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ARID ECOSYSTEMS 1993 IMPLEMENTATION PLAN

COLORADO PLATEAU PLOT DESIGN PILOT STUDY

by

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Arid Ecosystems 1993 Implementation Plan
Colorado Plateau Plot Design Pilot Study

NOTICE

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ABBREVIATIONS AND ACRONYMS

AIM	arid information management system
AVHRR	advanced very high resolution radiometer
BLM	U.S. Bureau of Land Management
DOI	U.S. Department of Interior
DQO	data quality objective
EMAP	Environmental Monitoring and Assessment Program
EMAP-Arid	Arid Ecosystem component of EMAP
EPA	U.S. Environmental Protection Agency
EQO	ecosystem quality objective
FIA	Forest Service Inventory Analysis
FS	U.S. Forest Service
GIS	geographic information system
GPS	global positioning system
IM	information management
IQO	indicator quality objective
INEL	Idaho National Engineering Laboratory
LAI	leaf area index
LESAT	Lockheed Environmental Systems & Technologies Co.
MQO	measurement quality objective
MSS	multispectral scanner
NASS	National Agricultural Statistics Survey
NCSS	National Cooperative Soil Survey
NPP	net primary productivity
NPS	National Park Service
NSH	National Soils Handbook
PC	personal computer
PDR	personal data recorder
PS-II	Personal Spectrometer II
QA	quality assurance
QA/QC	quality assurance/quality control
QAPjP	quality assurance project plan
RQO	resource quality objective
RUSLE	revised universal soil loss equation
SCS	Soil Conservation Service
SOP	standard operating procedure
SSM	Soil Survey Manual
TM	thematic mapper
UNEP	United Nations Environmental Program
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USLE	universal soil loss equation
WE	wind erosion
WEPP	Wind Erosion Prediction Project

SECTION 1
INTRODUCTION

1.1 THE EMAP SURVEY DESIGN AND ARID RESOURCES

The primary objectives of EMAP require estimates, with known confidence, for status, trends, and changes in the condition of the Nation's ecological resources as well as estimates, with known confidence, of their extent. The Program has developed a statistical sampling design for the survey of natural resources as a basis for statistical inferences about the condition and extent of ecological resources. The design furnishes a valid probability sample of ecological resources that provides the foundation for statistical estimation with known confidence levels and the means to detect changes and trends in the ecological indicators with known levels of confidence. It should be noted that EMAP was established to provide information on status and extent of ecological resources on a regional and national basis. The monitoring plan and survey design were therefore crafted with regional or national assessment as goals. Thus, monitoring and assessment are on a much different scale than that required to address issues associated with localized perturbations of the environment.

1.1.1 The EMAP Grid Design and Probability Samples

Probability-based surveys and probability sampling have been rigorously developed and documented in the statistical literature. In addition to the EMAP design, some other national probability-based sample survey designs that exist in the United States are the USDA National Agricultural Statistics Survey (NASS) (Cotter and Nealon, 1987) and the Forest Service Inventory Analysis (FIA) (Bickford et al., 1963; Hazard and Law, 1989). A thorough coverage of the development of the basic EMAP survey design can be found in Overton et al., (1990) and White et al. (1992). The design selected to sample the EMAP ecosystems is capable of sampling any spatially distributed and well-defined ecological resource.

The EMAP sampling design is based on a triangular grid of approximately 12,600 points distributed over the conterminous United States with approximately a 27-km spacing between points on the grid (Figure 1-1). The grid of points serves as the basis for constructing a sampling frame for spatially distributed ecological resources (Figure 1-2).

The cornerstone of grid-based sampling is the identification of a resource with its location. As a consequence, attributes of the resource, such as presence or absence of the resource or indicators of resource condition, are also associated with the resource location. The regular grid ensures a uniform dispersion of sample points over the spatially distributed ecological resources, thus ensuring the inclusion of all ecological resources in the sample in proportion to their geographic presence. Any statistical structure on the space of locations is transferred to a statistical structure on the resource and its attributes. In principle, any attribute of an extensive resource can be viewed as a surface in that a value can be assigned to all points where the resource is present. The resource attribute is then defined on a two-dimensional surface wherever the resource occurs and population inferences can be based, ordinarily, on the length or area of the resource that possesses certain well-defined properties such as those provided by the indicators.

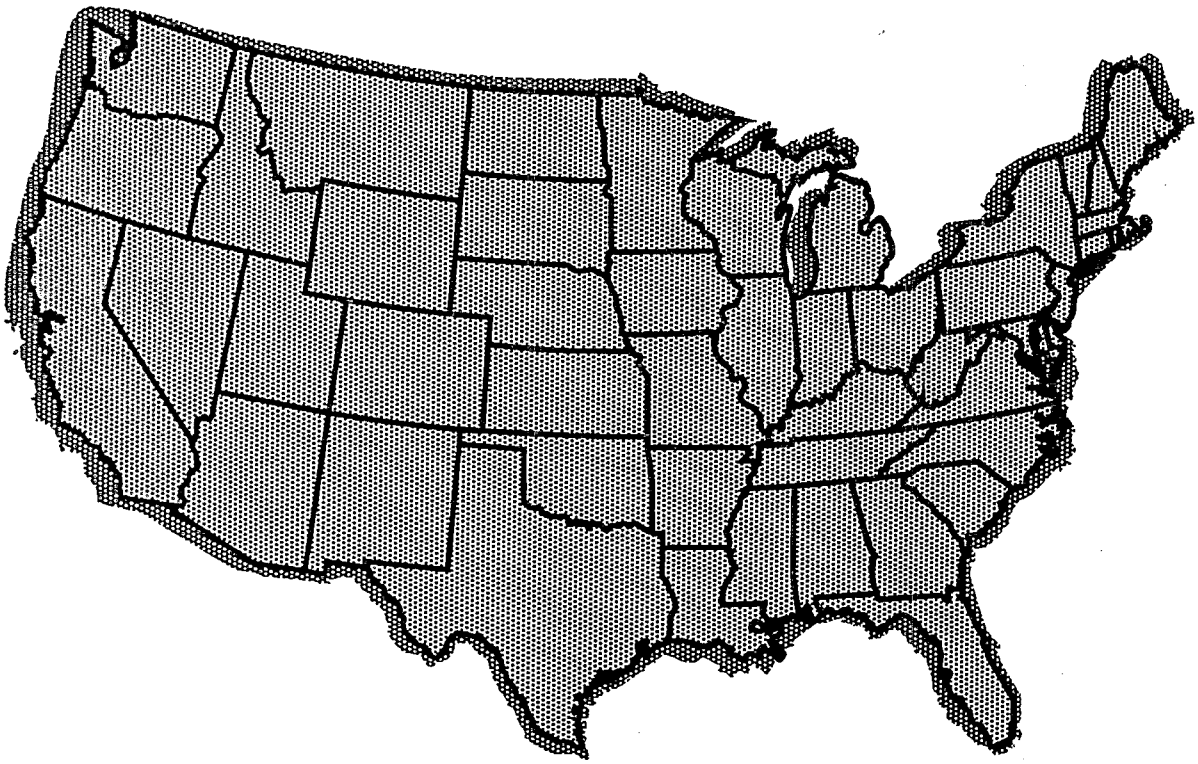

Figure 1-1. Baseline EMAP grid for the United States.

