Very steep, >45%". This classification asserts that it makes no difference for land use if the slope varies within any of these classes. Further, if the map indicates a slope class of "Nearly level" for a site, and in fact the slope was 3%, which falls in the adjacent "Gently sloping" class, the difference is significant for land use, but the site would still be acceptable for a land use that optimally should be on a "Nearly level" site; the site could thus be called "similar" to one with a "Nearly level" slope. However, if the slope was in fact 8%, which falls in the non-adjacent "Sloping" class, the difference is large enough for land use that the site would not be acceptable for some land uses that should be on a "Nearly level" site; one could thus fairly call this site "dissimilar" to the intended "Nearly level" site.

Classes and their limits are often defined in the legend, and should normally be used as presented, since the original mapping was based on them. Alternatively, the survey organization may have standard classes defined for all land characteristics. Some classes may be combined for convenience and economy, if the differences between the classes do not appear important for the intended uses of the survey. If no classes have been defined, the evaluator must define them, using the criteria given in the previous paragraph. In any case, a list should be prepared, showing the ground truth criteria, the units of measurement, and the classes and their limits.

Example:

Continuing the example from Part Paparua Co., New Zealand (Cox 1978), the required land quality classes for each ground truth criterion established in the previous example section could be set up as follows:

1 Natural drainage

1.1 slope
does not significantly vary in survey area
1.2 mottling and other signs of wetness in the profile
A) Well drained
B) Moderately well drained, Somewhat poorly drained
C) Poorly drained, Very poorly drained

2 Available water storage capacity

2.1 texture of mineral soil (particles < 2mm)
A) sand, loamy sand
B) sandy loam
C) fine sandy loam, silt loam, loam
D) clay loam
2.2 proportion of coarse fragments
A) very stony
B) stony
C) other
2.3 depth to underlying gravel
A) very shallow (<25 cm), shallow (25–46 cm)
B) moderately deep (46–60 cm)
Note - Class B grouped with Class C if texture of particles < 2mm is Class D (clay loam)
C) deep (>60 cm)
2.4 proportion of peat
A) significant peat in any horizon
B) other

3 Potential for subsidence if artificially drained

3.1 proportion of peat - same as 2.4

4 Wind erosion hazard

4.1 texture of mineral soil (particles < 2mm)
A) sand, loamy sand
B) other
4.2 land form
A) dunes
B) other

Note that in several cases, classes that were used in the soil survey report are grouped for purposes of evaluating ground truth. This is because these class differences are not perceived as important for the intended land use of general horticulture; they may be important for other land uses, and were important differentiating criteria between different soils during mapping. For example, in assessing wind erosion hazard, one only need determine whether the texture is very coarse (sands and loamy sands) or not (all other texture classes). Also note that one land characteristic, texture of the mineral soil fraction smaller than 2mm, is divided differently according to the land quality being estimated (wind erosion hazard or available water storage capacity). In this case, one would have to use the larger number of classes when testing.

Once the ground truth criteria are selected and the class limits are established, a table is prepared, showing all map units in the legend, and, for each map unit, the class into which it falls for each ground truth criterion. If the map unit is an association, each component of the association is listed as a sub-entry of the map unit, along with the proportion of each component in the association. This table will be used to score test sites.

Example:

Continuing the example from Part Paparua County, New Zealand (Cox 1978), a partial table, showing 3 of the 113 map units in this survey, was prepared by comparing the descriptions of each map unit with the classes previously determined. This table follows.

	Class					
Map Unit	Drainage	Texture	Stoniness	Depth	Peat	Landform
WM1	C	C	C	C	A	B
(Waimairi peaty loam)						
T1	A	C	C	C	B	B
(Templeton silt loam)						
HK+E4						
—HK(60%)	A	A	C	C	B	A
(Halkett sandy loam and sand)						
—E4 (40%)	A	C	C	A	B	B
(Eyre shallow fine sandy loam)						

4.3 Overall Ground Truth of the SRI

In this section, a methodology is presented for determining whether a land area as a whole is acceptably mapped, in terms of the ground truth criteria developed in the previous section.

The first step in the evaluation is to set up ground truth criteria on the basis of the map legend (section 4.2). Then, sample sites in the field have to be selected for testing. These sites constitute a sample drawn from the total population of map locations (section 4.3.1). At each site, each ground truth criterion is checked against the soil actually found, and the site is scored for ground truth (section 4.3.2). Finally, the results of all samples are combined statistically and checked against specified adequacy criteria (section 4.3.3), and the map is accepted or rejected.

The entire land area covered by the SRI may be evaluated as a unit, or it may be divided into sub-areas, each of which is evaluated separately. This process of subdivision is called **stratified sampling**, and the sub-areas may be called **strata**. Stratified sampling is appropriate when the evaluator believes that the strata are more homogeneous in some important attribute that affects ground truth, than the survey area taken as a whole. For example, dividing the map into quadrants will not ordinarily be a valid stratification. However, one might well stratify the map into the sub-areas that were mapped by different soil surveyors, since it is reasonable to assume that different surveyors systematically make different types of errors. Another example of a valid stratification is the division of the survey area into broad geographic regions, based on landforms, agro-ecological zones, lithology or surficial geology, or geologic history. These areas would typically have different groups of soils in different patterns, and consequently they would be expected to present different problems to the soil mapper. Another possible stratification would be into areas with different map textures (Average Size Delineations and delineation shapes); such a stratification was discussed in Chapter 1.

If the survey area is stratified, the strata and their boundaries are shown on a small-scale map, which is used when sample points are determined. The SRI may already contain such a map, for example, a general soil association map, on which the strata can be shown.

If the survey area is stratified, a statement about the ground truth will be made about each of the strata, rather than about the map as a whole. In this way, the ground truth may be adequate in part of the total survey area, but not in others.

Example:

Halifax County, North Carolina, U.S.A. has three major geographic divisions, based on lithology and landforms. The soils within each of the three sub-areas thus differ from those in the other sub-areas in parent material, dominant drainage, and delineation size and pattern. The three areas are also distinct in terms of human population patterns and land use. The areas are:

1 **Piedmont** - highly weathered crystalline rocks; moderately steep, rolling, fully dissected hills; soils are dominantly well-drained, deep, fine-textured and acid; delineations typically follow the dendritic drainage patterns and the contours of the hills.

2 **Atlantic Coastal Plain** - deep, highly weathered marine sediments of early Pleistocene age; broad poorly-dissected areas, separated by moderately dissected, gently-sloping areas; soils are very deep, dominantly medium and coarse textured, ranging from excessively to poorly drained, and acid; delineations are typically large polygons.

3 **Fluvial Terraces** - deep, young somewhat weathered fluvial sediments of recent age; on terraces, backswamps, and flood plains; soils are moderately deep to shallow, ranging from very fine to very coarse texture and from excessively to very poorly drained, with the relation to sedimentary patterns evident; delineations are linear and follow depositional patterns, e.g. point bars and slack-water areas.

A general soil association map of the county shows ten associations. Each of these is found in only one of the three proposed strata, except for an association of recent alluvial soils, which is found in both the Atlantic Coastal Plain and the Fluvial Terraces. Thus, the three strata may easily be delimited on this map by combining those associations that occur in each of the geographic areas. This stratification is shown in the accompanying figures. (4.1a, 4.1b).

4.3.1 Sampling

Since the entire land area can not be examined for its correspondence to the ground truth criteria, a sampling procedure must be used to determine which points or areas to test. Several sampling procedures are possible, including transect, grid, and completely random methods of picking sample points. In the present methodology, a completely random method of selecting points is presented. This insures that each point in the mapped area has an equal probability of being sampled. There is no possibility of a systematically biased sample, as would occur, for example, if the spacing between grid points happened to correspond to some period in the landscape or mapping pattern. The pattern of map delineations need not be considered in the sampling procedure, as it must be if transect or grid methods are used.

There are three steps in the sampling procedure: 1) determining the number of points to sample, 2) locating a random sample of test points on the map, and 3) locating each sample point in the field.

Figure 4.1a GENERAL LANDFORM MAP, HALIFAX CO., N.C.

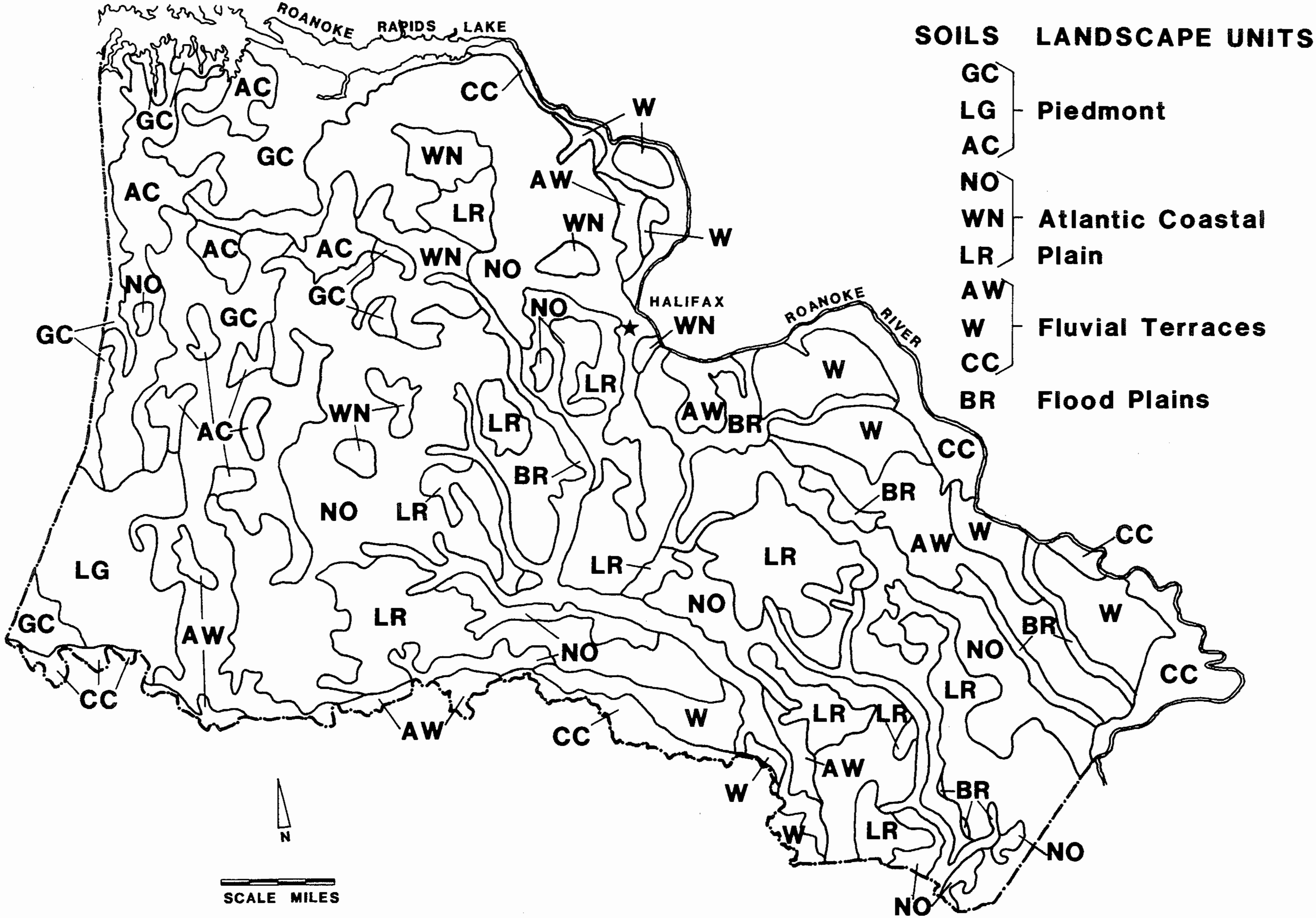
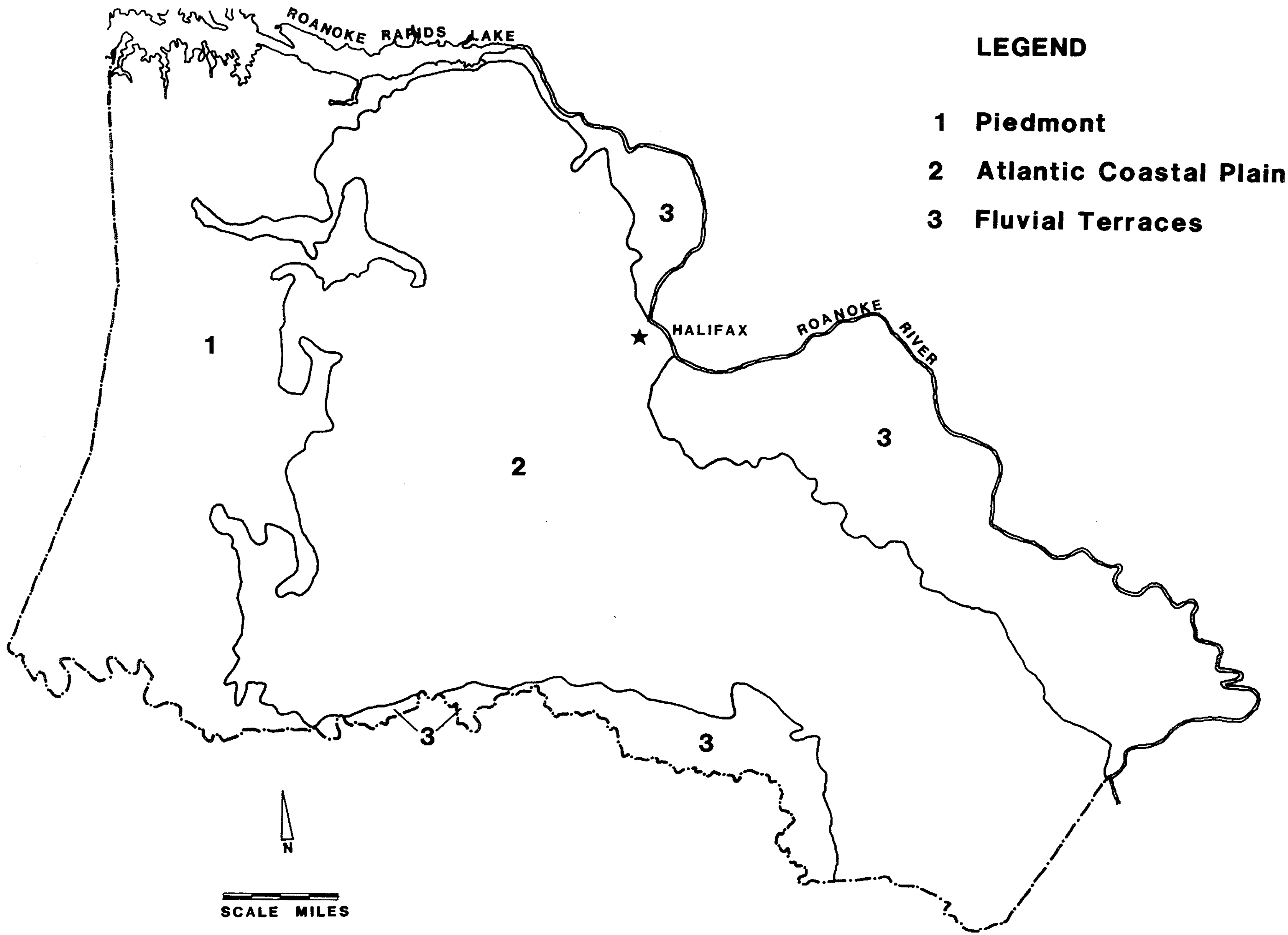


