APPENDIX B-1

Excerpt from "Methods for Evaluating the Attainment of Cleanup Standards, Vol 1: Soils and Solid Media", Section 5: Field Sampling Procedures, USEPA, 1989

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5. FIELD SAMPLING PROCEDURES

The procedures discussed in this chapter ensure that:

- The method of establishing soil sample locations in the field is consistent with the planned sample design;
- Each sample location is selected in a nonjudgmental and unbiased way; and
- Complete documentation of all sampling steps is maintained.

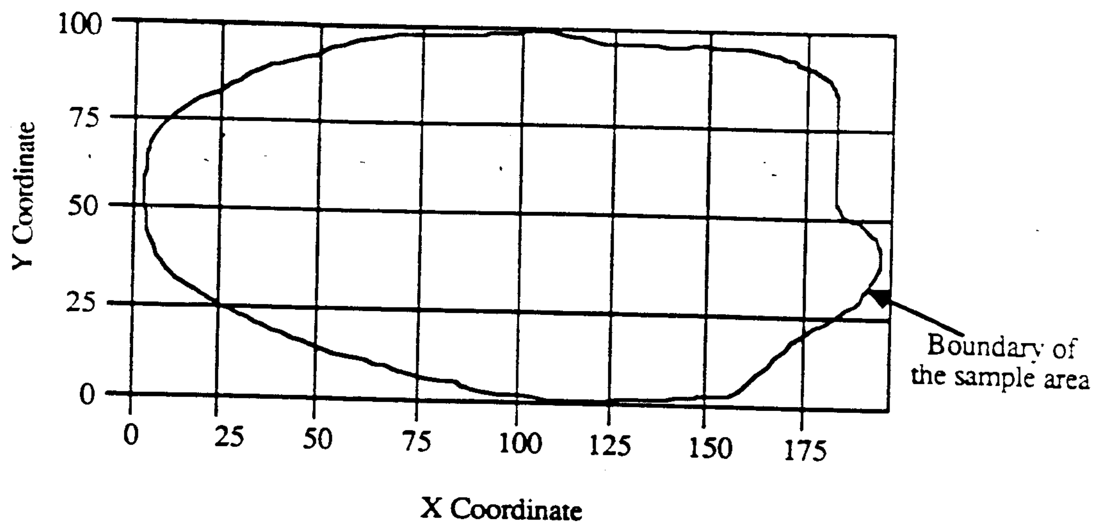
The procedures discussed in this chapter assume that the sampling plan has been selected; the boundaries of the waste site, the sample areas, and any strata have been defined; a detailed map of the waste site is available; and the sample size is known. Sample size determination is discussed in Chapters 6, 7, 8, and 9. Also, if sequential sampling or hot spot searches are planned, the reader should refer to Chapters 8 and 9, respectively, for additional guidance on field sampling.

5.1 Determining the General Sampling Location

Locating the soil samples is accomplished using a detailed map of the waste site with a coordinate system to identify sampling locations. Recording and automation of station-specific data should retain coordinate information, especially if geostatistical manipulations are performed (see Chapter 10) or a geographic information system will be used.

Soil sample locations will be identified by X and Y coordinates within the grid system. It is not necessary to draw a grid for the entire waste site; it is only necessary to identify the actual coordinates selected. Figure 5.1 is an example of a map with a coordinate system. In this example, the origin of the coordinate system is at the lower lefthand corner of the map; however, this may not be true for coordinate systems based on measurements from a reference point on the ground, i.e., a benchmark or a standard coordinate system such as latitude and longitude.

Figure 5.1 Map of a Sample Area with a Coordinate System



The boundaries of the sample areas (areas within the site for which separate attainment decisions are to be made) and strata within the sample areas (if stratified sampling is required) should be shown on the map. The map should also include other important features that will be useful in identifying sample locations in the field.

Accurate location of sampling points can be expensive and time consuming. Therefore, a method is suggested which uses the coordinate system to identify the general area within which the soil sample is to be collected, followed by a second stage of sampling, described in section 5.5, to identify the sample point accurately.

The X and Y coordinates of each sample location must be specified. This distance between coordinates on each axis represents a reasonable accuracy for measuring distance in the field, and is represented by M. If distances can be measured easily to within 2 m, but not to within 1 meter, the coordinates should be provided to the nearest 2 m (M = 2 m). The sampling coordinates can be identified with greater accuracy when the distances to be measured between reference points are short, the measuring equipment is accurate or easy to use, or there are few obstructions to line-of-sight measuring such as hills, trees, or bushy vegetation. For example, the location within a small lagoon, say, 30 by 30 m, can be established to within 5 cm. On the other hand, in a 10 hectare field it may only be reasonable to identify a location to within 10 m.