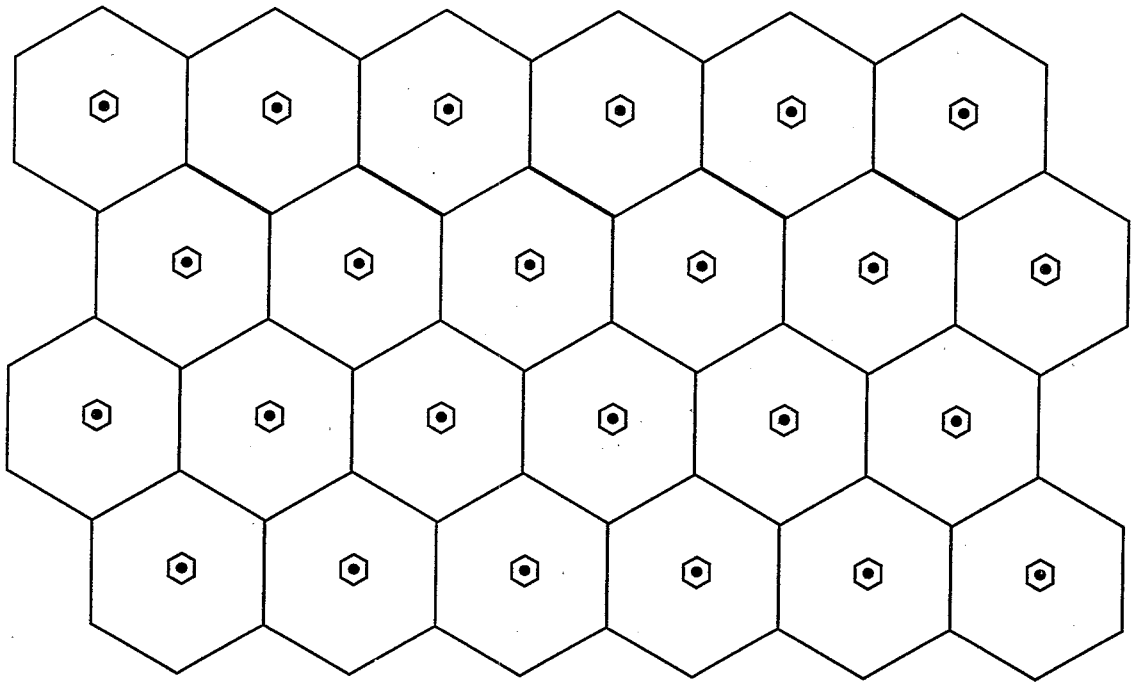

Figure 1-2. Large contiguous hexagons with an area of approximately 635 km^2 with 40 km^2 hexagons centered on each grid point.

The grid is a mechanism to generate probability samples even though the entire ecological resource is not explicitly delimited. That is, a valid probability sample of desert woodlands, for example, can be generated for indicator measurement without the need to identify all regions where they occur. The resource is framed by generating a probability-based point sample with the grid and in effect generating a population of resource indicator values for the resource via the point sample.

The probability sample of points can be located by several methods. They can be generated by a simple random sample of points on the surface, which may or may not provide a desirable spatial distribution of sample locations. The original EMAP method generated the sample of points by randomly placing the triangular grid over the geographic extent of a resource to provide a systematic random sample of points. The primary disadvantage of the randomly placed systematic grid of points is a deficiency in the estimation of variances for the indicator estimates (Overton and Stehman, 1993). A second alternative to generate a probability sample of points is known as a tessellation stratified design. A hexagonal tiling or tessellation around the triangular grid provides a means of artificially stratifying the surface of the resource. Instead of sampling at the center of the hexagon, a random point is picked independently in each hexagon. This option preserves the desired spatial dispersion of sample locations established by the systematic grid and provides a sufficient basis for the estimation of variances for the indicator estimates.

The design strategy based on the EMAP grid design uses samples of the ecological resources identified by the grid points to estimate their extent and condition. Researchers for the EMAP-Arid Ecosystems Resource Group (EMAP-Arid) are using a hierarchical two-stage sample structure for routine monitoring. The two stages of sampling allow for the incorporation of measurements with different cost requirements. For example, remote imagery and maps provide economical means to measure the extent and distribution of spatially distributed resources. On the other hand, field measurements required to estimate indicators of condition are relatively more expensive.

The first-stage sample, Stage 1, consists of prescribed areas around all points on the EMAP grid. These area samples can be measured for presence, extent, and distribution of the resources of interest through the use of maps and remote imagery. The methodology for Stage 1 samples identifies the location of all primary resource populations for which indicator estimates of condition are required. Thus, the Stage 1 sample provides the frame from which to select Stage 2 subsamples for resource condition. A sufficient sample size is determined for the resource of interest and the Stage 2 samples are then acquired at the selected points with sufficient spatial separation to cover the extent of the resource.

Field plots are established in a sample support area around each of the points selected for the Stage 2 sample of resource condition measurements. Variables such as temperature and rainfall can be measured as a point sample without significant area support, but measurements of vegetation and soil communities represented by the point sample require a certain amount of area support. The 1993 pilot activities for EMAP-Arid include field studies to develop a plot-based response design for Stage 2 samples in three kinds of arid extensive resources--desertscrub, grassland, and desert woodland.

1.1.2 Arid Resources

The arid ecosystem is characterized by specific climatic and vegetation regimes, and the EMAP-Arid researchers have chosen to use the Brown, Lowe, and Pase classification system (Brown et al., 1979) to describe the arid ecosystem at finer levels of landscape characterization (Figure 1-3). Classifications of primary interest to EMAP-Arid are the resource classes in the Brown, Lowe, and Pase system which are desertscrub, grassland, scrubland, woodland, tundra, riparian forest, riparian scrub, and strandland (Figure 1-4).

Ecological resources exist in several structural forms relative to the spatial regions in which they are found. They can exist as extensive resources over a continuous spatial region; as discrete entities; or as extensive elongated resources. The primary resources that must be sampled by EMAP-Arid researchers can be broadly identified as extensive resources. Extensive resources are generally not well identified as populations of individuals representing specific objects. Instead they occur over relatively large geographic areas and their spatial distribution can be fragmented and discontinuous over the regional landscape. The geographic continuity of the extensive arid resources is frequently interrupted by urban areas, areas of agricultural development, or other natural systems such as forests and thus these resources do not always have well-defined boundaries.

Desertscrub, grassland, scrubland, woodland, and tundra resource classes are extensive resources that exist over continuous spatial regions albeit sometimes fragmented over the region in a mosaic of formation types. For purposes of sampling, these resource classes can be characterized by the area they occupy in the arid regions. On the other hand riparian and strandland zones are elongated extensive resources that are best characterized by their length for purposes of sampling.

1.2 EMAP-ARID INDICATOR STRATEGY

The EMAP-Arid group will use a set of environmental indicators that can collectively describe the condition of an ecosystem (Hunsaker et al., 1990). Indicators "common" to the EMAP Terrestrial Resource Groups will be fostered by the EMAP-Arid group. The operating strategy is model based (Figure 1-5) identifying regional issues and assessment questions, linking them with societal values that have biological relevance, and identifying indicators that, when measured and integrated, can evaluate the status and trends in the condition of arid ecosystems. Issues that have been identified as regionally important in arid ecosystems (Kepner and Fox, 1991) are desertification, livestock grazing, biodiversity, water resource management, air quality, and global climatic change. Three societal values are currently identified as significant to arid ecosystems and have served to focus the conceptual development of the monitoring and research strategy for EMAP-Arid, especially relative to the selection and use of indicators. These values are:

> Biological integrity--species composition and structure (abundance and spatial arrangement) of biotic and abiotic elements and their associated functions (ecological processes) at various levels of biological organization (i.e., genetic, species, population, community, ecosystem, and landscape).