Figure 4.1b SAMPLING STRATA, HALIFAX CO., N.C.



4.3.1.1 Number of sample points

Enough points must be sampled to adequately cover the map (or stratum) area, and to provide sufficient statistical precision for the ground truth tests. The number of sample points must not be so excessive that ground truth testing will be too time-consuming or expensive. Because of the nature of the binomial test that is used in the present methodology (section 4.3.3) and the adequacy criteria outlined in section 4.3.4, there is little benefit, from the statistical viewpoint, in increasing sample sizes past 50, that is, it is quite unlikely that a different decision will be made on the acceptability of the map if the sample size is larger than this. Thus, the main consideration is whether there is a sufficient density of sample points on the map. One possibility for "complete" coverage would be to have one ground truth observation, on the average, in each average-size delineation (Chapter 1); however, this leads to very large sample sizes on most maps. Furthermore, this density of points often equals or exceeds the original survey intensity. The number of points needed to check the ground truth of an existing map is much less than the number of observations needed to make the map.

A suggested density of sample points is one per 10 average-size map delineations, or 30 points, whichever is greater. (Less than 30 points results in unreliable statistical inferences.) The actual average-size delineation computed in Chapter 1 may be used; however, it is preferable to use a standard map delineation size, so that different surveys (at the same scale) may be sampled at equal intensity. Forbes and Eswaran (1978) surveyed 200 soil resource inventories of widely different types from all over the world, and found that the average-size map delineation for maps of all scales smaller than 1:13,000 (i.e., almost all SRIs) was remarkably constant, ranging from 4 cm^2 at the largest scales to 6 cm^2 at the smallest. This result suggests that an average-size map delineation of 5 cm^2 may be taken as a reasonable figure on which to base the sample size. One point per 10 average-size delineations thus gives one point per 50 cm^2 of map. The ground density corresponding to a map density can be calculated by the formula:

$$\text{points/cm}^2 \times 10^{10} \times \text{RF}^2 = \text{points/km}^2$$

For example, at a scale of 1:20,000, a sampling density of 1 point/50 cm^2 corresponds to .5 points/km^2 (1 point for each 2 km^2). At a scale of 1:200,000, this same density corresponds to .005 points/km^2 (1 point for each 200 km^2).

Example:

The soil survey of Edgecombe County, North Carolina, U.S.A. (Goodwin 1979) contains 32 map sheets, each of which is a photographic map 56.4 cm wide, measured along the bottom margin, and 23.4 cm tall, measured along the left margin. Thus the total area of each sheet is (56.4)x(23.4) = 1,320 cm^2, and the total area of the survey is (1,320)x(32) = 42,232 cm^2. There are thus (42,232)/5 = 8,446 standard average-size delineations in this survey; picking 1 sample point for each 10 delineations gives 845 sample points. The map scale is 1:20,000, so each point corresponds to 2 km^2.

If the number of sample points is larger than 300 (as in the preceding example), the amount of work involved in ground truth checking becomes prohibitive. In this case, it is possible to reduce the number of sample points by **subsampling**, that is, dividing the map into smaller units, determining the ground truth of several of the units, and then extrapolating these results to the whole map. The map may be subsampled in a systematic manner, for example, by dividing into quadrants (or some other grid pattern) and randomly choosing a block for testing. It is preferable, however, to insure that sections of the map with different landforms, map textures, groups of soils, or that were mapped by different people, are all represented in the ground truth sample. The method of stratification, discussed in section 4.3, above, may be used to identify different areas. Then, each stratum is sampled in proportion to its extent, by a grid method.

4.3.1.2 Selecting sample points on the map

The second step of sampling is setting up a reference coordinate system for the map, selecting random sampling sites, and transferring those selected to the map. This is covered in Appendix C. However, some points should not be transferred to the map: 1) points outside the mapped area, 2) points falling on non-soil areas, such as roads, buildings, or rivers, and 3) points too close to a soil boundary. The first two cases are self-evident; the third requires some elaboration.

Points are to be rejected if they are "too close" to a soil boundary; just how close depends on the ground location accuracy of the base map, as determined in section 3.6. The ground location accuracy is the uncertainty with which one can locate arbitrary points in the field, with 90% confidence, using the base map (section 3.6.1). This accuracy figure is expressed in ground distance, converted to map distance (Appendix B), and a circle with a radius equal to this map distance is constructed. When a sample point is tentatively plotted, the circle is placed with its center over the point; if a portion of a delineation boundary line is contained within the circle, the sample point is rejected because, given the constraints of the accuracy of ground location, it is not certain in which delineation the point is actually located.

Example:

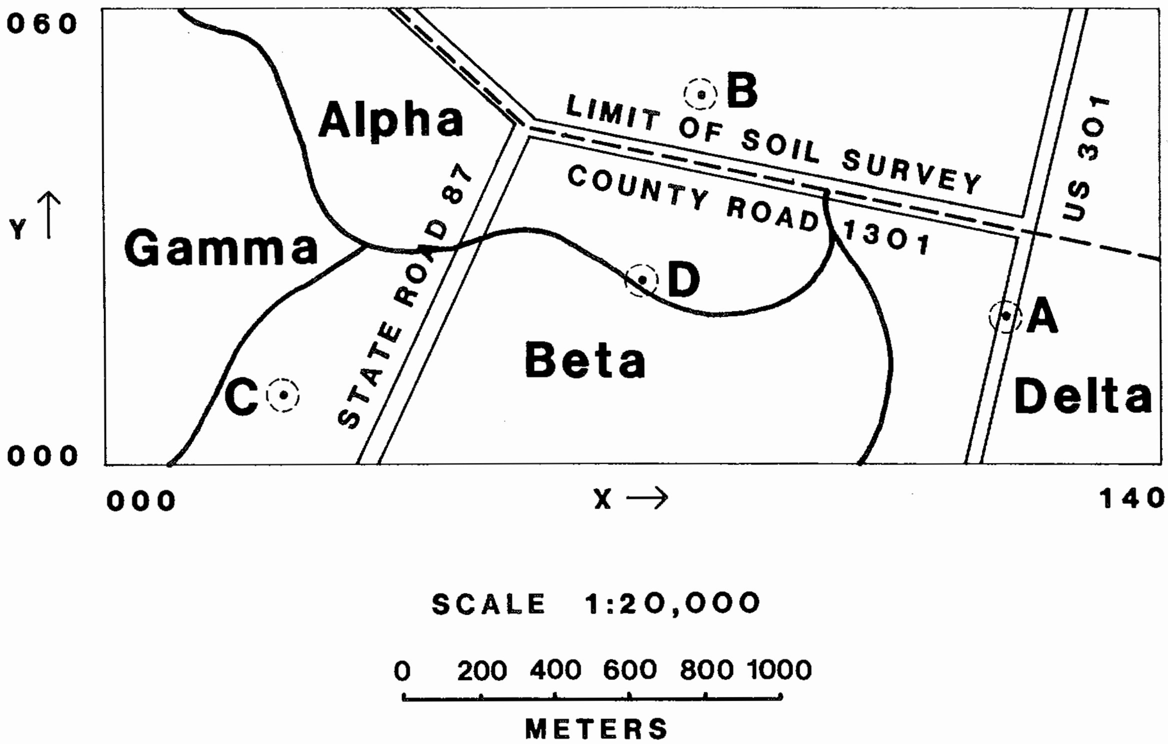
Consider the hypothetical map sheet shown in Figure 4.2. The map scale is 1:20,000, and its dimensions are 140 mm wide (X) by 60 mm tall (Y). Assume that the ground location accuracy was determined to be 40 meters. The map location accuracy is thus:

$$(40 \text{ m}) \times (1000 \text{ mm/m}) \times (1/20{,}000) = 2 \text{ mm}$$

Therefore, a circle with radius of 2 mm is to be drawn around each sample point. Suppose one desires to plot the following sample points: A = (120,020), B = (080,050), C = (025,010), D = (075,025). These are shown on Figure 4.2. Note that point A falls on a road; it is rejected. Point B falls outside of the survey area; it is rejected. The boundary between map units ALPHA and BETA falls within the 2 mm circle of uncertainty drawn around point D; this point is rejected because it is too close to this boundary. Point C is accepted; only one sample point has been transferred to the map.

Figure 4.2

TRANSFERRING SAMPLE POINTS TO A MAP



4.3.1.3 Location of sample points in the field

Once the sample points have been placed on the map, they must be located in the field. This can be done by one of the point location methods described in section 3.6, namely, location by control points or location by interpolation. (Note that the accuracy of point location was used to determine that sample points were not located too close to boundaries; further, that the map was judged acceptable for this degree of point location accuracy (Chapter 3). Therefore, the points as actually located on the ground should be inside the delineation in which the corresponding map point is located.)

It is very important that neither soil boundaries in the field nor the attributes of map units themselves be used to locate sample points in the field, for example, in the middle of delineations. This considerably overestimates the ground truth of the map, since ground truth is probably higher in the center of soil delineations than close to their boundaries.

4.3.2 Scoring ground truth

Each sample site is individually scored for ground truth, by determining in which class the site falls for each ground truth criterion, and checking these classes against those which are expected at the sample site, based on the map and legend. This requires field observations at each sample site, and may possibly require field or lab tests. It is sufficient for the purposes of ground truth evaluation to determine in which ground truth class the site falls; exact values of an observation or test are not required, but may be recorded for other purposes. A discrepancy between the predicted and observed ground truth class is called a **ground truth error**. Depending on the severity and number of these errors, each site is assigned one of four scores, which are defined as follows:

1 **Score 1** - All predicted and observed ground truth criteria agree.

2 **Score 2** - Less than some specified proportion (e.g. 20%) of the ground truth criteria are in adjacent classes, and none are in non-adjacent classes. For example, if there are between 10 and 14 ground truth criteria, no more than 2 may be in adjacent classes.