5.2 Selecting the Sample Coordinates for a Simple Random Sample

A random sample of soil units within the sample area or stratum will be selected by generating a series of random (X,Y) coordinates, finding the location in the field associated with these (X,Y) coordinates, and following the field procedures described in section 5.5 for collecting soil samples. If the waste site contains multiple sample areas and/or strata, the same procedure described above is used to generate random pairs of coordinates with the appropriate range until the specified sample size for the particular portion of the site has been met. In other words, a separate simple random sample of locations should be drawn for each sample area or stratum. To simplify the discussion, the procedures below discuss selection of a random sample in a sample area.

The number of soil samples to be collected must be specified for each sample area. In what follows, the term n_f will be used to denote the number of samples to be collected in the sample area.

To generate the n_f random coordinates (X_i,Y_i), i = 1 to n_f, for the sample area, determine the range of X and Y coordinates that will completely cover the sample area. These coordinate ranges will define a rectangle that circumscribes the sample area. Let the coordinate ranges be X_{min} to X_{max} and Y_{min} to Y_{max}. Thus, the point (X_{min}, Y_{min}) represents the lower lefthand corner of the rectangle, and (X_{max}, Y_{max}) represents the upper righthand corner of the rectangle. The n_f sample coordinates (X_i,Y_i) can be generated using a random number generator and the steps described in Box 5.1. Box 5.2 gives an example of generating random sample locations.

Box 5.1
Steps for Generating Random Coordinates That Define Sampling Locations

1) Generate a set of coordinates (X,Y) using the following equations:

$$X = X_{min} + (X_{max} - X_{min})*RND \qquad (5.1)$$

$$Y = Y_{min} + (Y_{max} - Y_{min})*RND \qquad (5.2)$$

RND is the next unused random number between 0 and 1 in a sequence of random numbers. Random numbers can be obtained from calculators, computer software, or tables of random numbers.

2) If (X,Y) is outside the sample area, return to step 1 to generate another random coordinate; otherwise go to step 3.

3) Define (X_i,Y_i) using the following steps:

Round X to the nearest unit that can be located easily in the field (see section 5.1); set this equal to X_i

Round Y to the nearest unit that can be located easily in the field (see section 5.1); set this equal to Y_i.

4) Continue to generate the next random coordinate, (X_{i+1},Y_{i+1}).

Box 5.2
An Example of Generating Random Sampling Locations

To illustrate the selection of simple random sample of locations, assume that seven soil units will be selected from the site in Figure 5.2. Pairs of random numbers (one X coordinate and Y coordinate for each pair) identify each sample point. X will be measured on the map's coordinate system in the horizontal direction and Y in the vertical direction. It is assumed for this example that selected coordinates can be identified to the nearest meter. The first number of pair, X_i, must be between 0 and 190 (i.e., $X_{min} = 0$ and $X_{max} = 190$) and the second, Y_i, between 0 and 100 ($Y_{min} = 0$ and $Y_{max} = 100$) for this example. If the X and Y coordinates for any pair identify a location outside the area of interest, they are ignored and the process is continued until the sample size n_f has been achieved.

X Y pair	Random X coordinate	Random Y coordinate
1	67	80
2	97	4
3	190	88 (outside of sample area)
4	17	15 (outside of sample ar :a)
5	94	76
6	123	49
7	25	52
8	35	39
9	152	14

It took nine attempts to secure seven coordinates that fall within the sample area. The randomly selected coordinates for pairs 3 and 4 fall outside the waste site and are to be discarded. The remaining seven locations are randomly distributed throughout the site.

These locations can now be plotted on the map, as shown in Figure 5.2.

5.3 Selecting the Sample Coordinates for a Systematic Sample

A square grid and a triangular grid are two common patterns used in systematic or grid sampling. These patterns are shown in Figure 5.3. Note that the rows of points in the triangular grid are closer (.866L) than the distance between points in a row (L) and that the points in every other row are offset by half a grid width.

Figure 5.2 Map of a Sample Area Showing Random Sampling Locations

Locations of the random samples are indicated by a •. The numbers reference the XY pairs in Box 5.2.