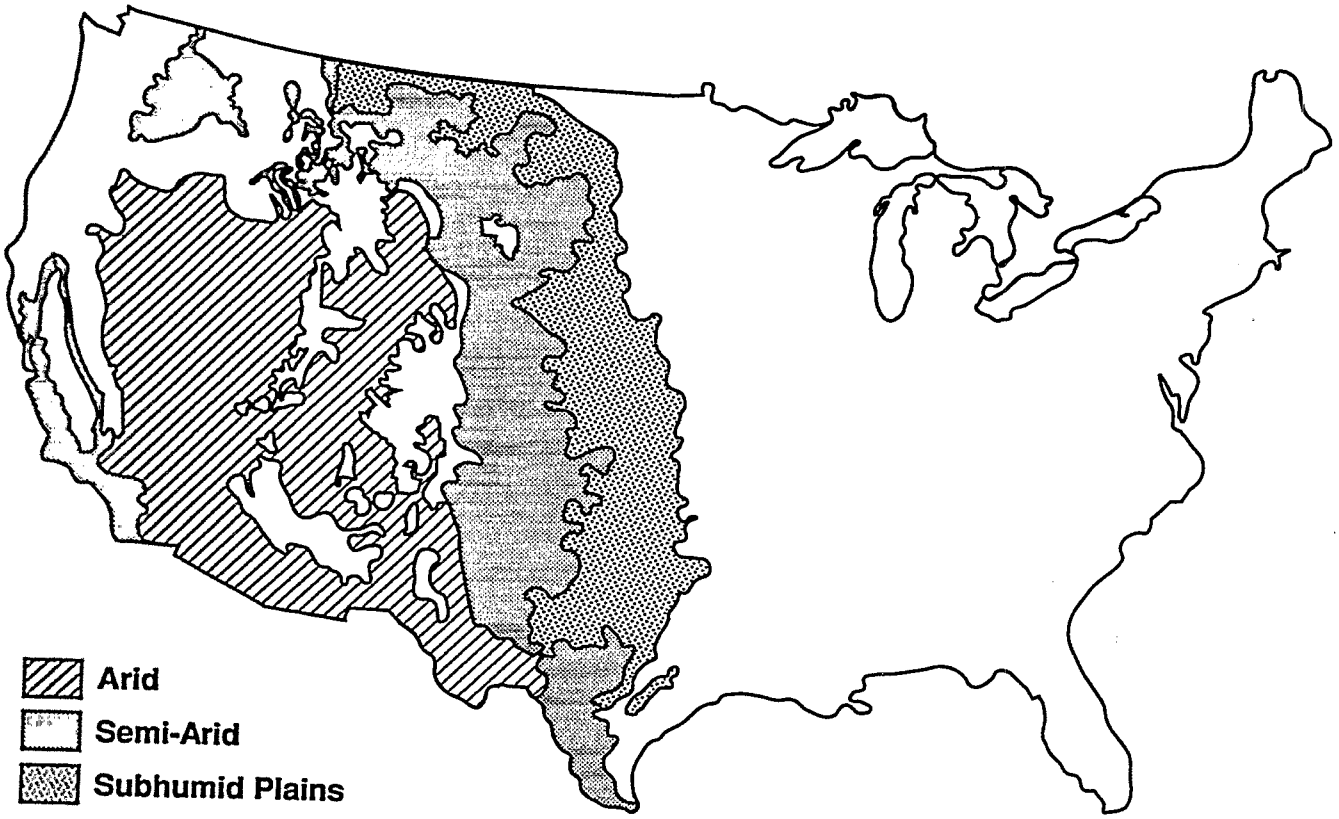

Figure 1-3. Aggregated arid ecoregions of the United States.

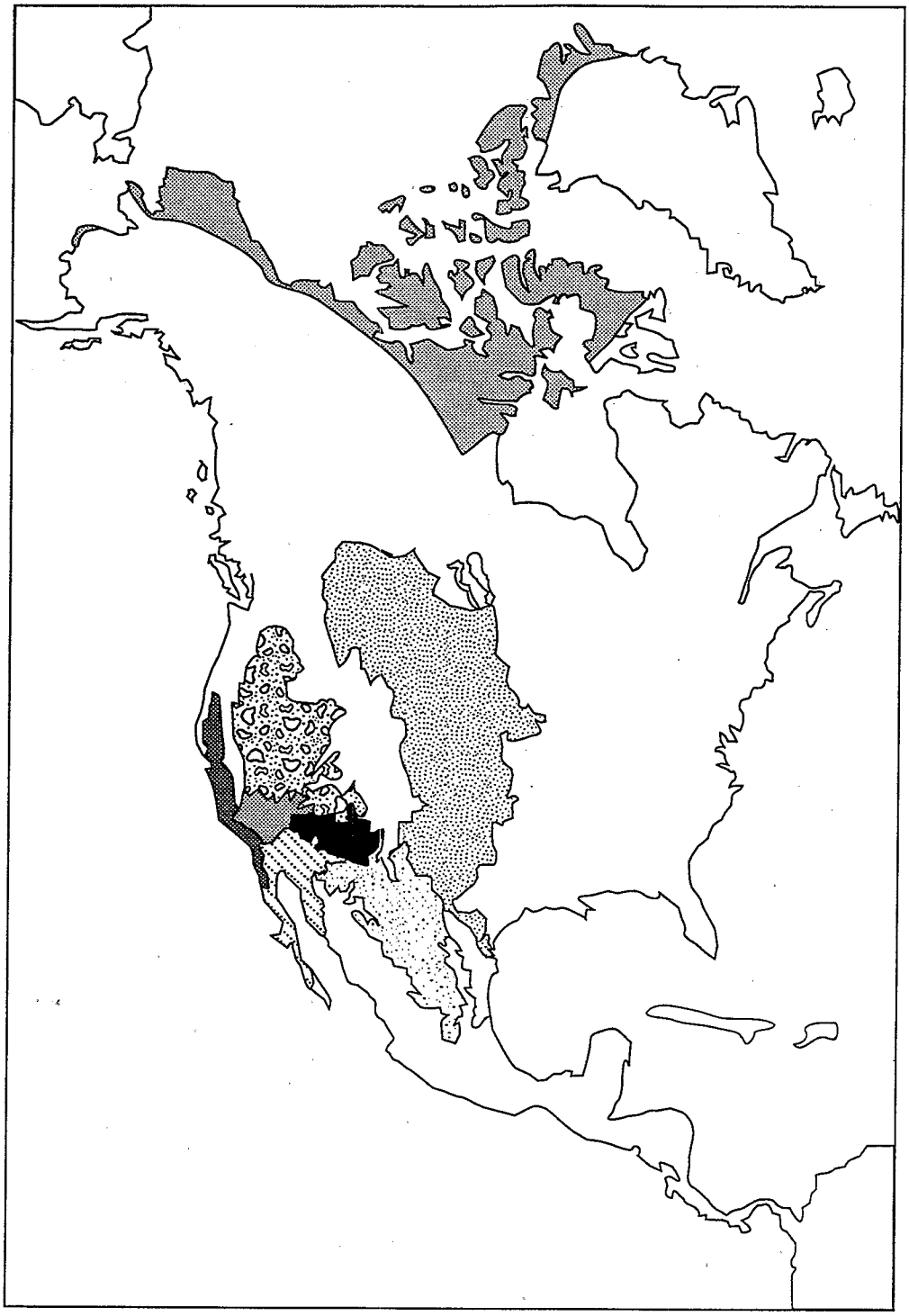

Figure 1-4. EMAP-Arid biogeographic provinces of North America.