3 **Score 3** - More than proportion specified in Score 2 (e.g. 20%) of the ground truth criteria are in adjacent classes, and/or exactly one ground truth criterion is in a non-adjacent class.

4 **Score 4** - More than one ground truth criterion is in a non-adjacent class.

A tabular score sheet is used to record the classes observed for each ground truth criterion at each sample point; for each point, the score (Score 1, Score 2, Score 3, or Score 4) is written in the rightmost column.

Example:

Continuing the example from Part Paparua County, New Zealand (Cox 1978), consider the following hypothetical field observation of a sample site in the WM1 map unit (Waimairi peaty loam). Each ground truth criterion developed in section 4.2 has been recorded.

Criterion	Field observation--	Class	WM1 class in SR1
Drainage	Poorly drained	C (pd,vpd)	C
Texture	silt loam	C (fsl,sil,l)	C
Stoniness	none	C (not stony)	C
Depth to gravel	100 cm	C (deep,>60cm)	C
Peat	about 25%	A (significant)	A
Landform	low terrace	A (not dune)	A

Thus this site is scored in Score 1 with respect to the WM1 map unit description, in terms of the defined ground truth criteria. However, this does not necessarily mean that the site agrees in every detail with the mapping unit. For example, the site differs from the exact definition of the WM1 map unit in the criterion of texture, which is silt loam rather than loam. Yet, since the criteria classes do not differ, the site is scored in Score 1 by the defined ground truth criteria. The site may also differ from the WM1 map unit in other characteristics that were not used as ground truth criteria.

The following hypothetical score sheet illustrates the ground truth classes. Note that since there are only six ground truth criteria, the limit between Score 2 and Score 3 is 20% of 6 (1 out of 6) criteria in adjacent classes.

(Observations in the WM1 map unit)

	——Ground truth criterion class——						
Sample	**Drainage**	**Texture**	**Stones**	**Depth**	**Peat**	**Landform**	**Score**
WM1	C	C	C	C	A	B	(Reference)
1	C	C	C	C	A	B	Score 1
2	C	B	C	C	A	B	Score 2
3	B	B	C	C	A	B	Score 3
4	B	B	B	B	B	A	Score 3
5	C	A	C	C	A	B	Score 3
6	A	A	C	C	A	B	Score 4

For example, observation 2 differs by only one class, in only one criterion (texture, e.g. it is a sandy loam (class B) rather than a fine sandy loam (class C)), from the WM1 map unit; this site is thus in Score 2 with respect to the WM1 map unit.

If the sample site is located in a heterogeneous map unit which contains a mixture of soils (e.g. an association or complex), the site must be scored against each component of the map unit separately; the ground truth criteria classes of the different soils making up the map unit can not be combined when scoring the site. The ground truth of the site is then defined as the best score of the site with respect to the individual components of the map unit. For example, a sample site is scored in Score 1 with respect to the map unit only if the site is identical in all ground truth criteria to any one of the components of the map unit; in this case, the site's ground truth with respect to the other components in the map unit is not important. In fact, if a site scores in Score 1 with respect to one component of a map unit, it probably scores in Score 3 or 4 with respect to the other components of that map unit.

Example:

Continuing the example from Part Paparua County, New Zealand (Cox 1978), consider the following hypothetical ground truth observations in the HK+E4 map unit (Halkett sandy loam and sand and Eyre shallow fine sandy loam), which is an association.

(Observations in the HK+E4 map unit)

	——Ground truth criterion class——						
Sample	**Drainage**	**Texture**	**Stones**	**Depth**	**Peat**	**Landform**	**Score**
HK	A	A	C	C	B	A	(Reference)
E4	A	C	C	A	B	B	(Reference)
1	A	A	C	C	B	A	HK-Score 1 E4-Score 4 HK+E4-Score 1
2	A	C	C	A	B	B	HK-Score 4 E4-Score 1 HK+E4-Score 1
3	A	C	C	C	B	A	HK-Score 3 E4-Score 3 HK+E4-Score 3
4	A	D	C	A	B	B	HK-Score 4 E4-Score 2 HK+E4-Score 2
5	A	B	A	B	B	B	HK-Score 4 E4-Score 4 HK+E4- Score 4

Note that although observation 3 matches one of the two components in all criteria, it is "Score 3" to both, when they are considered separately (its texture is in a non-adjacent class from HK, and its depth is in a non-adjacent class from E4), and thus it is "Score 3" from the map unit.

4.3.3 Adequacy criteria

The results of the scores for each ground truth observation may be combined into a composite statement about the level of ground truth observed in the sample as a whole. This statement gives the proportion of the scores obtained at each ground truth observation (Score 1, 2, 3, or 4).

Example:

Suppose there were 50 ground truth sample sites, of which 25 scored "Score 1", 10 scored "Score 2", 10 scored "Score 3", and 5 scored "Score 4". The composite ground truth values for this sample are thus 25/50 (50%) Score 1, 10/50 (20%) Score 2, 10/50 (20%) Score 3, and 5/50 (10%) Score 4.

The question then arises whether these composite values of ground truth for this map (or stratum from which the sample was drawn) are acceptable. To answer this question, standards are necessary, against which the results of statistical tests on the composite ground truth values may be judged. No generally accepted criteria have been developed, and there is no relevant experimental evidence. The following guidelines have been adapted from some concepts of acceptability of uniform map units (in the taxonomic sense) used by the Soil Conservation Service of the USDA in their mapping program (SCS 1951, SCS 1980).

Suggested adequacy criteria:

A map (or a stratum of a map) is **rejected** as having unacceptable ground truth if **either:**

1 It is 90% certain that more than 15% of the map area is scored in Score 4 with respect to the defined map units,

or

2 It is 90% certain that less than 50% of the map area is scored in Score 1 or 2 with respect to the defined map units.

Otherwise, the map (or stratum) is **accepted**.

The combination of Score 1 and Score 2 is referred to here as the "purity" of the map, and the area in Score 4 is referred to as the "strongly contrasting" area. Both these terms are borrowed from more precise usage in terms of taxonomic composition of map units; in the present methodology they refer to the ground truth criteria only. Since the sampling method covers the entire map area (or stratum) in an unbiased manner, results from the sample can be extrapolated to the entire map area (or stratum), as required in the definition of acceptability.

This definition of acceptability is such that maps are only rejected when it is most likely that they are bad. Given the inherent variability of soils and the difficult decisions that the soil mapper and correlator must make, it is best to err in favor of the mapper. To be 90% certain that less than 50% of the map area substantially agrees with the legend (i.e. is "pure"), or that more than 15% of the map area seriously disagrees with the legend (i.e. is "strongly contrasting"), is to be quite confident that the map is of marginal utility.

One could certainly specify more stringent acceptability criteria. For example, the sense of the probability statements could be reversed, thereby biasing the test against the mapper, so that a map would be **accepted** only if it is 90% certain that there are at **most** 15% strongly contrasting soils and at **least** 50% purity. This turns out to be a much stronger statistical statement. Such a requirement would emphasize accepting only maps that are almost certainly good. Other values could be used for the confidence limits, the purity, and the strongly contrasting soils. Appendix E provides information to allow the SRI evaluator to use different acceptability specifications than those presented here.

The two acceptability criteria may be tested with graphs prepared from the attributes of the binomial distribution. Two tests are performed, one for strongly contrasting soils and one for purity. The binomial test is appropriate for both of these criteria, because a ground truth sample may be in exactly one of two classes in each test; it is either in the required class or it is not. The four ground truth scores are combined in different ways for each of the tests to yield two binomial test classes. In the first test, for strongly contrasting soils, the Score 4 scores form one group and the Score 1, 2 and 3 scores form the other; in the second test, for purity, the Score 1 and 2 scores form one group and the Score 3 and 4 form the other.

Example:

Continuing the previous example, the following groups would be used for the two acceptability tests:

1 Strongly contrasting soils: 5 out of 50 observations score in Score 4. This implies 5/50 or 10% strongly contrasting soils.

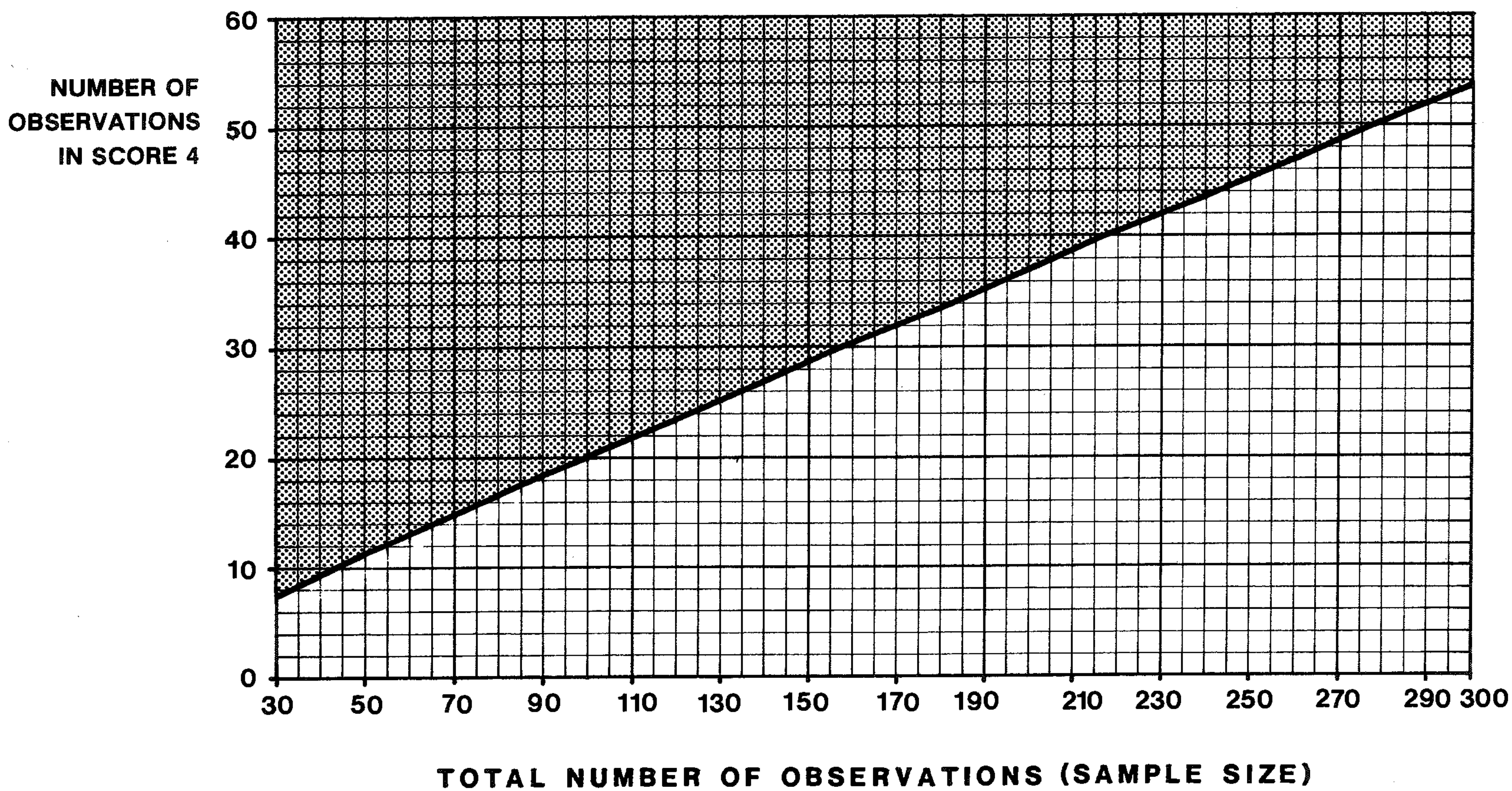
2 Purity: 25 out of 50 observations score in Score 1, and an additional 10 out of the 50 observations score in Score 2. This implies 35/50 or 70% purity.

The graphs in Figure 4.3 (pp. 35 & 36) are prepared from the binomial distribution. They show a confidence limit (upper for purity, lower for strongly contrasting soils) based on the sample size and the portion of the sample that is contained in the binomial class being tested. In addition, the rejection region is shaded; if the results of the binomial test fall in this region of the graph (on either graph), the map is rejected. Figure 4.3a is used to test strongly contrasting soils; figure 4.3b is used to test purity. These graphs may be used for sample sizes from 30 through 300.

To test a sample with these graphs, the sample size is located on the horizontal (X) axis, and a vertical line is raised from that point. Then, the number of the samples that were included in the group being tested (i.e. Score 4 scores if testing strongly contrasting soils, Class 1 + Score 2 scores if testing purity) is located on the vertical (Y) axis, and a horizontal line is drawn from that point. The two lines will meet at a point on the graph. If the point is in the shaded region of the graph, the map is rejected, otherwise, it is accepted for that test. If it is accepted for both tests, the ground truth of the map is acceptable by the criteria presented here.