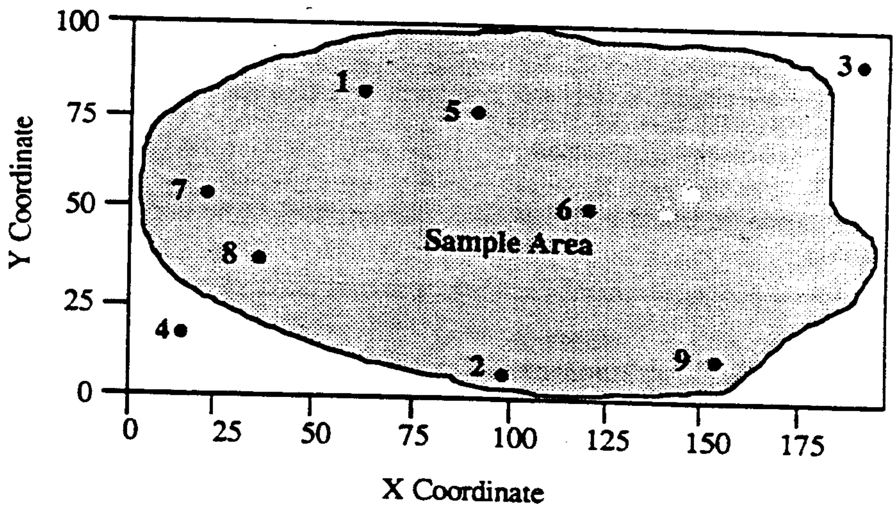
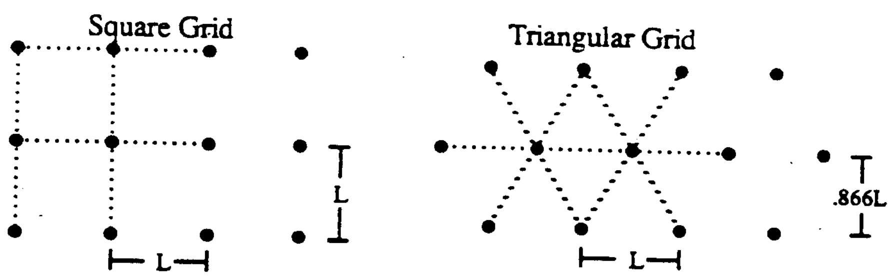


Figure 5.3 Examples of a Square and a Triangular Grid for Systematic Sampling



The size of the sample area must be determined in order to calculate the distance, L, between the sampling locations in the systematic grid. The area can be measured on a map using a planimeter. The units of the area measurement (such as square feet, hectares, square meters) should be recorded.

Denote the surface area of the sample area by A. Use the equations in Box 5.3 to calculate the spacing between adjacent sampling locations.

Box 5.3
Calculating Spacing Between Adjacent Sampling Locations

for the Square Grid in Figure 5.3

$$L = \sqrt{\frac{A}{n_f}} \qquad (5.3)$$

for the Triangular Grid in Figure 5.3

$$L = \sqrt{\frac{A}{.866 n_f}} \qquad (5.4)$$

The distance between adjacent points, L, should be rounded to the nearest unit that can be easily measured in the field.

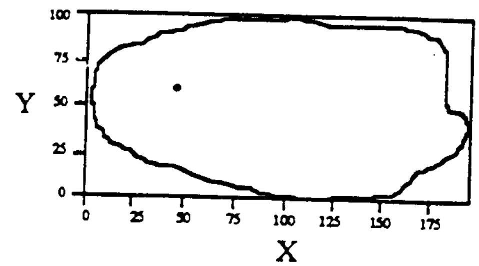
After computing L, the actual location of one point in the grid should be chosen by a random procedure. First, select a random coordinate (X,Y) following the procedure in Box 5.1. Using this location as one intersection of two gridlines, construct gridlines running parallel to the coordinate axes and separated by a distance L. The sampling locations are the points at the intersections of the gridlines that are within the sample area boundaries. Figure 5.4 illustrates this procedure. Using this procedure, the grid will always be oriented parallel to the coordinate axes. The grid intersections that lie outside the sample area are ignored. There will be some variation in sample size, depending on the location of the initial randomly drawn point. However, the relative variation in number of sample points becomes small as the number of desired sample points increases. For unusually shaped sample areas (or strata), the number of sample points can vary considerably from the desired number.