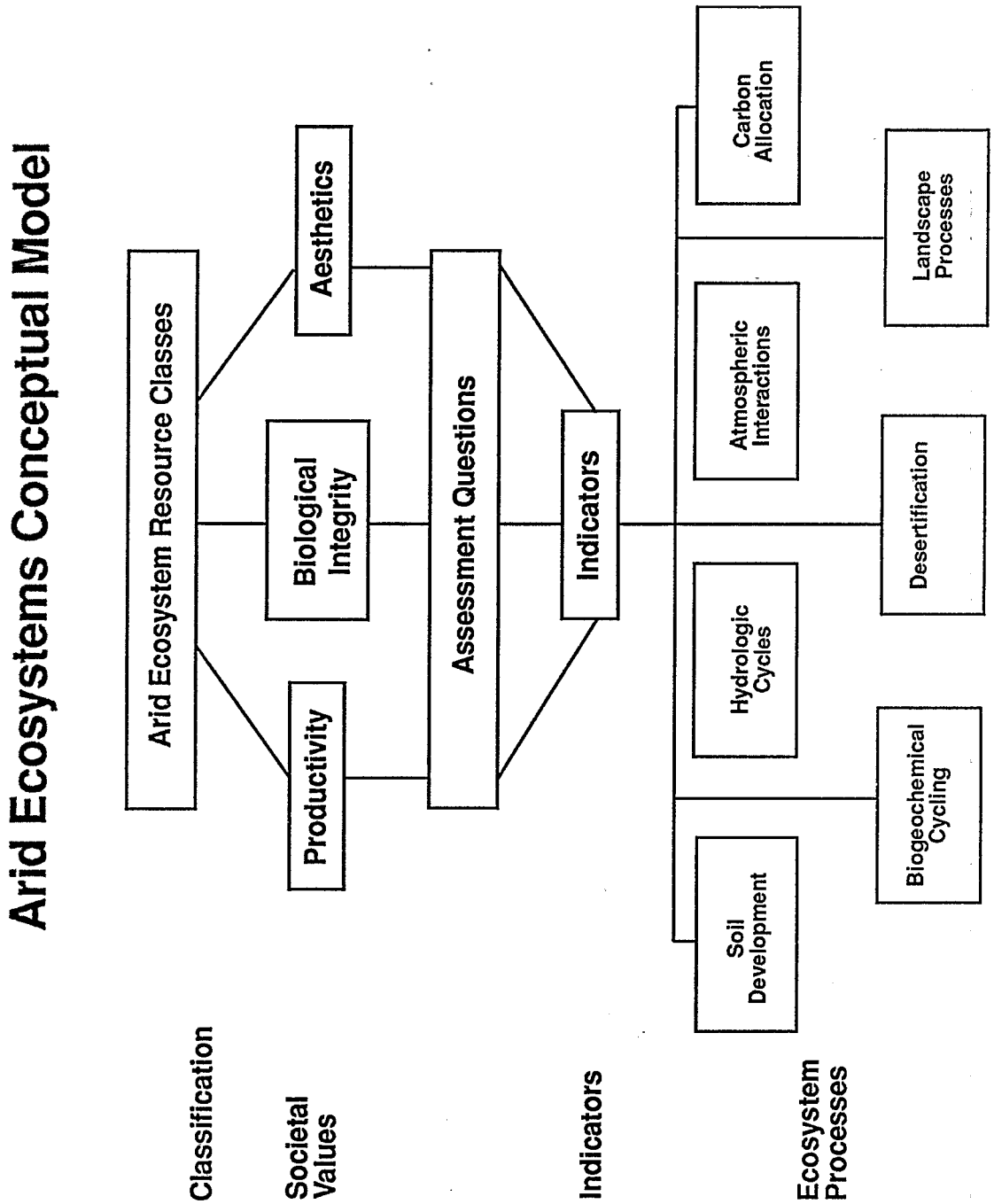

Figure 1-5. Arid Ecosystems conceptual model.

Aesthetics--broadly defined as attributes that affect human perception and appreciation of the environment.

Productivity--the quantity and quality of ecological and nonconsumptive services or products provided by arid resources and their capacity for long-term maintenance.

The EMAP-Arid group has elected to develop its first research indicators relative to productivity and biological integrity, significant social concerns relating to the critical issues of desertification and climate change in western North American landscapes. Multidecade changes in atmospheric composition, temperature, and precipitation patterns undoubtedly have influenced competitive relationships between rangeland plants. Thus dominant species may be able to maintain dominance relative to changing climate but, once displaced, may not retain a capability for reestablishment under less than suitable conditions. These changes lead to decreased diversity and usefulness--desertification. Desertification is considered a form of land degradation in arid, semiarid, and dry subhumid areas that results mainly from adverse human impact (UNEP, 1991) and can be exacerbated by xeric changes in climate. This degradation can result in loss of biotic potential, i.e., productivity and biodiversity, and inability of the system to recover after extended stress. Desertification is considered in the United Nations Environmental Programme (UNEP) to be one of the major environmental problems of our century operating on regional and global proportions. At present, desertification affects nearly 35 percent of the global land surface and almost one fifth of the world population (UNEP, 1991). More than 20 million hectares are reduced annually to near or complete uselessness, particularly in Africa, Asia, and South America and in western North America. Unfortunately, little primary data is available on desertification, especially in regard to estimates of severity or extent. In addition, there have been few regional or national scale studies to actually monitor and document desertification through repeated observations (Olsson, 1990). Therefore, our present level of knowledge impedes our ability to formulate policies for socioeconomic change to combat desertification and prescribe land rehabilitation development projects.

The framework for selecting and testing indicators follows a process outlined in Hunsaker and Carpenter (1990). Each EMAP resource group is expected to select and test a number of indicator measures in limited field tests or pilot exercises; and to investigate the capability to develop indicators that are effective across the various EMAP resource groups. These tests are intended to evaluate the ability of selected research indicators, both separately and in combination, to discriminate environmental condition and ultimately to determine which indicators are retained (i.e., moved to a higher indicator category), rejected, or held for further evaluation. When an indicator is retained, it is further tested on a regional scale via a demonstration project. A final set of core indicators will be selected for long-term implementation based on the results of regional demonstration projects and external peer review (Hunsaker and Carpenter, 1990). New or improved versions of indicators can be added to the core set following periodic reevaluation and testing of indicator performance.

Various measures, attributes, and indices are being evaluated as indicators related to specific indicator categories. Discussions of EMAP-Arid indicator categories and related measures are presented in Franson (1992) and in Kepner and Fox (1991). Conceptual models were used to link indicator categories to assessment questions (Breckenridge et al., 1993; Mouat et al., 1992). A decision analysis process (Kepner and Tregoe 1981) was used to document selection of

indicators for the 1992 pilot (Breckenridge et al., 1993). These indicators are being evaluated in more detail on a larger scale in 1993. Data from pilot studies will be used "...to develop specific EMAP-Arid indicators as well as those "common" indicators that can prove useful across the program's Terrestrial Resource Groups, where practicable."

1.3 SITE SELECTION

In selecting a regional focus for the 1992 pilot indicator study, EMAP-Arid researchers first looked at the availability of relevant existing data and monitoring sites to assess sites located in "data rich" areas. This step was taken to enhance the use of existing data for interpretation of indicators and to foster interagency collaboration.

The areas considered were identified by evaluating the sources of data relevant to indicator categories identified in the EMAP-Arid Strategic Plan (Kepner and Fox, 1991) against a list of criteria that considered data quantity (number of years), data quality, site and data access, cost, and multiple agency collaboration. The Colorado Plateau was selected for pilot activities in 1992 based on its ability to meet these criteria (Franson 1992).

To maintain continuity with the 1992 pilot activities, field activities in 1993 are continuing in the Colorado Plateau. The Colorado Plateau contains a number of vegetative communities, particularly within three predominant resource classes (i.e., desertscrub, woodland, and grassland), which have been chosen for the 1993 plot design study. The historical development, economic base, demography, geology, climate, and dominant plant communities of the Colorado Plateau are described in detail in Franson (1992).

1.4 1992 PILOT ACTIVITIES

Three indicator categories of arid ecosystem condition (spectral properties; vegetation composition and abundance; and soil properties) were tested during the summer of 1992 in the southeastern Utah portion of the Colorado Plateau. These indicator categories were selected through a number of workshops (Breckenridge et al., 1993) and peer reviews and appear to meet all the criteria, such as being applicable and interpretable on a regional scale, for indicator development as suggested by Hunsaker and Carpenter (1990). Thus, they are of high priority for EMAP-Arid evaluation. Although these indicator categories appear to demonstrate the highest potential or capability for diagnosing ecosystem change (i.e., the ability to be merged with other data sets to make integrated assessments of ecosystem condition at the regional level), they must first be further field tested for confirmation of regional diagnostic ability prior to their incorporation into long-term implementation.

The focus of the 1992 study was the development of three indicator categories with particular regard to (1) estimation of selected components of sampling variance, (2) use of remotely sensed information to select sample frame materials, and (3) operational aspects of indicator implementation such as field logistics, quality assurance procedures, and information management. The 1992 Colorado Plateau Pilot Study provided a significant first step towards regional and national implementation of EMAP-Arid. Additionally, the study results provide a further mechanism for coordination of indicator development and for evaluation with collaborators from participating agencies and the external scientific community, especially via the peer review process. A report summarizing 1992 pilot results is in preparation.

Although considerable progress was made on the development of the indicator categories, preliminary results from the 1992 Pilot Study indicate the need to more clearly determine the sampling support area required at a monitoring site and to conduct additional pilot studies to determine optimal sample plot design for each selected indicator category.

1.5 1993 ACTIVITIES

The 1993 activities will concentrate on the development of optimal field plot sampling designs for Stage 2 samples from which to obtain measurements for the three indicator categories evaluated in the 1992 Pilot Study. In addition, late in the planning process for 1993 activities, a small, preliminary investigation of the value of harvester ants as a possible new indicator in 1994 was combined with the 1993 field work. The optimum plot design should provide the maximum information per unit cost for the sampling support area, that area at the Stage 2 monitoring site that provides an adequate sample representation of an extensive EMAP-Arid subpopulation. The extensive EMAP-Arid subpopulations included in the 1993 study are the desertscrub, grassland, and woodland resource classes in the Colorado Plateau biogeographical region.