Figure 4.3a

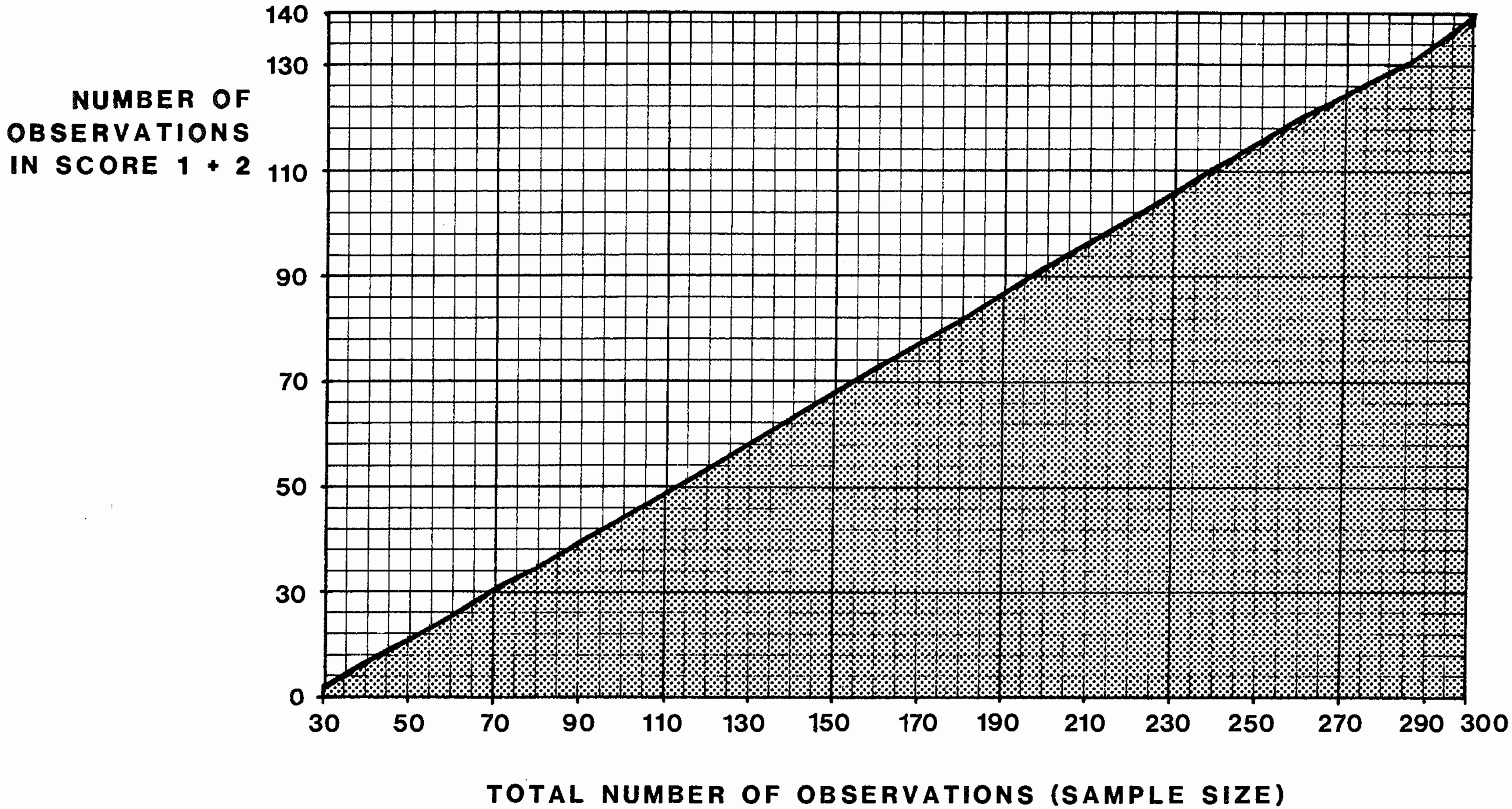
GROUND TRUTH TEST GRAPH 1: SHOWING REJECTION REGION WITH 90% PROBABILITY OF GREATER THAN 15% STRONGLY CONTRASTING SOILS



(REJECTION REGION IS SHADED)

Figure 4.3b

GROUND TRUTH TEST GRAPH 2: SHOWING REJECTION REGION WITH 90% PROBABILITY OF LESS THAN 50% PURITY



(REJECTION REGION IS SHADED)

Example:

Continuing the previous example, to test for strongly contrasting soils, figure 4.3a is used. There are 5/50 points in the "strongly contrasting soils" (Score 4 scores) group; the point X=50, Y=5 does not fall within the (shaded) rejection region; this sample passes the test for strongly contrasting soils. Similarly, to test for purity, figure 4.3b is used. There are 35/50 points in the "pure" (Score 1 + Score 2 scores) binomial group; the point X=50, Y=35 does not fall within the (shaded) rejection region; thus it passes the test for purity. Since the sample passes both tests, the map has acceptable ground truth, in terms of the specified ground truth criteria and acceptance standards.

4.4 Composition of heterogeneous map units

The methodology presented in section 4.3, above, determines whether the land area that is mapped in heterogeneous map units is correctly classified with respect to **any** of the constituents of the map unit (see the example in section 4.3.2 concerning the "HK+E4" map unit). However, it does not address an additional question, namely, whether the actual relative proportion of the different constituents of the heterogeneous map unit in the field agrees with the proportions as presented in the SRI report. This may be a very important consideration when evaluating surveys where associations of soils of dissimilar land use potential are the dominant map units, for example, intermediate-scale surveys of a region or state.

Example:

Consider the "Bernardston-Nassau areas" map unit on the general soil map of New York State (Cline and Marshall 1977). These landscapes are composed of two dominant soils, "Bernardston" and "Nassau". The deep, well-drained Bernardston soils are well-suited for the field crops of the region, but the shallow Nassau soils contain many rock outcrops and are not arable (they may, however, support permanent pasture). The SRI states that the map unit is composed of 50 to 70% Bernardston soils and 10 to 35% Nassau soils, with some other constituents. Thus, land in these areas would be suitable for dairy farming, having mostly good crop land, with some pasture. On the other hand, if the proportions of Bernardston and Nassau soils were reversed, there would not be enough crop land to support dairy farming. Using the methodology of section 4.3, all that can be determined is whether the land mapped in this map unit agrees substantially with either the Bernardston or the Nassau soils; the proportion of each soil is not determined.

Several investigators, including dos Santos (1978) and Hajek and Steers (1977), have developed methods to attack this problem. The basic idea of these methods is to make field transects across a number of delineations of the map unit in question, and determine the proportion of each distinct soil along each transect. Confidence intervals of the proportions are determined with statistical techniques; the resulting intervals may be compared against the proportions stated in the SRI report. These methods were developed for the soil surveyor, rather than for the SRI evaluator. In particular, they require that each field observation be unambiguously assigned to the closest soil unit (usually a soil series) that could be mapped in the given landscape. This assumes that the SRI evaluator has detailed knowledge of all soils of the region. A variant of these methods that extends the methodology of section 4.3 is to classify the field observations on the basis of the ground truth criteria developed in section 4.2, rather than in terms of soil series. This variant is now presented in detail.

4.4.1 Transects

There are usually many delineations on the soils map of the map unit to be tested. A random sample of these must be drawn that fairly represents the entire set. There are two simple sampling methods. First, the delineations may be numbered, from 1 to the total number of delineations in the map unit, and then random numbers may be drawn to select which delineations to sample. Note that in this method, large and small delineations are equally likely to be sampled. The second method is to pick random map points (possibly using the methods of Appendix **B**) and, if the point falls in a delineation of the map unit to be tested, select that delineation. In this second method, larger delineations are more likely to be selected than smaller ones. The number of delineations to select is explained in section 4.4.3, below; it is most efficient to start out with a moderate number (e.g. 5) and then use the results from these to estimate how many more will be needed.

In the context of soil surveying, a **transect** (sometimes called a point transect) is a straight line across a land area, with sample sites spaced along the line at either fixed or variable intervals. The simplest scheme is to sample at fixed intervals. Dos Santos (1978) found that a sampling interval of 50 to 500 meters will accurately sample the major soils in most landscapes; there was no benefit in sampling closer than 200 meters. However, there should be at least 10 observations in each transect, in order to arrive at reasonable precision in the percentage composition of each constituent within each transect.

Transects must cross all significant landscape features within a heterogeneous map unit. Thus, when laying out transects on a map, or in following them in the field, one should attempt to go "across the grain" of the landscape. Obvious linear features, such as ridge lines or streams, should be crossed at oblique angles, not paralleled. If there are no obvious linear features, the transect should cross the longest dimension of the delineation. If the delineation is irregular in shape, the transect may cross areas that are not in the delineation; sample sites should not be located in these areas, but the line should be continued across it.

4.4.2 Scoring sample sites

Each observation within a transect must be assigned either to the named constituent of the map unit that it most resembles, or to the "Other" class, if it does not resemble any constituent closely enough. An observation is placed with the constituent (or constituents) of the heterogeneous map unit with which it most closely agrees, in terms of the ground truth criteria. Only Score 1 and Score 2 scores are placed with a constituent. All Score 3 and Score 4 scores are placed in the "Other" category, which does not contribute to any constituent's observed proportion.

Example:

Consider the following hypothetical map unit description: "Lordstown-Volusia-Mardin association: 50% Lordstown, 20% Volusia, 15% Mardin, 15% other". Suppose the following observations were made in a transect across a delineation of this map unit:

Observation Number	Ground Truth Class with respect to: Lordstown	Volusia	Mardin--	Result
1	Score 1	Score 4	Score 3	Lordstown
2	Score 1	Score 2	Score 4	Lordstown
3	Score 3	Score 4	Score 4	Other
4	Score 2	Score 2	Score 2	1/3 Lordstown 1/3 Volusia 1/3 Mardin
5	Score 4	Score 1	Score 2	Volusia
6	Score 3	Score 3	Score 1	Mardin
7	Score 1	Score 2	Score 1	1/2 Lordstown 1/2 Mardin
8	Score 1	Score 3	Score 4	Lordstown
9	Score 3	Score 4	Score 3	Other
10	Score 2	Score 3	Score 4	Lordstown

TOTALS: 4 5/6 Lordstown, 1 1/3 Volusia, 1 5/6 Mardin, 2 Other (Sum = 10)

Observation 1 is identical (in terms of the ground truth criteria) with Lordstown, and contrasts with Volusia and Mardin; clearly it is classified with Lordstown. Observation 2 is also closest to Lordstown, even though it does not agree exactly with it. Observation 3 is not close enough (Score 1 or Score 2) to any of the three constituents; it is therefore placed with the "Other" group. Observation 4 agrees equally well with all three constituents (this would be very rare in reality), and thus the observation is divided into three parts, one for each constituent. The scoring of observations 5 through 10 proceeds similarly. Finally, the totals in each constituent are summed. These provide an estimate of the map unit composition, based on this transect.

4.4.3 Statistical analysis of transects

Each transect is analyzed separately, giving as many estimates as there are transects of the true composition of the map unit. To account for the variation in transect length and number of samples within each transect, the composition within each transect is expressed as percentages of each named constituent, plus the "Other" class. The "sample size" in the following discussion is thus the number of transects, and the percentages of each constituent in a transect are the "observations".

Each constituent is considered separately, assuming that its percentage of the map unit follows a normal distribution. A confidence interval is calculated for each constituent, according to a pre-defined level of confidence. This confidence level is used to select an appropriate value of the 't' statistic from a 't-table'. An 80% confidence level is suggested; higher confidences require a much larger number of transects. The calculated confidence limits are compared against the percentages given in the map unit description in the SRI.

The number of transects that must be performed in order to arrive at a reasonable estimate of composition depends on the inherent variability in the map unit, and also on the desired precision. Any precision can be specified; it is recommended that the estimated percentage of each constituent be within 30% of its mean percentage, to the specified confidence. For example, if the mean is 40%, the confidence limits should be (0.3)x(40) = 12% on either side of the mean of 40%.