The coordinates for the sample points will be all coordinates (X_i, Y_i) such that:

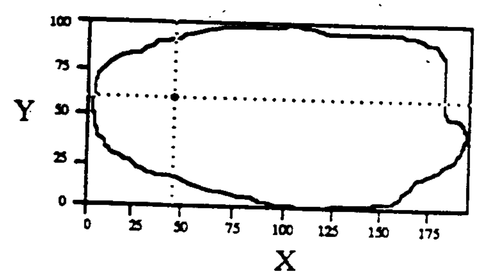
- (X_i, Y_i) is inside the sample area or stratum;
- $X_i = X + j*L$, for some positive or negative integer j, and;
- $Y_i = Y + k*L$, for some positive or negative integer k.

Figure 5.4 Locating a Square Grid Systematic Sample

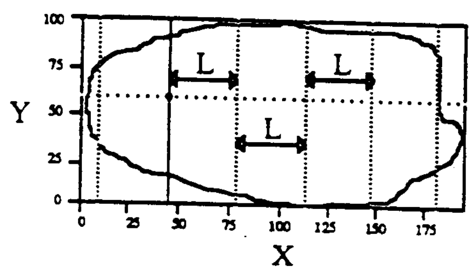
(1) Select initial random point.



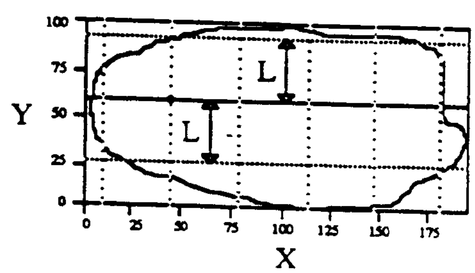
(2) Construct coordinate axis going through initial point.



(3) Construct lines parallel to vertical axis, separated by a distance of L.



(4) Construct lines parallel to horizontal axis, separated by a distance of L.



Box 5.4 and Figure 5.5 give an example of locating systematic coordinates and the resultant sampling locations plotted on a map of the site.

Box 5.4
Locating Systematic Coordinates

Using the map in Figure 5.1 and a planimeter, the area of the sample area is determined to be 14,025 sq. m. If the sample size is 12, the spacing between adjacent points is:

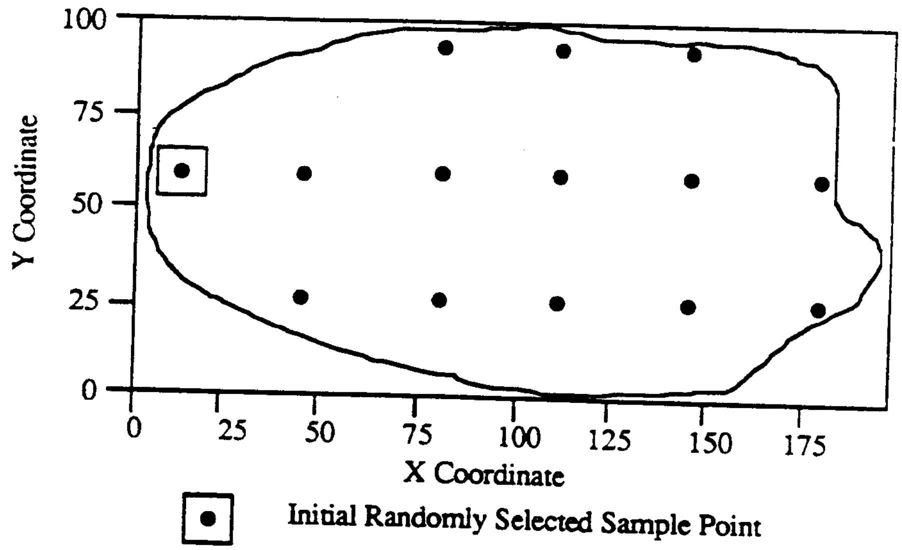
$$L = \sqrt{\frac{A}{n_f}} = \sqrt{\frac{14025}{12}} = 34 \text{ m, rounded to the nearest meter}$$

Using the procedure in Box 5.1, a random coordinate (X,Y) = (11,60) is generated. Starting from this point, the following sampling points can be calculated:

		(79,94)	(113,94)	(147,94)	
(11,60)	(45,60)	(79,60)	(113,60)	(147,60)	(181,60)
	(45,26)	(79,26)	(113,26)	(147,26)	(181,26)

These points are shown in Figure 5.5. The intended sample size was 12; however, because of the random selection process and the irregularity of the sample area boundary, there are 14 sample points within the sample area. A sample will be collected at all 14 locations.