SECTION 2
STUDY OBJECTIVE AND APPROACH

The development of indicators of the condition of arid ecosystems depends on the quality of measurements that are required to quantify the indicators. Effective ecological interpretation of information gathered on monitored sites requires measurements which adequately describe the biological communities located at the monitoring site. To make these measurements consistent with the biology of the EMAP-Arid subpopulation requires a sample plot configuration, within a sampling support area, that is sufficient to capture the characteristics of the biological communities at the site.

A distinction must be made between the sample plot design as a focus of this pilot study and the sample survey design that will be used for the EMAP-Arid monitoring survey. The sample plot at a given location or site in the EMAP-Arid sample survey design will provide one observation on indicator measurements for the monitoring survey. Inferences on a regional or landscape basis will not be made on the basis of the observations on indicators at a particular site. Rather, those measurements at a site will be used as one observation of the indicator in the region or landscape. Only when that observation is included with the observations collected at all other sites within the landscape or region is the sample complete for inferences about the region. The survey will require sufficient numbers of sites during any one field session in any region of interest to provide good statistical estimates of the indicators from which to draw inferences about the condition of ecological resources over that region.

The plot design at a site may be considered a "response" design for indicator measurement at a monitoring site, whereas, the collection of sites with their individual observation of the indicator from the response design are part of the survey design for the region. The observations from the survey design are those used for regional and landscape interpretations.

This section discusses the study objective and approach to the 1993 EMAP-Arid pilot study to determine the sampling support area and optimum plot size for selected indicator measurements at a site.

2.1 RELEVANT STUDIES

Interpretation of ecological condition at EMAP-Arid monitoring sites requires an adequate representation of the vegetation and soils communities at a site. The ecological concept of minimal area (Dietvorst et al., 1982) is usually defined as the smallest area on which the species composition of a plant community is adequately represented. Two renderings of the minimum area concept have been described--the biological and methodological minimum areas.

A biological minimum area refers to the smallest area on which the species composition of a plant community is adequately represented or, equivalently, to the size of stand required to be well developed.

The methodological minimum area refers to the size of sample plots within a stand that is required to complete at least an adequate description of that stand (Barkman, 1989). The

methodological minimum area has been further divided into qualitative and quantitative parts. The qualitative area is that plot size above which the number of species does not increase at all or only insignificantly within the same stand (Barkman, 1989), whereas the quantitative area is distinguished as that "above which the quantitative shares of all species do not change significantly." For example, Barkman (1989) observed that the gain in information is less each time the sample plot area is doubled, particularly with respect to the cost of sampling. Thus, the EMAP-Arid team concluded that a pragmatic definition of methodological minimum area should be that plot size where further enlargement of plot size produces an insufficient gain in information relative to the added cost.

A number of criteria have been used by researchers to determine the minimum plot size and shape required to adequately describe an area. Species area curves, similarity analysis, frequency area curves, species representation, and pattern representation have had various applications. The Braun-Blanquet cover abundance scale (Bonham, 1989) is commonly used as a measurement to evaluate the minimum area. Historically, monotonic relationships have been observed between the size of a sampled area and the criteria used to identify the methodological minimum area such as species area curves and similarity measurements (Dietvorst et al., 1982; Barbour et al., 1980). Monotonic relationships between size of sampled areas and variances of measured variables have also been observed in a variety of settings including biomass of grasses and forbs (Wiegert, 1962), tree volume (Tardif, 1965), basal area (Bormann, 1953), agricultural experimental yield trials (Smith, 1938), surveys for plant disease incidence (Proctor, 1985), and agricultural acreage and yield sample surveys (Cochran, 1977).

Cochran (1977) presented a general monotonic variance law that has been used to describe the relationship between cluster size and variance in cluster sampling. The variance function in conjunction with a cost function can be used to develop optimum cluster sizes for sample surveys.

Smith (1938) developed an empirical law describing the relationship between the variability of yield measurements and the size of plots for agricultural crop experiments. This relationship provided the background for experiments to determine optimum size and shape of plots for crop yield trials when subject to cost constraints. The uniformity trial is a common method employed to estimate the variance of yield to plot size relationship (Kuehl and Kittock, 1969). The uniformity trial consists of harvesting an area as a number of small plots. Upon combining data for adjacent units, the yields of plots of different sizes and shapes can be determined. The relationship between the variance in yield measurements and plot size can be estimated from these data. This relationship has been evaluated primarily for biomass production in natural systems. The relationship proposed by Smith (1938) has been observed in communities of grasses and forbs (Wiegert, 1962) and fir-birch forest stands (Tardif, 1965). Also, Proctor (1985) found the Smith variance law to be adequate for cluster sampling in crop disease surveys.

Modjeska and Rawlings (1983) presented a spatial correlation analysis of uniformity data as an adjunct to the conventional analysis based on the Smith model. Their analyses of several sets of agricultural uniformity data demonstrated that Smith's model did not adequately describe the behavior of spatial correlation but did in some cases describe the behavior of variances.

Another method to determine optimum plot size is based on a tangent to the species area curve. This method has been used for plant frequency data in sagebrush-bunchgrass communities

(Hyder et al., 1963). Optimum plot sizes for forestry studies have also been determined on the basis of sample size requirements for specific degrees of precision for confidence interval estimation with cost constraints (Bormann, 1953; O'Regan and Arvanitis, 1966).

The measurement of variables for indicators on EMAP-Arid monitoring sites is intended to reflect the status of plant and soil communities present in the sampled resource community. Thus, it is important that the sampling support area is of a sufficient size to adequately characterize those indicator variables for the plant and soil communities under consideration. The approach to determining the EMAP-Arid indicator sampling support area and plot design will be based to some extent on the research discussed above.

The literature previously cited on plot size has been concerned primarily with vegetation communities. In addition, plot size in natural systems most often refers to quadrants for which the entire quadrat area is censured for vegetation community characteristics such as species abundance or composition and biomass. The agricultural studies have concentrated on plot size studies for biomass, grain, or fruit yield in comparative experimental trials.

The uniformity sampling trial is a common method that is used to provide data for several types of studies related to sampling area. Uniformity trials for agricultural crops use harvest data from a field planted to a single cultivar divided into small contiguous areas known as basic units. These data are used to find optimum plot sizes from among various aggregations of the basic units.

Contiguous rows of quadrants are used in ecological studies to evaluate the occurrence of contagious patterns. Increasing quadrat sizes are built up by blocking adjacent quadrants in pairs, fours, eights, and so forth. The variances of different block sizes are related to block size in a graph and different scales are detected as peaks in the graph. This method has been suggested by Grieg-Smith (1952).

Contiguous quadrants are measured over a designated area in ecological studies to determine biological minimum areas (Barkman, 1989). The contiguous quadrants are combined into larger quadrants of different sizes, much like that done for contagion pattern studies. Various measures are calculated from the nested sets of quadrants to ascertain biological and methodological minimum areas.

A version of the uniformity sampling trail will be used by EMAP-Arid to develop a field plot sampling design for future monitoring sites.

The EMAP-Arid survey requirements for sampling plots will differ from these other studies in several facets. The sampling plots will have to serve as monitoring sites for a multiplicity of measurements with the potential for repeated visits to the site over decades. Complete census of the plots may be neither feasible nor desirable under these circumstances. They must be set up with minimal disturbance to the measurement areas. The number of plots or replicate samples at the site for monitoring purposes will be the number required for specified confidence estimates in the survey. Thus, questions of replication blocking with different treatments on the plots within blocks as in experimental trials are not relevant to the survey.

Finally, the EMAP-Arid program is concerned not only with vegetation but also with soils and spectral measurements for indicator attributes. Thus, EMAP-Arid must construct a sample plot design that integrates the sampling support area and optimum plot size required for all types of measurement.

2.2 OBJECTIVE AND RESEARCH QUESTIONS

The objective of the 1993 EMAP-Arid pilot study is to determine the sampling support area and optimum plot size for selected indicator measurements. The determinations will be made for selected measurements of indicator attributes for vegetation, soils, and spectral properties in desertscrub, woodland, and grassland formations of the Colorado Plateau biogeographical region.

RESEARCH QUESTIONS:

1. What is the relationship between indicator measurement properties and the size and shape of plot for selected vegetation, soils, and spectral indicator measures?