Example:

This analysis is from actual data from transects in Alabama (Hajek and Steers, 1977). Fifteen transects were made, and the percentage of the Norfolk series in each was recorded as follows:

Transect:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Norfolk %:	0	17	7	18	15	33	31	61	27	58	14	17	41	9	41

Statistics on the Norfolk series:

N = 15

$\Sigma x = 389$; $(\Sigma x)^2 = 151{,}321$; $\Sigma x^2 = 14{,}679$

$$\bar{x} = \frac{\Sigma x}{N} = \frac{389}{15} = 25.93$$

$$s^2 = \frac{\Sigma x-(\Sigma x)^2/N}{N-1} = \frac{14{,}679 - 151{,}321/15}{14} = 327.93$$

$$\bar{s} = \sqrt{\frac{s^2}{N}} = \sqrt{\frac{327.93}{15}} = 4.68$$

Thus, based on the fifteen transects, one would expect that 25.93% (the mean) of the map unit is in the Norfolk series. To find out the largest and smallest means that one would expect in samples of 15 transects with a given confidence (e.g. 80% of the time), the standard deviation of the mean is multiplied by an appropriate value of the t-statistic. This value is based on both the desired confidence and on the original sample size. Tables of this statistic are found in every statistics text and reference, for example in Steel and Torrie (1980) and Beyer (1981); an abbreviated t-table follows:

Table 4.1 - Values of 't'

Sample Size (N)	—Confidence (2-tailed)— 80%	90%	95%
5	1.53	2.13	2.78
10	1.38	1.83	2.26
15	1.35	1.76	2.15
20	1.33	1.73	2.09

In the present example, the desired confidence (two-tailed) is 0.80 (80%), and the original sample size was 15; the tabulated value of the t-statistic is 1.35.

$$C.\ I. = \overline{x} \pm t\overline{s}$$

$$= 25.93 \pm 1.35 \times 4.68$$

$$= 25.93 \pm 6.3$$

LOW = 25.93 − 6.3 = 19.63%

HIGH = 25.93 + 6.3 = 32.23%

The width of the confidence interval is 6.3% on each side of the mean. The maximum acceptable width, is (MEAN) × (.3) = (25.93) × (.3) = 7.78% on each side. The calculated confidence interval is narrower, and so it may be used to test the reported composition of the map unit. In the present example, if the SRI stated that the map unit being tested contained anywhere from 19.6% to 32.2% of the Norfolk series, this stated composition would be accepted as accurate; stated values outside of this range would be rejected as inaccurate.

If one has data from a group of transects, it is possible to estimate how many transects would be necessary to determine a confidence interval of a required width. This may be more or less transects than were taken; typically one makes a small number of transects and then determines how many more will be necessary. This estimate is calculated from the sample variance, the t-statistic (which takes into account the sample size and the confidence) and the desired width (on one side) of the confidence interval. The formula is:

$$N = \frac{s \times t^2}{width^2}$$

In the present example, the t-statistic is 1.35 (as shown above), the sample variance is 327.92, and the desired width is (MEAN) × (0.3) = 7.78, so that the necessary sample size is:

$$\frac{(1.35)^2 \times 327.92}{(7.78)^2} = 9.87$$

Thus, only 10 observations would have been necessary, instead of the 15 actually made, to establish the percentage of the Norfolk series in this map unit, within the required tolerance of 30% of its mean percentage.

4.5 Summary

The ground truth of a soils map was defined as the degree to which the map and legend accurately represent the soilscape. Ground truth was evaluated in terms of ground truth criteria that are related to land use. Two types of ground truth evaluation were presented, 1) the overall ground truth of the map, and 2) the ground truth of the composition of heterogeneous map units. The former is applicable to all soils maps, and the latter to (especially medium-scale) maps where heterogeneous map units, such as associations, are important.

Appendix A
Glossary

Accuracy: The closeness of an estimate of a value to the corresponding actual value. Cf. "precision", "map accuracy".

Area accuracy: Accuracy with which areas are represented on a map.

Area location: The process of locating ground areas on maps and vice-versa.

Area of interest: A land area that the map user wishes to locate on the ground or on the map.

ASD: Average size delineation (q.v.).

Association of uniform land areas: A map unit with more than one major land type, each of which could have been mapped as a uniform map unit (q.v.) at a larger map scale. In addition, the proportion and landscape position of each constituent are described.

Average size delineation: Arithmetic mean of the delineation sizes on a map (or portion of map), expressed in units of map area. Abbreviation: ASD.

Base map: Any cartographic material on which soil information is shown. The two basic types of base maps are photographic, where the map is some sort of photograph of the area, and schematic, where the map is some sort of line drawing.

Base map date: The most recent date on which the base map accurately represents the cultural features in the mapped area.

Boundary error: An error in the placement of a boundary of a delineation on a soil map. Cf. "classification error".

Chroma: see "color".

Classification error: An error in naming or characterizing a delineation on a soil map. Cf. "boundary error".

Color: Sensation produced on eyes by light, divided into: 1) Hue: the spectral quality of the light; 2) Value: the amount of reflectance (brightness); and 3) Chroma: the saturation of a hue.

Contrast (of a photograph): Maximum difference of values (q.v.) in a photograph.

Delineation (on a map): The undivided portion of a map sheet inside a continuous boundary line. Each delineation belongs to exactly one map unit (q.v.). Areas of delineations are usually measured in cm^2.

Descriptive legend: Text or tables describing each map unit in the SRI. This usually describes the proportions, landscape pattern, and properties of the soil bodies and non-soil areas in each map unit.

Diagnostic criterion: A variable (for example, a land quality (q.v.) or land characteristic (q.v.)), or a function of several variables, that has an understood influence on the output from, or the required inputs to, a specified kind of land use, and which serves as a basis for assessing the suitability of a given type of land for that use. For every diagnostic criterion, there will be a critical value or set of these which are used to define suitability class limits.

FAO: Food and Agriculture Organization of the United Nations.

Ground control point: A point on a map that can be precisely located on the ground, independently of other points. In other words, a point that is easily visible or recoverable on both the map and in the field.

Ground location accuracy: Certainty with which arbitrary points on the map can be found in the field.

Ground resolution (of an aerial photograph): The smallest object on the ground that can be clearly distinguished on the photograph.

Ground truth (of a soil resource inventory): The degree to which the SRI map and legend accurately represent the soilscape.

Ground truth class: A range of values of a ground truth criterion (q.v.) within which the differences between values are considered not significant.

Ground truth criterion: Land attribute (either land quality (q.v.) or land characteristic (q.v.)) by which the ground truth of an SRI is measured.

Ground truth error: Discrepancy between the predicted and observed ground truth class (q.v.) at a sample site.

Homogeneity (of a map unit): The proportion of the land area mapped as delineations of the map unit that performs uniformly for a given land use.

Hue: see "color".

Identification legend: List of map unit names and their symbols on the map.

IMR: Index of maximum reduction (q.v.).

Index of maximum reduction (of a map): Factor by which the scale of the map could be reduced before the map would become illegible (i.e. the ASD is equal to or less than the MLD). Abbreviation: IMR.

Interpolation feature: Any natural or cultural point, linear feature, or areal feature, that is visible both on the map and on the ground, used to interpolate an approximate location in the field.

Interpretations: Information on the optimum use and recommended management of the soils in a map unit, based on land attributes.

Interpretive legend: Interpretations (q.v.) for each map unit.

Land: "An area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictibly cyclic, attributes of the biosphere (vertically) above and below this area, including those of the atmosphere, soil, geology, hydrology, plant and animal populations, and the results of past and present human activity." (FAO 1976).

Land capability: The suitability of land for general types of use (e.g., row crops, woodland) without permanent damage (after Soil Conservation Society of America, 1976). This refers to more general land use systems than "land suitability" (q.v.).

Land characteristic: "An attribute of the land that can be measured or estimated." (FAO 1976). Cf. "land quality."

Land evaluation: The ranking of land units according to their capacity to provide the optimum return from uses under given management practices.

Landform: A feature of the earth's surface attributable to natural causes.

Land quality: "A complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use." (FAO 1976). Cf. "land characteristic".

Landscape: The aggregate of landforms of a region.

Land suitability: "The fitness of a given type of land for a specified kind of land use." (FAO 1976). This refers to more specific land use systems than "land capability" (q.v.).

Land use: More or less specific description of the use of a land area. The more specific description is called a "land utilitization type" and the more general is called a "major kind of land use." (FAO 1976)

Legibility (of a map): Ease with which information on the map can be read.

Limitations (of a land area for a use): Attributes of a land area that make it less than completely suitable for a land use.

Map accuracy: Agreement between a map and the area that it represents. This includes "point accuracy" (q.v.) and "area accuracy" (q.v.).

Map legend: 1) Identification legend (q.v.); 2) Descriptive legend (q.v.); 3) Interpretive legend (q.v.); 4) All map units on a map, considered as an aggregate.

Mapping intensity: Number of observations per unit of land area that are made when mapping.

Map projection: Representation of the three-dimensional surface of the earth on a two-dimensional map.

Map reproduction: The actual means of placing information on a map sheet, e.g. printing or photography.

Map scale: Relation between distances on the map and corresponding distances on the ground. This is usually expressed as the representative fraction (q.v.).

Map texture: Density and pattern of delineations on a map.

Map unit (also "mapping unit"): A set of map delineations designated by a single name (the map unit name); also, the land areas represented by these delineations.

Minimum legible area: Smallest land area that can be legibly represented on a map at a given scale. Thus, it is the land area represented by the minimum legible delineation (q.v.).

Minimum legible delineation: Smallest map area that can be read, defined to be 0.4 cm^2. Abbreviation: MLD.

MLD: Minimum legible delineation (q.v.).

Non-uniform map unit: A map unit that is not a "uniform map unit" (q.v.).

Optimum legible delineation: Defined as 4 times as large as the MLD, that is, 1.6 cm^2.

Orthophotomap: A rectified and controlled photographic map, with horizontal errors due to relief displacement also corrected.

Physical quality (of a base map): Those qualities of the base map that are independent of its information content, for example, paper, reproduction, folding.

Pixel (abbreviation of "picture element"): Smallest resolvable element of a digitized image. In LANDSAT imagery, a pixel represents a ground area of either 40x40 m (1600 m^2) or 80x80 m (6400 m^2).

Point accuracy: Accuracy with which ground points are represented on a map. Some aspects of point accuracy are: 1) Relative: the inter-relation of points; 2) Absolute: the relation of points to geodetic position; 3) Vertical: accuracy of elevation; and 4) Horizontal: accuracy of plan.

Point location: Location of map points on the ground, or vice-versa.

Precision: The repeatability of a measurement, often expressed as the ratio of the standard deviation of a measurement to its mean. Cf. "accuracy".

Representative fraction: Ratio of a unit distance on the map to the corresponding distance on the ground. For example, "1:20,000" means that 1 cm on the map represents 20,000 cm (or 200 m) on the ground. Abbreviation: RF.

Resolution (of a photograph): Size of detail that can be discriminated on the photograph.

RF: Representative fraction (q.v.).

SCS: Soil Conservation Service of the United States Department of Agriculture.

Site-specific use (of an SRI): Uses which imply the location of land areas ("sites") that are appraised for some purpose.

Soil: "The collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors". (Soil Survey Staff, 1975).

Soil resource inventory: Any document that describes the attributes and spatial distribution of soils. This is a more general term than "soil survey" (q.v.), and includes general-purpose soil surveys, single-use surveys, land evaluations, land-use surveys, and natural resource inventories. Abbreviation: SRI.

Soilscape: The pattern of soils in the landscape.

Soil survey: A publication whose primary aim is the description of the attributes and spatial distribution of soils.

Specificity (of a map unit): Degree to which the map unit name, description, and interpretation allow the prediction of performance of land areas mapped as delineations of the map unit.

Spot symbols: Figures on the map that indicate the presence of small areas of strongly contrasting soils within larger delineations. The symbol shows the type of limitation.

SRI: Soil resource inventory (q.v.).

Stratified sampling (of a map area): Division of an area into more homogeneous sub-areas ("strata") prior to sampling.

Suitability (of a land area for a given land use): "The fitness of a given type of land for a specified kind of land use." (FAO 1976).

Suitability group: Set of map units with the same general suitability and specific limitations for a land use.

Transect: Straight line across a land area, with sample sites located at either fixed or variable intervals along the line.

Uniform map unit: A map unit wherein the major proportion (e.g. 85%) of the land area is in the same suitability group, and thus is expected to perform uniformly for the land use. In addition, the minor proportion is not totally dissimilar.

USDA: United States Department of Agriculture.

Value: see "color".

Value range: List of values (q.v.) in a photograph.

Appendix B

Converting between map and ground distances and areas

1 Distances

Distances on the ground may be measured in meters (m) or kilometers (km). Distances on a map may be measured in millimeters (mm) or centimeters (cm). The **representative fraction**, abbreviated "RF", is the amount of any unit of distance measurement on the ground that is represented by one of that same unit on the map. It is written as the ratio of the two distances. For example, "1:20,000" means that 1 cm on the map represents 20,000 cm (or 200 m, or 0.2 km) on the ground. Converting between map and ground distances involves multiplying or dividing, as appropriate, by the RF and then converting between distance units (mm, cm, m, and km) as required. The following formulas are most useful.