Figure 5.5 Map of a Sample Site Showing Systematic Sampling Locations



5.3.1 An Alternative Method for Locating the Random Start Position for a Systematic Sample

An alternative method may be used to locate the random start position for a systematic triangular grid sample (J. Barich, Pers. Com., 1988). This approach, as detailed in Box 5.5, determines a random start location by choosing a random angle A and a random distance Y from point X. This approach is useful under circumstances where a transit and stadia rod are available for turning angles, measuring distances, and establishing transects. This method is essentially equivalent to the method described above.

Box 5.5
Alternative Method for Locating the Random
Start Position for a Systematic Sample

Figure 5.6 and the following steps explain how to implement the sequence.

1) Establish the main transect with endpoints X and X' using any convenient reference line (e.g., established boundary). Notice that the transect X-X' must be longer than the line indicated in Figure 5.6 in order to site all of the transects that intersect the sample area.

2) Randomly choose a point Y between X and X'.

3) Randomly choose an angle A between 0° and 90°.

4) Locate transect with endpoints Y and Y', A degrees from transect X and X'. If this transect intersects the boundary of the sample area, mark the transect.

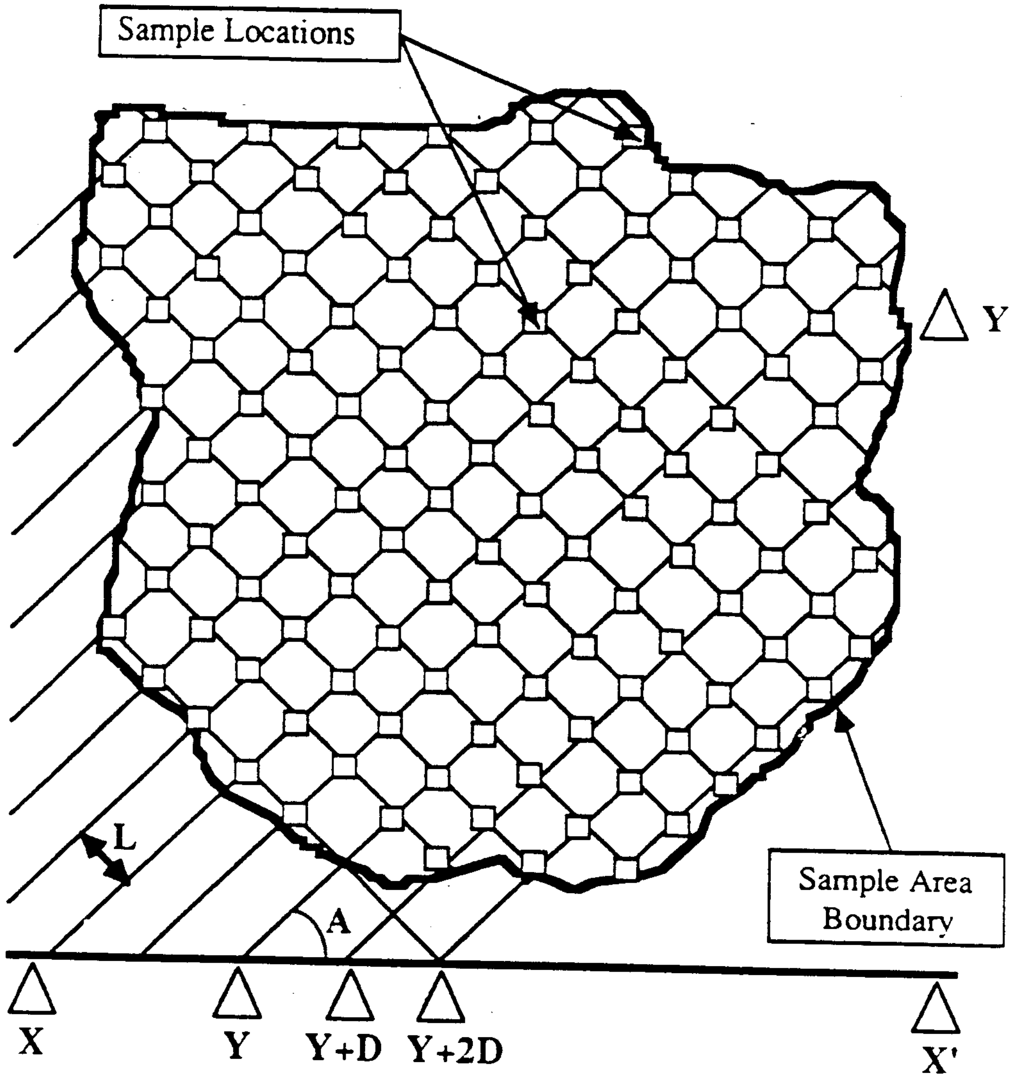
5) Locate another transect beginning at point Y and 90° +A (i.e., perpendicular) from that transect that intersects the boundary of the sample area; then mark the transect Y-Y'. If this transect intersects the boundary of the sample area then mark the transect.