   Past research has shown, in general, relationships between the size of measurement areas and certain measured properties of natural populations. Investigations of this question can address (1) the relationship of sampling support area to qualitative properties of plant communities in terms of various measures of plant species abundance and composition for minimal area determinations; (2) the relationship between measurement plot sizes and variances for quantitative measures in the vegetation, soils, and spectral indicator categories; and (3) the spatial covariances and correlations for the same quantitative measures.

   The relationships can provide the capacity to evaluate the sizes of sampling support areas, or minimal areas, beyond which the amount of information about the plant and soil communities does not increase at the monitoring site with increased sampling area. They also can provide information toward the determination of measurement plot sizes for quantitative measures beyond which the amount of information on the measure is not increased with a greater measurement area. Spatial correlations provide information on the degree of spatial separation that will produce independent samples for the indicator measures.

2. What are the costs associated with setting up and sampling basic units for measuring the selected vegetation, soils, and spectral indicator categories?

   Cost evaluations as well as variability evaluations are necessary components to develop adequate sampling plans in a monitoring survey. The costs to be evaluated include those for the setup, sampling, and analysis of data from basic measurement units for the selected vegetation, soils, and spectral measurements. These costs in conjunction with variances associated with the measurements can be used to evaluate cost- and time-effective, and statistically efficient, plot sizes for an indicator measurement at a monitoring site.

3. What are the sizes and shapes of plots that maximize the amount of information per unit cost for the selected vegetation, soils, and spectral indicator measures?

Information from the preceding two questions on relationships between variability and plot sizes and costs of sampling plots can be used to determine optimal plot sizes. Although a mathematical optimum can be achieved with variance and cost estimates, other factors invariably must enter into the consideration of a viable plot size. Given the variety of plot sizes and shapes that can be devised, the logistics of on-site plot setup and sampling as well as constraints on total cost at a monitoring site must enter into the ultimate decision.

4. What are the effects of spatial correlation patterns, if they exist, on the choice of plot size and shape?

   If spatial correlations exist for the quantitative measures, then consideration should be given to the spatial distance between measurement units. Greater increase in information is achieved with independent replicate samples than with samples that have highly correlated measurements. The spatial correlation estimates can provide information on the spatial distance required to have a greater degree of independence between replicate samples at a sampling site.

5. How similar are the variances and correlation patterns across EMAP-Arid sub-population formation types?

   EMAP-Arid subpopulations are important components for interpretation of condition in the arid resource population. Each of the subpopulations must be sampled to achieve statistical estimates with known confidence. Differing variance and correlation patterns can affect the samples sizes and spacings required at a monitoring site. It is incumbent on EMAP-Arid to evaluate whether these patterns are consistent among the several important subpopulations for purposes of planning sampling strategy in the monitoring program.

2.3 DEFINITIONS AND DESCRIPTIONS OF TERMS

The following definitions and descriptions of terms used in this plan are presented here to assist in providing understanding and clarity.

· site	the location for data collection in this pilot study.
· sampling support area	the area that captures the local scale of variation for the selected indicator measurements and provides the maximum information per unit cost.
· macroplot	the total sampling area at the site subjectively determined to be larger than the sampling support area. The macroplot sampling areas for the three indicators are:

- soils	180 m by 180 m
- spectral properties	120 m by 120 m
- vegetation	120 m by 120 m

The 120-m by 120-m macroplot is centered within the 180-m by 180-m macroplot.

- basic unit — an area of the macroplot used to measure specific variables, attributes, or properties. The basic unit areas used in this study for each of the indicator measurements are:
  - vegetation and spectral properties — 10 m by 10 m
  - soil samples — 30 m by 30 m
  - soil samples (intensive) — 10 m by 10 m

- plot — any regular array of basic units

- quadrat — a smaller sampling area within the basic unit used to measure high-density populations (e.g., grasses and forbs). All measurements taken within the quadrat are index samples representative of the basic unit area and thus represent the basic unit. The quadrat areas used in this study are as follows:
  - trees — 5 m by 5 m
  - shrubs — 1 m by 2 m
  - grasses and forbs and spectral properties — 0.5 m by 0.5 m

- unit — an area on the macroplot measuring 10 m by 10 m which is equivalent to the vegetation and spectral properties basic units. A 324-alphanumeric array of these units is used as a simple information management scheme for locating sampling sites and identifying samples for analysis.

2.4 APPROACH

The field sampling areas required for this study will be coordinated and integrated by the three indicator groups. Large macroplots estimated to be larger than the indicator sampling support area will be established at each site and intensively sampled. Each macroplot will be selected so that it is in a single landscape unit. These macroplots will be established in three biomes (in parallel EMAP terms, these are research types)--desertscrub, woodland, and grassland.

The macroplots will be the basis for a uniformity sampling trial at each site. Plots of varying configurations can be crafted from the uniformity sampling trial on the macroplot to evaluate their qualitative and quantitative properties.

A schematic diagram of a macroplot is shown in Figure 2-1. Each macroplot is subdivided into a rectangular array of basic sampling units. See Section 3 for detailed descriptions and definitions for the macroplot design. The size of basic units is such that a sample measurement can be made for each of the selected measurements in the three indicator categories in each of the biomes.

The area within a basic unit required for a particular measurement will vary with the type of indicator category measurement (Figure 2-1). The measurement areas may be small quadrants for vegetation cover measures, a soil sample, or spectral reading area. The measurement taken in these areas will be sufficient to represent the characteristics of the basic unit.

The arrangement of measurement areas, relative to one another within the basic units, will be set up to accommodate sampling logistics that are anticipated at a monitoring site for future surveys. All measurements for each of the indicator categories included in the study will be made on each of the basic units. Sampling support areas and plot sizes of different sizes and shapes can be constructed by combining groups of basic units. Some examples shown in Figure 2-2 include sizes of 1, 4, 9, and 16 units that can be constructed from regular arrays of units. Many other shapes, sizes, and spatial separations of basic units in a plot can be constructed for the analysis. Those sizes and shapes thought feasible, based on professional experience of the indicator groups, will be used for the analysis.

Properties of indicator measures, such as variances, relative to plot sizes will be determined for the arrangements of measurement areas. Spatial correlation patterns among the units at different spatial distances can also be estimated from measurements made on the basic units.

The goal is to have a cost-efficient sampling strategy that is sufficient to provide an adequate description of the vegetation and soils community at the site. The relationship between properties of indicator parameters and the plot size and shape will be established and estimated for all measurements most critical to the quantifiable indicators identified for EMAP-Arid monitoring. A final plot design operationally feasible for indicator measurement purposes in a future EMAP-Arid demonstration survey will be determined from data collected in 1993 on these large macroplots.

Five combinations of biome and productivity have been selected for study. Productivity is defined for this effort as the potential mean annual vascular vegetation biomass as described in existing ecological (range) site descriptions (USDA 1976, USDI 1990). Within a biogeographic province, vegetation community physiognomy and cover characteristics may differ significantly between naturally low production sites and high production sites. However, physiognomy and cover characteristics are expected to exhibit greater similarity between communities with similar production potential when subjected to similar environmental and anthropogenic stresses.

Arid environments produce natural communities that range from a mean annual productivity of less than 178 kg/ha to over 890 kg/ha because of the natural variance in the interrelationships between soil, climate, and vegetation community. Ecological site correlation procedures developed by the Bureau of Land Management (BLM) (Leonard et al., 1992) suggest that there are natural breaks at various productivity levels.

Groupings of sites less than 445 kg/ha, 445 to 890 kg/ha, and greater than 890 kg/ha are used for EMAP-Arid comparison. Other criteria such as dominant species and community composition that relate to biome characteristics at the larger scale considered by EMAP are also described.