1) map mm = ground m × RF × 1,000 mm/m

2) map mm = ground km × RF × 1,000,000 mm/km

3) map cm = ground m × RF × 100 cm/m

4) map cm = ground km × RF × 100,000 cm/km

5) ground m = map mm / (RF × 1,000 mm/m)

6) ground m = map cm / (RF × 100 cm/m)

7) ground km = map mm / (RF × 1,000,000 mm/km)

8) ground km = map cm / (RF × 100,000 cm/km)

Note : km × 1,000 = m ; m × 100 = cm ; cm × 10 = mm

For example, at a map scale of 1:20,000, to find the ground distance represented by 1 cm on the map, use formula 6) to obtain:

1 cm / (1/20,000 × 100 cm/m) = 1/(1/200) = 1 × 200 = 200 m

Conversely, to find the map distance corresponding to 1 kilometer on the ground at this scale, use formula 4) to obtain:

1 km × 1/20,000 × 100,000 cm/km = 5 cm

2 Areas

Areas on the ground may be measured in square kilometers (km^2), hectares (ha), ares, or square meters (m^2). Ares and square meters are not common in soil survey applications. The relation between these four units is:

1 km^2 = 100 ha ; 1 ha = 100 ares ; 1 are = 100 m^2

Areas on a map may be measured in square centimeters (cm^2) or square millimeters (mm^2). Only square centimeters are considered here; the conversion between these two units is:

1 cm^2 = 100 mm^2

The following formulas may be used to convert between map and ground areas.

1) map cm^2 = ground ha × RF^2 × 10^8 cm^2/ha

2) map cm^2 = ground km^2 × RF^2 × 10^{10} cm^2/km^2

3) ground ha = map cm^2 / (RF^2 × 10^8 cm^2/ha)

4) ground km^2 = map cm^2 / (RF^2 × 10^{10} cm^2/km^2)

For example, at a map scale of 1:20,000, to find the ground area represented by 100 cm^2 on the map (a square 10 cm on each side), use formula 3) to obtain:

100 cm^2 / (1/20,000 × 1/20,000 × 10^8 cm^2/ha) = 400 ha

Conversely, to find the map area corresponding to 1 ha on the ground at this scale, use formula 1) to obtain:

1 ha × 1/20,000 × 1/20,000 × 10^8 cm^2/ha = 0.25 cm^2

Appendix C
Reference Coordinates

A system of reference coordinates is a method of unambiguously specifying points on a map in order to convert abstract numbers to actual map points. Some maps may already have a coordinate system printed on them, for example, a Universal Transmercator (UTM) grid, a national grid, or latitude and longitude. If so, this system can be used for reference, although the coordinates must be divided somewhat differently for the purposes of map adequacy evaluation. Otherwise, a grid can be constructed as follows.

First, the number of coordinate axes is determined. This is two if the map is just one sheet; the two axes are left-to-right ("X-axis"), and bottom-to-top ("Y-axis"), as measured along the margin of the map. If there is more than one map sheet, there is a third axis, namely, the sheet number ("S-axis"). This is listed first (if it is present), followed by the X and Y coordinates.

Second, the maximum number of distinct intervals on each axis is determined. For the S-axis, the number of intervals is just the number of sheets. For the X and Y axes, the maximum number of distinct intervals is determined by the dimension of the map along the axis (the map margin), measured in some convenient unit (e.g. cm), multiplied by the number of plottable intervals in one measurement unit. This latter is the reciprocal of the plotting accuracy of the map, which depends on the methods available to plot points. Using a good-quality scale and pricking the desired point with a pin, the plotting accuracy may typically be 0.25 mm, which corresponds to 40 divisions/cm. In this case, one would multiply the dimensions, measured in cm, along the X and Y axes by 40 to obtain the number of distinct points on each axis. Other, lower, values for the plotting accuracy should be used if less precise methods are used to plot points; a plotting accuracy of 1 mm is a reasonable value if ordinary scales and pencils are used to plot points. This corresponds to 10 divisions/cm.

Example:

The soil survey of Edgecombe County, North Carolina, U.S.A. (Goodwin 1979) contains 32 map sheets, each of which is a photographic map 56.4 cm wide, measured along the bottom margin, and 23.4 cm tall, measured along the left margin. Some sheets contain areas that were not surveyed; sample points falling in these areas will be discarded, but for convenience each of the 32 sheets is considered to be the same size. The plotting accuracy to be used in marking sample points on the sheets is 1 mm, so there are 10 distinct points/cm. There are thus 3 axes:

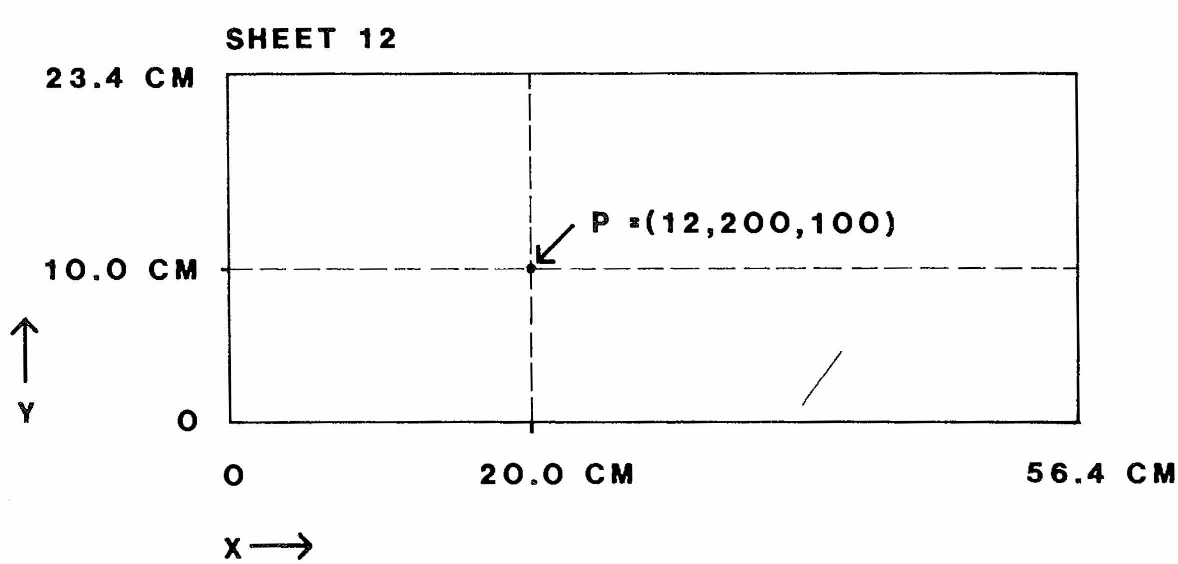
S-Axis (sheets) : ranging from 1 to 32 (sheet number)

X-Axis (left-to-right) : 56.4 cm × 10 divisions/cm = 564 distinct points, ranging from 0 (left margin) to 564 (right margin).

Y-Axis (bottom-to-top) : 23.4 cm × 10 divisions/cm = 234 distinct points, ranging from 0 (bottom margin) to 234 (top margin).

Each point in the survey can be uniquely determined by its 3 coordinates: S, X, and Y. For example, point (12,200,100) is located as follows:

LOCATION OF A POINT BY REFERENCE COORDINATES



Selecting random numbers

The coordinates of each of the sample points is randomly determined. Several methods are available for drawing random numbers. In particular, if a good random number generator is available on a calculator or computer, it can be programmed to produce random numbers in the desired range for each coordinate in turn. However, an equally satisfactory non-electronic method is the use of a random number table.

Appendix D is a table of 10,000 random digits that can be used to produce random numbers for the coordinates. This table contains random sequences of digits, which may be used in order, once a random starting point in the table is determined. Since the table's rows and columns are numbered, the starting point can be specified by randomly picking a row and column number, each from 00 to 99. To obtain a row and column, it is sufficient to blindly point one's finger at the table; the two digits nearest the fingertip give the row, and the next two digits to the right give the column.

Once the starting point is chosen, digits are read in groups to the right. When a margin is reached, one can continue onto the next page (using the same row) or reverse direction on the next column. The digits are grouped to represent coordinates, taking as many digits as necessary. For example, if numbers from 0 to 500 are needed, three digits must be read in a group. These can be considered as numbers from 000 through 999; any value greater than 500 is ignored. This process is continued until all coordinates for all points to be sampled are drawn.

Example:

Continuing the example above, two sample points will be drawn. To obtain a starting point, blindly point at the third table page; for instance, at row 75, column 20, at which point is read "38", followed by "04". Thus the starting point is row 38, column 04, which is found on the first table page. Starting here, and reading to the right, is the sequence:

"3 17972 12690 00452 93766 16414 01212 27964 02766 ..."

Three coordinates are needed for each point : S (01–32), X (000–564), and Y (000–234). So, two digits are needed for the first coordinate and three for the others. Scanning the sequence of digits, S=31 is immediately obtained from the first two digits. The next three, 797, are outside the range for X, but the following three, 212, are within the range, so X=212 is the required value. Rejecting the next three, 690, since they are outside the Y range, Y=004 is obtained from the following three digits. The first sample point is thus (S, X, Y) = (31, 212, 004). Similarly, the next sample point is (14, 012, 122).

Locating sample points on the map

Once the sample points are calculated, they must be transferred to the map. They may be plotted directly on the map, or on an overlay of acetate or tracing paper. If an overlay is used, it is very important that the material not shrink or swell appreciably, and the map and overlay must be properly registered each time a point is plotted on the map or located in the field. Points are transferred by finding the desired points as referenced by their coordinates, using a ruler to scale along the axes (margins) and a square angle (T-square or triangle) to insure that points are measured parallel to each margin.

Appendix D Table of Random Digits

	00–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
00	88758	66605	33843	43623	62774	25517	09560	41880	85126	60755
01	35661	42832	16240	77410	20686	26656	59698	86241	13152	49187
02	26335	03771	46115	88133	40721	06787	95962	60841	91788	86386
03	60826	74718	56527	29508	91975	13695	25215	72237	06337	73439
04	95044	99896	13763	31764	93970	60987	14692	71039	34165	21297
05	83746	47694	06143	42741	38338	97694	69300	99864	19641	15083
06	27998	42562	63402	10056	81668	48744	08400	83124	19896	18805
07	82685	32323	74625	14510	85927	28017	80588	14756	54937	76379
08	18386	13862	10988	04197	18770	72757	71418	81133	69503	44037
09	21717	13141	22707	68165	58440	19187	08421	23872	03036	34208
10	18446	83052	31842	08634	11887	86070	08464	20565	74390	36541
11	66027	75177	47398	66423	70160	16232	67343	36205	50036	59411
12	51420	96779	54309	87456	78967	79638	68869	49062	02196	55109
13	27045	62626	73159	91149	96509	44204	92237	29969	49315	11804
14	13094	17725	14103	00067	68843	63565	93578	24756	10814	15185
15	92382	62518	17752	53163	63852	44840	02592	88572	03107	90169
16	16215	50809	49326	77232	90155	69955	93892	70445	00906	57002
17	09342	14528	64727	71403	84156	34083	35613	35670	10549	07468
18	38148	79001	03509	79424	39625	73315	18811	86230	99682	82896
19	23689	19997	72382	15247	80205	58090	43804	94548	82693	22799
20	25407	37726	73099	51057	68733	75768	77991	72641	95386	70138
21	25349	69456	19693	85568	93876	18661	69018	10332	83137	88257
22	02322	77491	56095	03055	37738	18216	81781	32245	84081	18436
23	15072	33261	99219	43307	39239	79712	94753	41450	30944	53912
24	27002	31036	85278	74547	84809	36252	09373	69471	15606	77209
25	66181	83316	40386	54316	29505	86032	34563	93204	72973	90760
26	09779	01822	45537	13128	51128	82703	75350	25179	86104	40638
27	10791	07706	87481	26107	24857	27805	42710	63471	08804	23455
28	74833	55767	31312	76611	67389	04691	39687	13596	88730	86850
29	17583	24038	83701	28570	63561	00098	60784	76098	84217	34997
30	45601	46977	39325	09286	41133	34031	94867	11849	75171	57682
31	60683	33112	65995	64203	18070	65437	13624	90896	80945	71987
32	29956	81169	18877	15296	94368	16317	34239	03643	66081	12242
33	91713	84235	75296	69875	82414	05197	66596	13083	46278	73498
34	85704	86588	82837	67822	95963	83021	90732	32661	64751	83903
35	17921	26111	35373	86494	48266	01888	65735	05315	79328	13367
36	13929	71341	80488	89827	48277	07229	71953	16128	65074	28782
37	03248	18880	21667	01311	61806	80201	47889	83052	31029	06023
38	50583	17972	12690	00452	93766	16414	01212	27964	02766	28786
39	10636	46975	09449	45986	34672	46916	63881	83117	53947	95218
40	43896	41278	42205	10425	66560	59967	90139	73563	29875	79033
41	76714	80963	74907	16890	15492	27489	06067	22287	19760	13056
42	22393	46719	02083	62428	45177	57562	49243	31748	64278	05731
43	70942	92042	22776	47761	13503	16037	30875	80754	47491	96012
44	92011	60326	86346	26738	01983	04186	41388	03848	78354	14964
45	66456	00126	45685	67607	70796	04889	98128	13599	93710	23974
46	96292	44348	20898	02227	76512	53185	03057	61375	10760	26889
47	19680	07146	53951	10935	23333	76233	13706	20502	60405	09745
48	67347	51442	24536	60151	05498	64678	87569	65066	17790	55413
49	95888	59255	06898	99137	50871	81265	42223	83303	48694	81953