6) Move away from point Y on transect X-X' a distance D, where D=L/sin(A). L is the desired interval between sampling points along the grid pattern.

7) At the point D units away from Y, establish two more transects: one A degrees from transect X-X' and parallel to transect Y-Y', and the other 90°+A degrees from X-X' also beginning at the point D units from point Y.

8) Continue to move intervals of distance D along the transect X-X' until two transects intersect within the boundary of the sample area. Establish the first sample location at that point. Then measure along that transect from the first sampling location a distance of L and establish more transects and grid points using the approach described in the previous method for systematic samples.

Figure 5.6 Method for Positioning Systematic Sample Locations in the Field



Where **D = L/sin A**

Y is chosen randomly

A is chosen randomly

L is determined from sample size calculations

□ is a physical sampling location

5.4 Extension to Stratified Sampling

The extension of these procedures to stratified sampling is straightforward. Each stratum is sampled separately using the methods discussed above. Different random sequences (or random numbers for locating the grids) should be used in each stratum within the sample area. The sampling approach chosen for one stratum does not have to be used in another stratum. For example, if a sample area is made up of a small waste pile and a large 200-acre hillside, then it would be possible to use systematic sampling for the hillside and random sampling for the waste pile.

5.5 Field Procedures for Determining the Exact Sampling Location

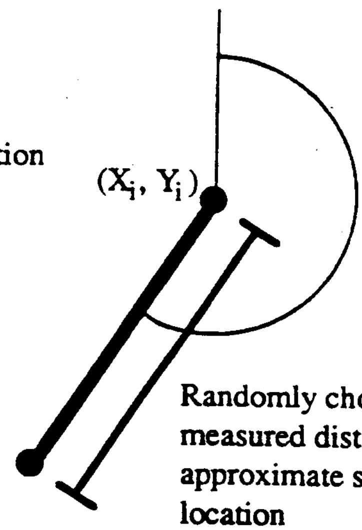
The grid points specified for the coordinate system or other reference points (e.g., trees, boulders, or other landmarks) provide the starting point for locating the sample points in the field. The location of a sample point in the field will be approximate because the sampling coordinates were rounded to distances that are easy to measure, the measurement has some inaccuracies, and there is judgment on the part of the field staff in locating the sample point.

A procedure to locate the exact sample collection point is recommended to avoid subjective factors that may affect the results. Without this precaution, subtle factors such as the difficulty in collecting a sample, the presence of vegetation, or the color of the soil may affect where the sample is taken, and thus bias the results.

To locate the exact sample collection point in the field, use one of the following procedures (or a similar procedure) to move from the location identified when measuring from the reference points to the final sample collection point. In the methods below, M is the accuracy to which distances can be easily measured in the field.

- Choose a random compass direction (0 to 360 degrees or N, NE, E, SE, etc.) and a random distance (from zero to M meters) to go to the sample location (as illustrated in Figure 5.7).
- Choose a random distance (from -M meters to M meters) to go in the X direction and a random distance (from -M meters to M meters) to go in the Y direction, based on the coordinate system.

Figure 5.7 An Example Illustration of How to Choose an Exact Field Sampling Location from an Approximate Location



For either of these procedures, the random numbers can be generated in the field using a hand-held calculator or by generating the random numbers prior to sampling. The sample should be collected as close to this exact sampling location as possible.

5.6 Subsampling and Sampling Across Depth

Methods for deciding how and where to subsample a soil core are important to understand and include in a sampling plan. These methods should be executed consistently throughout the site. The field methods that are used will depend on many things including the soil sampling device, the quantity of material needed for analysis, the contaminants that are present, and the consistency of the solid or soils media that is being sampled. The details of how these considerations influence field procedures are not the subject of this discussion, but they are important and related to the discussion. More detail can be obtained in the Soil Sampling Quality Assurance User's Guide (USEPA, 1984).