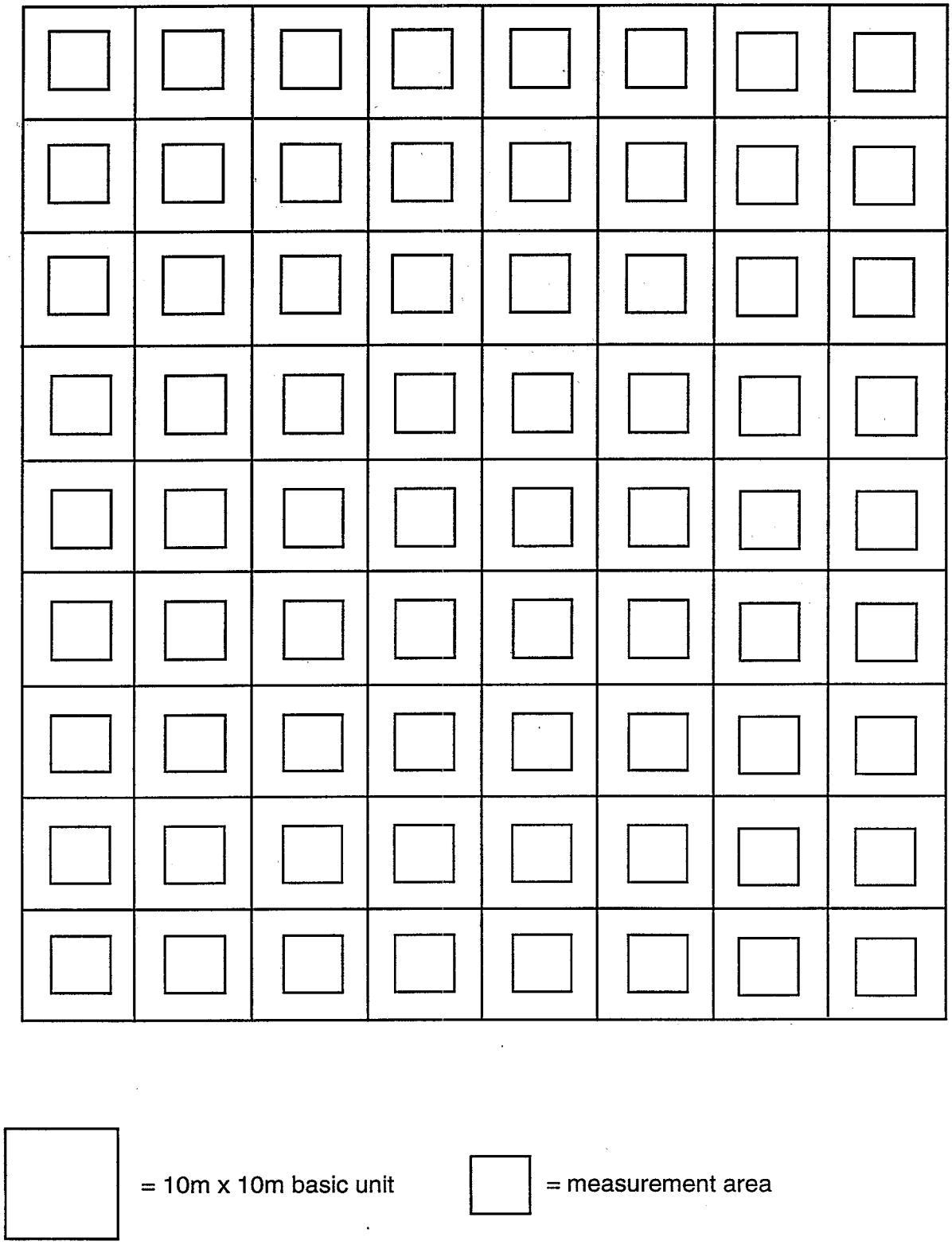

Figure 2-1. Schematic diagram of a macroplot.

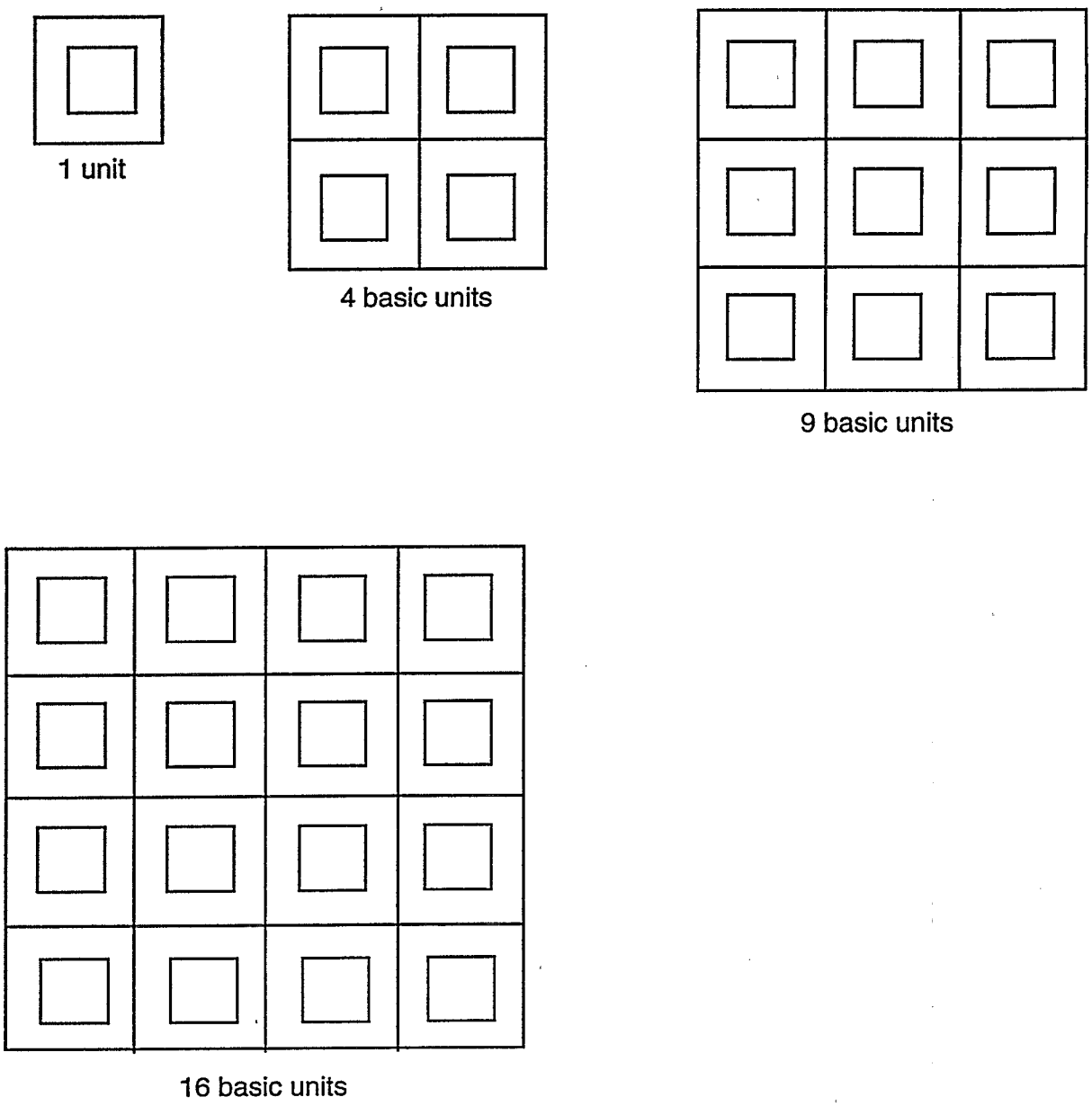

Figure 2-2. Examples of plot sizes of 1, 4, 9, and 16 units constructed from regular arrays of basic units.

Study sites for 1993 were selected to represent readily observable differences in biome and productivity combinations; however, every possible combination is not represented because of time and cost constraints. The desert scrub biome is the most extensive biome in the Great Basin biogeographic region. Low-, medium-, and (medium) high-producing sites were selected to represent this major biome. A medium producing grassland and high-producing pinyon-juniper site were also selected. Low-producing grassland and pinyon-juniper sites are rare in the Great Basin biogeographic province.

The size of the macroplot for the 1993 plot study was selected to be more than large enough to provide an adequate sample to characterize the local scale of variation at the site. Literature and professional judgement were used to select the macroplots for soils, vegetation, and spectral indicators. The final macroplot size was adjusted to maximize integration of data between the indicator groups and to ensure that all data could be collected within 1 week. A week is scheduled to sample each of the five different sites within a period that could be supported with existing funding and personnel resources.

The overall size of the soil macroplot was selected to be 180 m by 180 m to allow adequate soil samples to characterize variability. Previous research (Campbell, 1978; Warrick et al., 1986; Wilding and Drees, 1983) suggest a spacing of 30 m would result in spatially independent samples; thus, 36 basic units (30 m by 30 m) are within the 180-m by 180-m macroplot. Thirty-six additional 10-m by 10-m basic units are nested within the 180-m by 180-m macroplot to have spatially dependent basic units in order to measure spatial correlations.