	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99
00	70896	44520	64720	49898	78088	76740	47460	83150	78905	59870
01	56809	42909	25853	47624	29486	14196	75841	00393	42390	24847
02	66109	84775	07515	49949	61482	91836	48126	80778	21302	24975
03	18071	36263	14053	52526	44347	04923	68100	57805	19521	15345
04	98732	15120	91754	12657	74675	78500	01247	49719	47635	55514
05	36075	83967	22268	77971	31169	68584	21336	72541	66959	39708
06	04110	45061	78062	18911	27855	09419	56459	00695	70323	04538
07	75658	58509	24479	10202	13150	95946	55087	38398	18718	95561
08	87403	19142	27208	35149	34889	27003	14181	44813	17784	41036
09	00005	52142	65021	64438	69610	12154	98422	65320	79996	01935
10	43674	47103	48614	70823	78252	82403	93424	05236	54588	27757
11	68597	68874	35567	98463	99671	05634	81533	47406	17228	44455
12	91874	70208	06308	40719	02772	69589	79936	07514	44950	35190
13	73854	19470	53014	29375	62256	77488	74388	53949	49607	19816
14	65926	34117	55344	68155	38099	56009	03513	05926	35584	42328
15	40005	35246	49440	40295	44390	83043	26090	80201	02934	49260
16	46686	29890	14821	69783	34733	11803	64845	32065	14527	38702
17	02717	61518	39583	72863	50707	96115	07416	05041	36756	61065
18	17048	22281	35573	28944	96889	51823	57268	03866	27658	91950
19	75304	53248	42151	93928	17343	88322	28683	11252	10355	65175
20	97844	62947	62230	30500	92816	85232	27222	91701	11057	83257
21	07611	71163	82212	20653	21499	51496	40715	78952	33029	64207
22	47744	04603	44522	62783	39347	72310	41460	31052	40814	94297
23	54293	43576	88116	67416	34908	15238	40561	73940	56850	31078
24	67556	93979	73363	00300	11217	74405	18937	79000	68834	48307
25	86581	73041	95809	73986	49408	53316	90841	73808	53421	82315
26	28020	86282	83365	76600	11261	74354	20968	60770	12141	09539
27	42578	32471	37840	30872	75074	79027	57813	62831	54715	26693
28	47290	15997	86163	10571	81911	92124	92971	80860	41012	58666
29	24856	63911	13221	77028	06573	33667	30732	47280	12926	67276
30	16352	24836	60799	76281	83402	44709	78930	82969	84468	36910
31	89060	79852	97854	28324	39638	86936	06702	74304	39873	19496
32	07637	30412	04921	26471	09605	07355	20466	49793	40539	21077
33	37711	47786	37468	31963	16908	50283	80884	08252	72655	58926
34	82994	53232	58202	73318	62471	49650	15888	73370	98748	69181
35	31722	67288	12110	04776	15168	68862	92347	90789	66961	04162
36	93819	78050	19364	38037	25706	90879	05215	00260	14426	88207
37	65557	24496	04713	23688	26623	41356	47049	60676	72236	01214
38	88001	91382	05129	36041	10257	55558	89979	58061	28957	10701
39	96648	70303	18191	62404	26558	92804	15415	02865	52449	78509
40	04118	51573	59356	02426	35010	37104	98316	44602	96478	08433
41	19317	27753	39431	26996	04465	69695	61374	06317	42225	62025
42	37182	91221	17307	68507	85725	81898	22588	22241	80337	89033
43	82990	03607	29560	60413	59743	75000	03806	13741	79671	25416
44	97294	21991	11217	98087	79124	52275	31088	32085	23089	21498
45	86771	69504	13345	42544	59616	07867	78717	82840	74669	21515
46	26046	55559	12200	95106	56496	76662	44880	89457	84209	01332
47	39689	05999	92290	79024	70271	93352	90272	94495	26842	54477
48	83265	89573	01437	43786	52986	49041	17952	35035	88985	84671
49	15128	35791	11296	45319	06330	82027	90808	54351	43091	30387

	00–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
50	54441	64681	93190	00993	62130	44484	46293	60717	50239	76319
51	08573	52937	84274	95106	89117	65849	41356	65549	78787	50442
52	81067	68052	14270	19718	88499	63303	13533	91882	51136	60828
53	39737	58891	75278	98046	52284	40164	72442	77824	72900	14886
54	34958	76090	08827	61623	31114	86952	83645	91786	29633	78294
55	61417	72424	92626	71952	69709	81259	58472	43409	84454	88648
56	99187	14149	57474	32268	85424	90378	34682	47606	89295	02420
57	13130	13064	36485	48133	35319	05720	76317	70953	50823	06793
58	65563	11831	82402	46929	91446	72037	17205	89600	59084	55718
59	28737	49502	06060	52100	43704	50839	22538	56768	83467	19313
60	50353	74022	59767	49927	45882	74099	18758	57510	58560	07050
61	65208	96466	29917	22862	69972	35178	32911	08172	06277	62795
62	21323	38148	26696	81741	25131	20087	67452	19670	35898	50636
63	67875	29831	59330	46570	69768	36671	01031	95995	68417	68665
64	82631	26260	86554	31881	70512	37899	38851	40568	54284	24056
65	91989	39633	59039	12526	37730	68848	71399	28513	69018	10289
66	12950	31418	93425	69756	34036	55097	97241	92480	49745	42461
67	00328	27427	95474	97217	05034	26676	49629	13594	50525	13485
68	63986	16698	82804	04524	39919	32381	67488	05223	89537	59490
69	55775	75005	57912	20977	35722	51931	89565	77579	93085	06467
70	24761	56877	56357	78809	40748	69727	56652	12462	40528	75269
71	43820	80926	26795	57553	28319	25376	51795	26123	51102	89853
72	66669	02880	02987	33615	54206	20013	75872	88678	17726	60640
73	49944	66725	19779	50416	42800	71733	82052	28504	15593	51799
74	71003	87598	61296	95019	21568	86134	66096	65403	47166	78638
75	52715	04593	69484	93411	38046	13000	04293	60830	03914	75357
76	21998	31729	89963	11573	49442	69467	40265	56066	36024	25705
77	58970	96827	18377	31564	23555	86338	79250	43168	96929	97732
78	67592	59149	42554	42719	13553	48560	81167	10747	92552	19867
79	18298	18429	09357	96436	11237	88039	81020	00428	75731	37779
80	88420	28841	42628	84647	59024	52032	31251	72017	43875	48320
81	07627	88424	23381	29680	14027	75905	27037	22113	77873	78711
82	37917	93581	04979	21041	95252	62450	05937	81670	44894	47262
83	14783	95119	68464	08726	74818	91700	05961	23554	74649	50540
84	05378	32640	64562	15303	13168	23189	88198	63617	58566	56047
85	19640	96709	22047	07825	40583	99500	39989	96593	32254	37158
86	20514	11081	51131	56469	33947	77703	35679	45774	06776	67062
87	96763	56249	81243	62416	84451	14696	38195	70435	45948	67690
88	49439	61075	31558	59740	52759	55323	95226	01385	20158	54054
89	16294	50548	71317	32168	86071	47314	65393	56367	46910	51269
90	31381	94301	79273	32843	05862	36211	93960	00671	67631	23952
91	98032	87203	03227	66021	99666	98368	39222	36056	81992	20121
92	40700	31826	94774	11366	81391	33602	69608	84119	93204	26825
93	68692	66849	29366	77540	14978	06508	10824	65416	23629	63029
94	19047	10784	19607	20296	31804	72984	60060	50353	23260	58909
95	82867	69266	50733	62630	00956	61500	89913	30049	82321	62367
96	26528	28928	52600	72997	80943	04084	86662	90025	14360	64867
97	51166	00607	49962	30724	81707	14548	25844	47336	57492	02207
98	97245	15440	55182	15368	85136	98869	33712	95152	50973	98658
99	54998	88830	95639	45104	72676	28220	82576	57381	34438	24565

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	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99
50	58649	85086	16502	97541	76611	94229	34987	86718	87208	05426
51	97306	52449	55596	66739	36525	97563	29469	31235	79276	10831
52	09942	79344	78160	11015	55777	22047	57615	15717	86239	36578
53	83842	28631	74893	47911	92170	38181	30416	54860	44120	73031
54	73778	30395	20163	76111	13712	33449	99224	18206	51418	70006
55	88381	56550	47467	59663	61117	39716	32927	06168	06217	45477
56	31044	21404	15968	21357	30772	81482	38807	67231	84283	63552
57	00909	63837	91328	81106	11740	50193	86806	21931	18054	49601
58	69882	37028	41732	37425	80832	03320	20690	32653	90145	03029
59	26059	78324	22501	73825	16927	31545	15695	74216	98372	28547
60	38573	98078	38982	33078	93524	45606	53463	20391	81637	37269
61	70624	00063	81455	16924	12848	23801	55481	78978	26795	10553
62	49806	23976	05640	29804	38988	25024	76951	02341	63219	75864
63	05461	67523	48316	14613	08541	35231	38312	14969	67279	50502
64	76582	62153	53801	51219	30424	32599	49099	83959	68408	20147
65	16660	80470	75062	75588	24384	27874	20018	11428	32265	07692
66	60166	42424	97470	88451	81270	80070	72959	26220	59939	31127
67	28953	03272	31460	41691	57736	72052	22762	96323	27616	53123
68	47536	86439	95210	96386	38704	15484	07426	70675	06888	81203
69	73457	26657	36983	72410	30244	97711	25652	09373	66218	64077
70	11190	66193	66287	09116	48140	37669	02932	50799	17255	06181
71	57062	78964	44455	14036	36098	40773	11688	33150	07459	36127
72	99624	67254	67302	18991	97687	54099	94884	42283	63258	50651
73	97521	83669	85968	16135	30133	51312	17831	75016	80278	68953
74	40273	04838	13661	64757	17461	78085	60094	27010	80945	66439
75	57260	06176	49963	29760	69546	61336	39429	41985	18572	98128
76	03451	47098	63495	71227	79304	29753	99131	18419	71791	81515
77	62331	20492	15393	84270	24396	32962	21632	92965	38670	44923
78	32290	51079	06512	38806	93327	80086	19088	59887	98416	24918
79	28014	80428	92853	31333	32648	16734	43418	90124	15086	48444
80	18950	16091	29543	65817	07002	73115	94115	20271	50250	25061
81	17403	69503	01866	13049	07263	13039	83844	80143	39048	62654
82	27999	50489	66613	21843	71746	65868	16208	46781	93402	12323
83	87076	53174	12165	84495	47947	60706	64034	31635	65169	93070
84	89044	45974	14524	46906	26052	51851	84197	61694	57429	63395
85	98048	64400	24705	75711	36232	57624	41424	77366	52790	84705
86	09345	12956	49770	80311	32319	48238	16952	92088	51222	82865
87	07086	77628	76195	47584	62411	40397	71857	54823	26536	56792
88	93128	25657	46872	11206	06831	87944	97914	64670	45760	34353
89	85137	70964	29947	27795	25547	37682	96105	26848	09389	64326
90	32798	39024	13814	98546	46585	84108	74603	94812	73968	68766
91	62496	26371	89880	52078	47781	95260	83464	65942	91761	53727
92	62707	81825	40987	97656	89714	52177	23778	07482	91678	40128
93	05500	28982	86124	19554	80818	94935	61924	31828	79369	23507
94	79476	31445	59498	85132	24582	26024	24002	63718	79164	43556
95	10653	29954	97568	91541	33139	84525	72271	02546	64818	14381
96	30524	06495	00886	40666	68574	49574	19705	16429	90981	08103
97	69050	22019	74066	14500	14506	06423	38332	34191	82663	85323
98	27908	78802	63446	07674	98871	63831	72449	42705	26513	19883
99	64520	16618	47409	19574	78136	46047	01277	79146	95759	36781

Appendix E

Constructing binomial acceptance test graphs

This appendix describes the method by which the SRI evaluator may construct binomial test graphs, similar to figures 4.3a and 4.3b, for various combinations of the underlying binomial population (e.g. the percentages required for purity or strongly contrasting soils) and the confidence desired in the statistical statement. Thus, if acceptance criteria other than those specified in these guidelines (section 4.3.3) are adopted, the evaluator can make the required graphs to use these criteria to test the ground truth of soil maps.