This discussion describes methods for soil acquisition across depth once an exact auguring or coring position has been determined and describes how these approaches influence the interpretation of sampling results. There are several approaches that might be considered each with advantages and disadvantages; these are outlined in Figure 5.8.

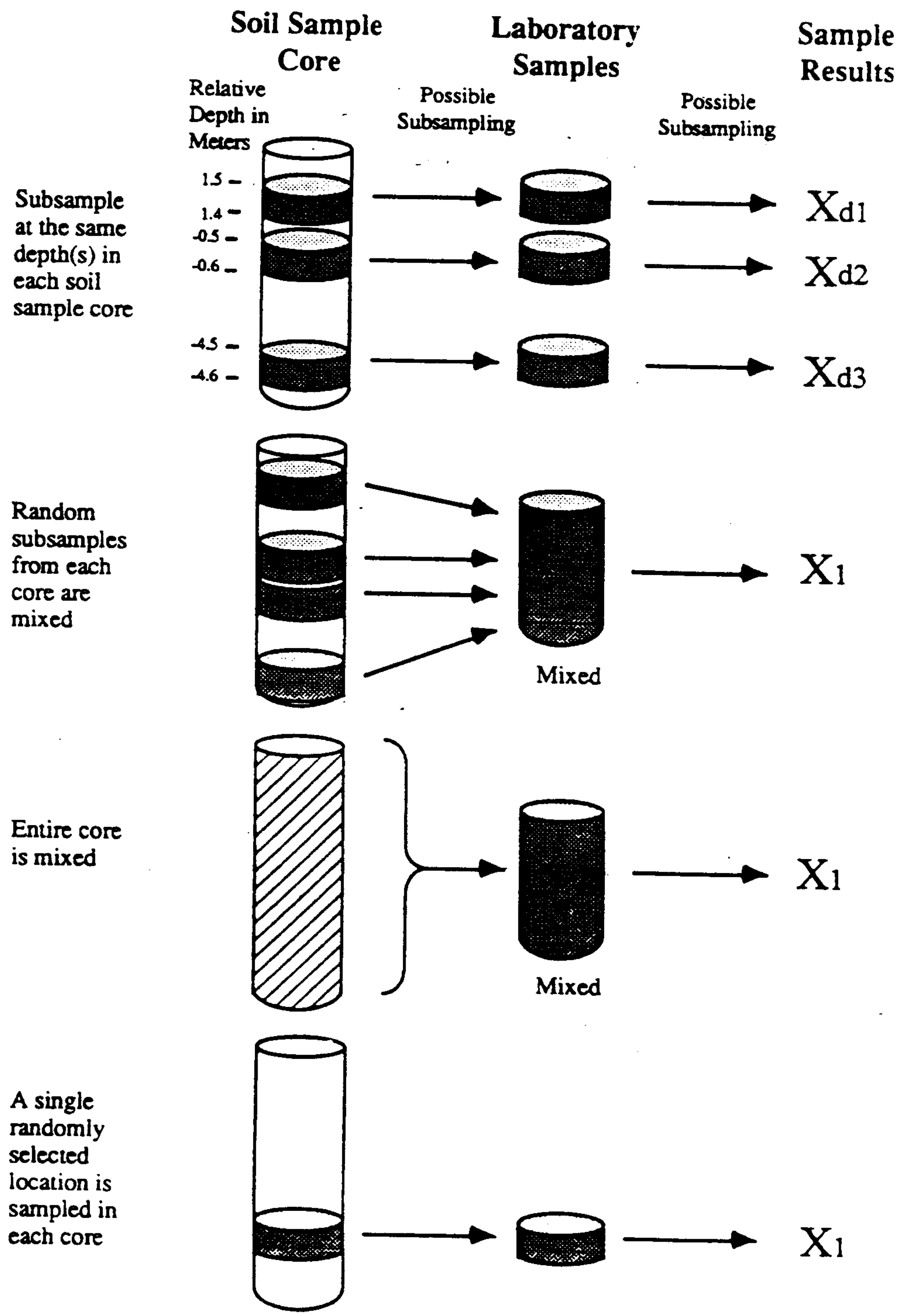
5.6.1 Depth Discrete Sampling

The first approach is to decide before sampling on an exact position or positions across depth that will be retained for analysis. For example, it may be decided that throughout the site a split spoon will be driven so that the soil within the following intervals is retained and sent to the laboratory for separate analysis: at elevations 1.5 m to 1.4 m, -0.5m to -0.6 m, and -4.5 m to -4.6 m (relative to a geodetic or site standard elevation). The size of the interval would depend on the volume required by the laboratory. In this example, all the soils material within each interval is extracted and analyzed. Advantages of this approach are that each depth can be considered a different sample area and conclusions regarding the attainment of cleanup standards can be made independently for each soil horizon. This is also a preferred method when the presence of volatiles in the soils media prevents the application of compositing methods.

5.6.2 Compositing Across Depth

Other approaches to sample acquisition within a core are based on compositing methods. Compositing methods are generally to be approached with caution unless the statistical parameter of interest is the mean concentration. If the mean is the statistic of interest, then the variance of the mean contributed by differences in location across the site from composited samples will be lower than the same variance associated with the mean from noncomposited samples. However, compositing will restrict the evaluation of the proportion of soil above an established cleanup standard because of the physical averaging that occurs in the compositing process. Clearly compositing is not recommended if the compositing process will influence the mass of material in the sample as in the case of volatile organics within a soils matrix. Numerous authors have contributed to the understanding of the effects of compositing (Duncan, 1962; Elder et al., 1980; Rohde, 1976; Schaeffer and Janardan, 1978; and Schaeffer et al., 1980), and these references or a statistician should be consulted if complicated compositing strategies are planned.

Figure 5.8 Subsampling and Sampling Across Depth



Under one compositing method, segments of the soil core are retained from randomly or systematically identified locations. Then only the sampled portions are homogenized and then subsampled. Another approach calls for retaining the entire core and homogenizing all of the material and then subsampling. The latter approach is preferred from a statistical point of view because the subsampling variance will be lower. However, the second method may present difficulties if the soil samples are obtained to considerable depth or by split spoon. In these situations, it is clearly not reasonable or cost effective to acquire a core from the entire soil profile. On the other hand, if a hand-held core or continuous coring device such as a vibra-corer is being used, then homogenization of the entire core may be possible. In general, large amounts of material, material that is difficult to manipulate because of its physical properties, material containing analytes that will volatilize, or hazardous soil make thorough mixing more difficult, which may eventually defeat the positive features associated with homogenization of the entire core.

5.6.3 Random Sampling Across Depth

A final approach involves randomly sampling a single location within each core. At first, this approach appears to have many difficulties, but if the interest is in verifying that the proportion of soil above a cleanup standard is low, this approach will work quite well.

Suppose that an in situ soils stabilization method was used to treat all of the overburden soils within a former lagoon. The treatment was previously found to yield effective and homogeneous results over depth and space. It would clearly not be appropriate to sample at a single depth of, say, 3m. Since depth homogeneity is expected, it may also not be necessary to evaluate several specific depths by sampling 1-m, 3-m, 7-m, and 15-m horizons in each boring. Finally and most importantly, it would not be recommended to perform compositing because the statistical parameter of interest is the proportion of soil at the site above the cleanup standard and not the mean concentration.

In this situation it may be useful to pick a random depth at each location. In this way, many depths will be represented across the lagoon. Also, cost may be reduced because at many locations the auger will not have to drill to bedrock because the sample will be obtained from a random location that, in some samples, will be near the surface.

5.7 Quality Assurance/Quality Control (QA/QC) in Handling the Sample During and After Collection

Data resulting from a sampling program can only be evaluated and interpreted with confidence when adequate quality assurance methods and procedures have been incorporated into the design. An adequate quality assurance program requires awareness of the sources of error associated with each step of the sampling effort.

A full discussion of this topic is beyond the scope of the document; however, the implementation of a QA program is important. For additional details, see *Soil Sampling Quality Assurance User's Guide* (USEPA, 1984), Brown and Black (1983), and Garner (1985).

5.8 Summary

Locating soil samples is accomplished using a detailed map of the waste site with a coordinate system to identify sampling locations. The boundaries of the sample areas (areas within the site for which separate cleanup verification decisions are to be made) and strata within the sample areas should be shown on the map. It is not necessary to draw a grid for the entire waste site, only to identify the actual coordinates selected.

A random sample of soil units within the sample area or stratum will be selected by generating a series of random (X,Y) coordinates and identifying the location associated with these coordinates.

When selecting the sample coordinates for a systematic sample, two common patterns of systematic or grid samples are a square grid and a triangular grid. Various methods can be used to select a systematic sample; however, the most important point is that one of the systematic sample locations must be identified randomly.