Three tables are provided, for three common confidence levels : .95, .90, and .85 (the guidelines use .90). This is the confidence in whatever statistical statement is made with the graphs. The higher the confidence, the more difficult the statement is to establish.

Each table is further organized by the assumed underlying binomial probability, here called 'theta'. This is the proportion to be tested. For example, if it were desired to test whether the map contains 75% 'Score 1', the line with 'theta' of .75 would be used.

There are two sets of values on each line (value of 'theta'). The first set contains the **minimum** numbers of observations that are consistent with the hypothesized 'theta', and the second set contains the **maximum** numbers of observations consistent with the hypothesized 'theta'. These numbers are given for four sample sizes (numbers of observations) each: 30, 90, 150, and 210 observations. For example, suppose the 95% confidence level is selected; this is presented in the third table. To test that 75% of the observations are in ground truth Score 1, one would use the line in that table for 'theta' of .75. For a sample size of 150, the **minimum** number of observations in Score 1 that are consistent with these hypotheses is 104.13, and the **maximum** is 121.61. Note that 75% of 150 is 112.5; this is the value expected from the 150 observations, so that a deviation of about 8 (on either side of the mean) from this expected value is still consistent with the hypothesis of 75%.

Which of the "minimum within-class" (104 in the example of the preceding paragraph) or "maximum within-class" (122 in the same example) to choose for the binomial test depends on the type of statement one wishes to make, and, in particular, whether one wishes to err in favor of or against the existing map. To err in favor of the map is to assume that the map is correct until conclusively proven otherwise, with the selected confidence (85, 90, or 95%). In the other approach, the map is assumed to be incorrect until conclusively proven correct, again with the selected confidence. The SRI evaluator must weigh the relative consequences of an erroneous result in each case. In the present guidelines, the existing map is favored.

If a **minimum** proportion (e.g. minimum purity) is being tested, the "minimum within-class" figure favors the existing map, whereas if a **maximum** proportion (e.g. maximum strongly contrasting soils) is being tested, the "maximum within-class" figure favors the existing map. In the previous example, since the test is for at least 75% Score 1 (i.e. a minimum proportion of Score 1), the minimum within-class figure of 104/150 observations in Score 1 is used as the acceptance criterion, if the existing map is being favored, otherwise, the maximum within-class figure of 122/150 is used; the map is accepted according to either criterion if more than the required number of observations are in Score 1.

Once it is decided whether to use the minimum or maximum, a graph may easily by constructed, with the four sample sizes (30, 90, 150, and 210) along the horizontal (X) axis, and the tabular values along the vertical (Y) axis. The four points (X,Y coordinates) are graphed, and these points are then connected with straight lines, resulting in a curve that separates the graph into two areas: an **acceptance** and a **rejection** region. In figures 4.3a and 4.3.b, the rejection region has been shaded, so that if a point falls in this region on either graph, the map may be rejected. The rejection region is the area **above** the line on a **maximum** within-class graph, and the area **below** the line on a **minimum** within-class graph.

These graphs are exact only at the four points used to construct them (sample sizes of 30, 90, 150 and 210). The linear interpolation for other sample sizes is accurate to within one observation at almost all points, so that an incorrect decision will only very rarely be made with these approximate graphs.

Tables E1, E2, and E3

Numbers of 'within-class' observations consistent with a hypothesized underling binomial population 'Theta'

Table E1 - 1-tail confidence of .85

	—Minimum within-class—				—Maximum within-class—			
	Sample Size							
Theta	30	90	150	210	30	90	150	210
.05	0.70	2.85	5.22	7.71	3.30	7.17	10.80	14.31
.10	1.76	6.52	11.68	17.01	5.25	12.49	19.34	26.01
.15	2.99	10.47	18.45	26.63	7.03	17.55	27.56	37.39
.20	4.21	14.54	25.41	36.48	8.81	22.47	35.61	48.53
.25	5.50	18.73	32.49	46.48	10.51	27.29	43.52	59.53
.30	6.89	23.00	39.67	56.60	12.12	32.01	51.34	70.41
.35	8.26	27.29	46.95	66.83	13.75	36.72	59.06	81.18
.40	9.68	31.66	54.27	77.14	15.32	41.34	66.74	91.87
.45	11.15	36.10	61.67	87.51	16.85	45.90	74.33	102.56
.50	12.62	40.56	69.14	97.99	18.38	50.44	81.86	113.20
.55	14.15	45.10	76.67	112.01	19.85	54.90	89.33	123.56
.60	15.68	49.66	84.26	119.57	21.32	59.34	96.73	134.34
.65	17.25	54.28	91.94	129.84	22.74	63.71	104.05	144.19
.70	18.88	58.99	99.66	140.60	24.11	68.00	111.33	154.40
.75	20.49	63.71	107.48	151.47	25.50	72.27	118.51	164.52
.80	22.19	68.53	115.39	162.47	26.79	76.46	125.59	174.52
.85	23.97	73.45	123.44	173.61	28.01	80.53	132.55	184.37
.90	25.75	78.51	131.66	184.99	29.24	84.48	139.32	193.99
.95	27.70	83.83	140.20	196.69	30.40	88.15	145.78	203.29

Table E2 - 1-tail confidence of .90

	Minimum within-class				Maximum within-class			
	Sample Size							
Theta	30	90	150	210	30	90	150	210
.05	0.47	2.39	4.64	7.06	3.69	7.77	11.55	15.15
.10	1.41	5.94	10.87	16.02	5.74	13.26	20.32	27.17
.15	2.50	9.71	17.44	25.42	7.64	18.45	28.70	38.72
.20	3.71	13.67	24.27	35.13	9.42	23.46	36.85	49.99
.25	5.02	17.77	31.24	45.01	11.10	28.35	44.86	61.10
.30	6.28	21.97	38.33	55.03	12.79	33.12	52.75	72.05
.35	7.64	26.21	45.52	65.16	14.43	37.85	60.54	82.90
.40	9.07	30.53	52.82	75.40	15.96	42.51	68.23	93.64
.45	10.47	34.96	60.19	85.76	17.55	47.06	75.83	104.40
.50	12.00	39.39	67.63	96.20	19.00	51.61	83.37	115.20
.55	13.45	43.94	75.17	110.90	20.53	56.04	90.81	126.00
.60	15.04	48.49	82.77	117.96	21.93	60.47	98.18	136.22
.65	16.57	53.15	90.46	128.12	23.36	64.79	105.48	145.86
.70	18.21	57.88	98.25	138.95	24.72	69.03	112.67	155.97
.75	19.90	62.65	106.14	149.90	25.98	73.23	119.76	165.99
.80	21.58	67.54	114.15	161.01	27.29	77.33	126.73	175.87
.85	23.36	72.55	122.30	172.28	28.50	81.29	133.56	185.58
.90	25.26	77.74	130.68	183.83	29.59	85.06	140.13	194.98
.95	27.31	83.23	139.45	195.85	30.70	88.61	146.36	203.94

Table E3 - 1-tail confidence of .95

	Minimum within-class				Maximum within-class			
	Sample Size							
Theta	30	90	150	210	30	90	150	210
.05	0.23	1.86	3,87	6.07	4.24	8.69	12.68	16.48
.10	1.05	5.06	9.66	14.55	6.49	14.44	21.79	28.88
.15	2.02	8.59	16.02	23.67	8.47	19.79	30.42	40.73
.20	3.07	12.39	22.59	33.13	10.31	24.91	38.75	52.21
.25	4.21	16.35	29.39	42.81	12.02	29.90	46.87	63.48
.30	5.43	20.43	36.36	52.67	13.78	34.78	54.85	74.56
.35	6.76	24.61	43.45	62.70	15.43	39.56	62.71	85.47
.40	8.13	28.91	50.67	72.88	16.96	44.22	70.45	96.25
.45	9.49	33.24	58.01	83.16	18.56	48.81	78.05	107.00
.50	11.01	37.67	65.40	93.56	19.99	53.33	85.60	117.75
.55	12.44	42.19	72.95	109.64	21.51	57.76	92.99	128.50
.60	14.04	46.78	80.55	115.69	22.87	62.09	100.33	139.29
.65	15.57	51.44	88.29	125.56	24.24	66.39	107.55	148.34
.70	17.22	56.22	96.15	136.44	25.57	70.57	114.64	158.33
.75	18.98	61.10	104.13	147.52	26.79	74.65	121.61	168.19
.80	20.69	66.09	112.25	158.79	27.93	78.61	128.41	177.87
.85	22.53	71.21	120.58	170.27	28.98	82.41	134.98	187.33
.90	24.51	76.56	129.21	182.12	29.95	85.94	141.34	196.45
.95	26.76	82.31	138.32	194.52	30.98	89.14	147.13	204.93

Appendix F
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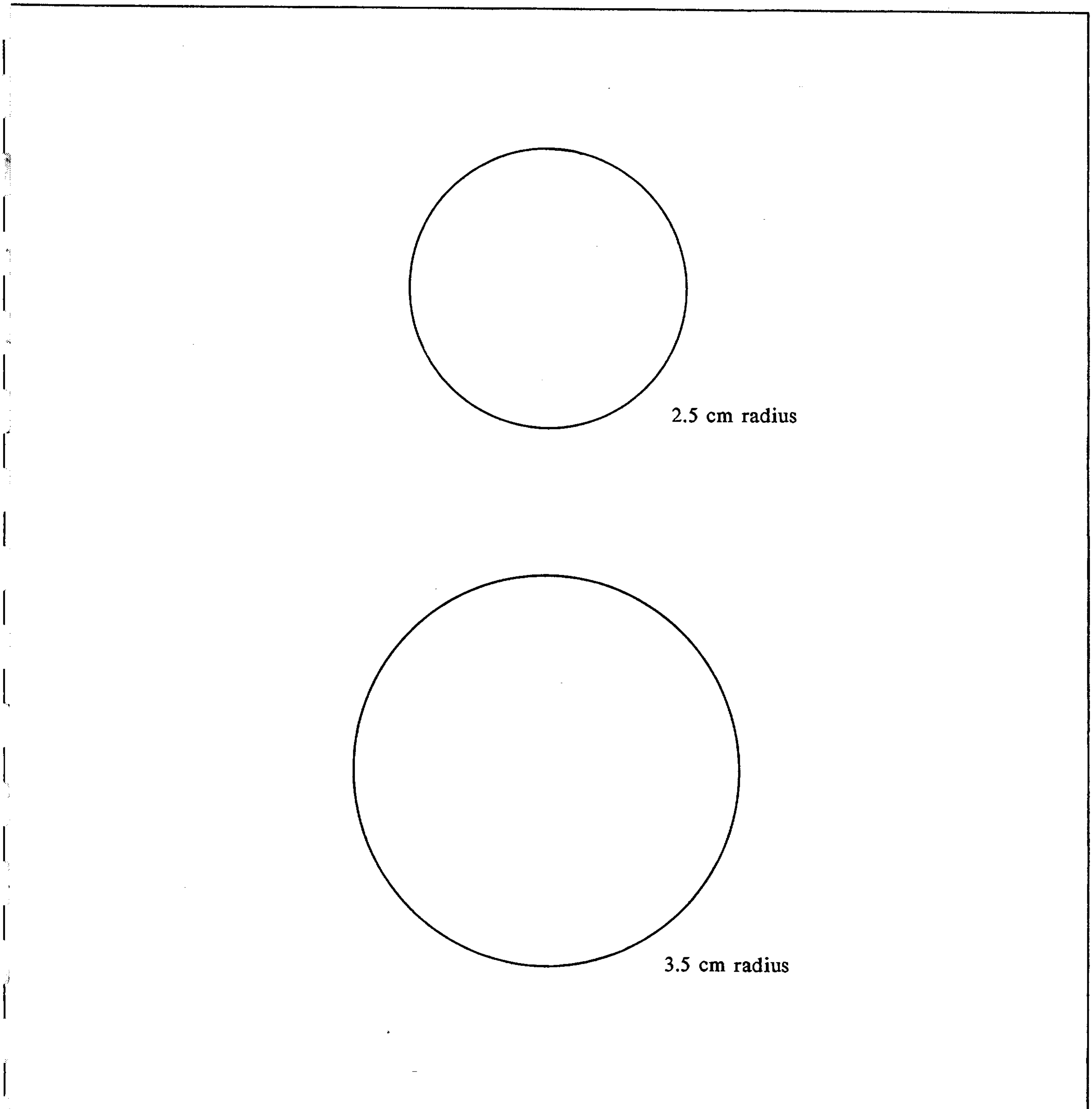

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