Soil properties have different orders of variation and spatial correlation. In order to measure the variation and spatial correlation, observations and samples are taken at different densities. The 10-m spacing was chosen to estimate the spatial correlation of surface properties which are more variable at a small scale and have higher coefficients of variation. These properties are organic carbon, total nitrogen, and hydraulic conductivity (Mausbach et al., 1980; Wilding and Drees, 1983). Properties which are variable at a larger scale and have coefficients of variation from 15 to 30 percent are sampled at 30-m intervals. These properties are the texture and structure of the A horizon. Properties which are less variable and have coefficients of variation of less than 15 percent, such as the soil color and thickness of the A horizon and soil classification, are sampled at 60-m intervals.

The macroplot for vegetation and spectral properties is 120 m by 120 m and is centered within the soil macroplot. Harvester ant colonies will also be measured within this 120-m by 120-m area. This area is large enough to provide adequate representation of the spectral signature from different remote platforms (i.e., Thematic Mapper (TM) versus Advanced Very High Resolution Radiometer (AVHRR); see Section 4.3). The macroplot size for each indicator group was selected to provide enough replication to supply adequate degrees of freedom to statistically evaluate the spatial variability of the resources across the site. A detailed description of the macroplots is provided in the following section.

SECTION 3
MACROPLOT DESIGN

Ecological interpretation of information gathered on monitoring sites requires plot configurations that provide sufficient areal support to capture the characteristics of the biological communities. Plot size variance and configuration relationships along with cost of data collection in terms of available resources, e.g., time and money will be used for optimal plot design evaluations. Optimal plot design will be determined empirically for all important indicator measurements via uniformity sampling trials with nested plot designs on three EMAP-Arid formation types or biomes, i.e., desertscrub, grassland, and conifer woodland (pinyon-juniper). This study needs to precede or coincide with indicator development before undertaking projects at the survey demonstration level.

3.1 PLOT SIZE

For the 1993 plot design pilot study, five macroplots will be established near Moab, Utah. Each macroplot will be laid out on an 18 by 18 grid of 10-m units, resulting in a macroplot measuring 180 m by 180 m with a 120-m by 120-m macroplot centered within the 180-m by 180-m macroplot (Figure 3-1). The field crew will use a stepwise single protocol that integrates all three indicators to establish the macroplot. Details of macroplot sampling procedures are found in the 1993 Field Operations and Training Manual (O'Leary and Byers, 1993). An alphanumerical numbering system identifies sampling location points on the macroplot, the samples taken for analysis or identification, and the macroplot basic units. Each "unit" (the basic unit measuring 10 m by 10 m) on all rows and columns will be identified with a letter and number as shown in figures 3-1 and 3-2. For example, the first unit on the northwest corner of the 180-m by 180-m macroplot (the soils sampling area) has an identification of 1A; the first unit to be measured in the spectral and vegetation sampling area is identified as 4D. This process results in 324 possible identifications for locations ranging from 1A to 18R. According to convention the northwest corner is the starting point for the macroplot identification system.

3.2 VEGETATION SAMPLING AREA

The macroplot sampling design for vegetation is an area measuring 120 m by 120 m (figures 3-2 and 3-3). There are 144 basic units measuring 10 m by 10 m within this sampling area. Since the design calls for one 5-m by 5-m quadrat within each 10-m by 10-m basic unit, each of these quadrats will be located so that their centers coincide with the centers of the 144 basic units. Therefore, the positioning of each 5-m by 5-m quadrat is 2.5 m in from the outer edges of each 10-m by 10-m basic unit, and the centers of all the 5-m by 5-m quadrats are 10 meters apart (Figure 3-2). This design of 144 basic units within the macroplot allows for 144 quadrats (5 m by 5 m) within the vegetation sampling area. Vegetation measurements for stem diameters, crown diameters, and height of large trees and the counting of small trees of height greater that 1.5 m will be conducted inside the 5-m by 5-m quadrats.

Counts of small trees (less than 1.5 m in height), small tree cover, and shrub cover will be measured on the 1-m by 2-m quadrat, two of which are located within each of the 5-m by 5-m quadrat described above. This design results in a total of 288 (144 pairs of 1-m by 2-m quadrats) of each of these measurements (figures 3-2 and 3-3) within the vegetation macroplot sampling area.

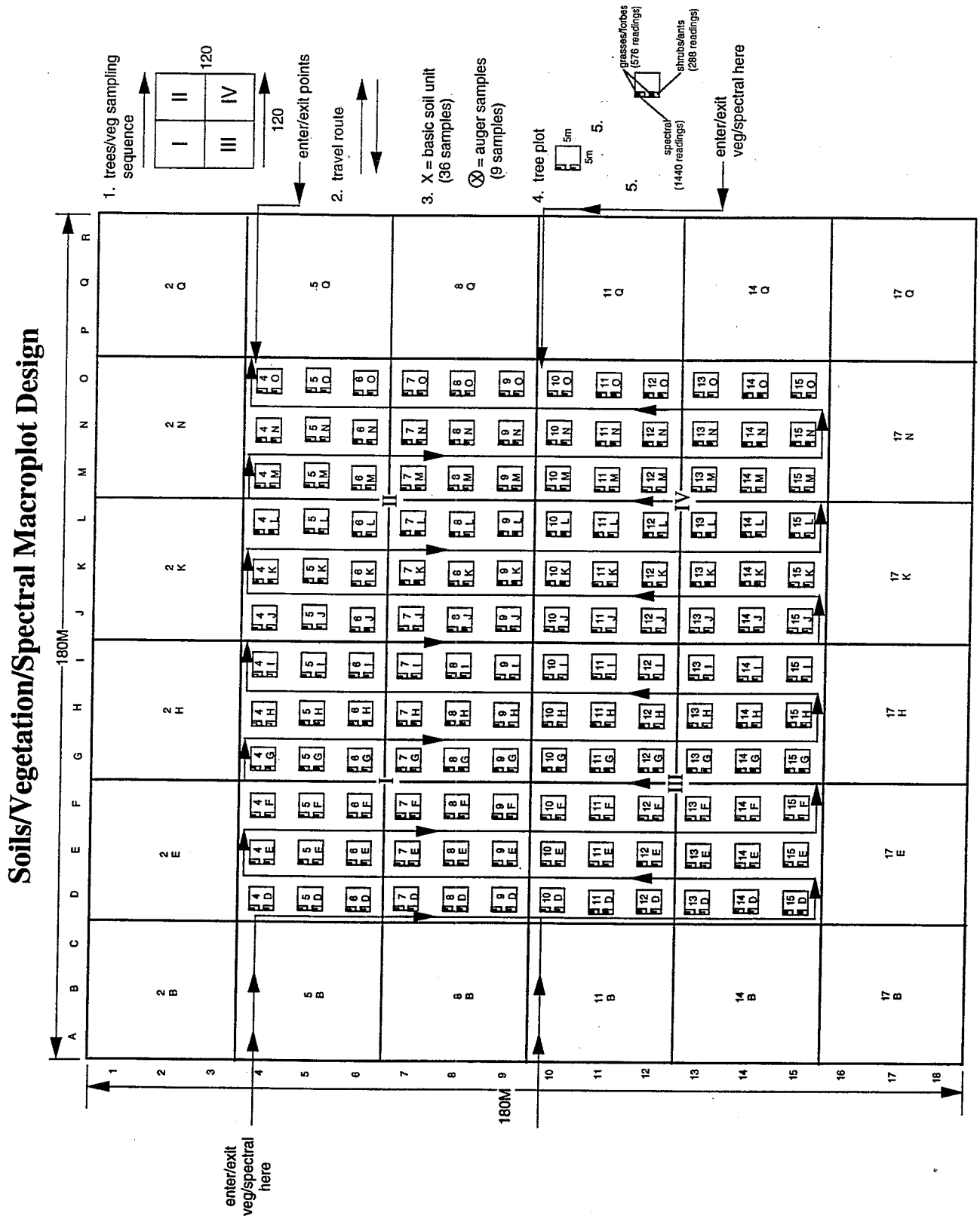

Figure 3-1. Macroplot Design for soils, vegetation, and spectral properties indicators.

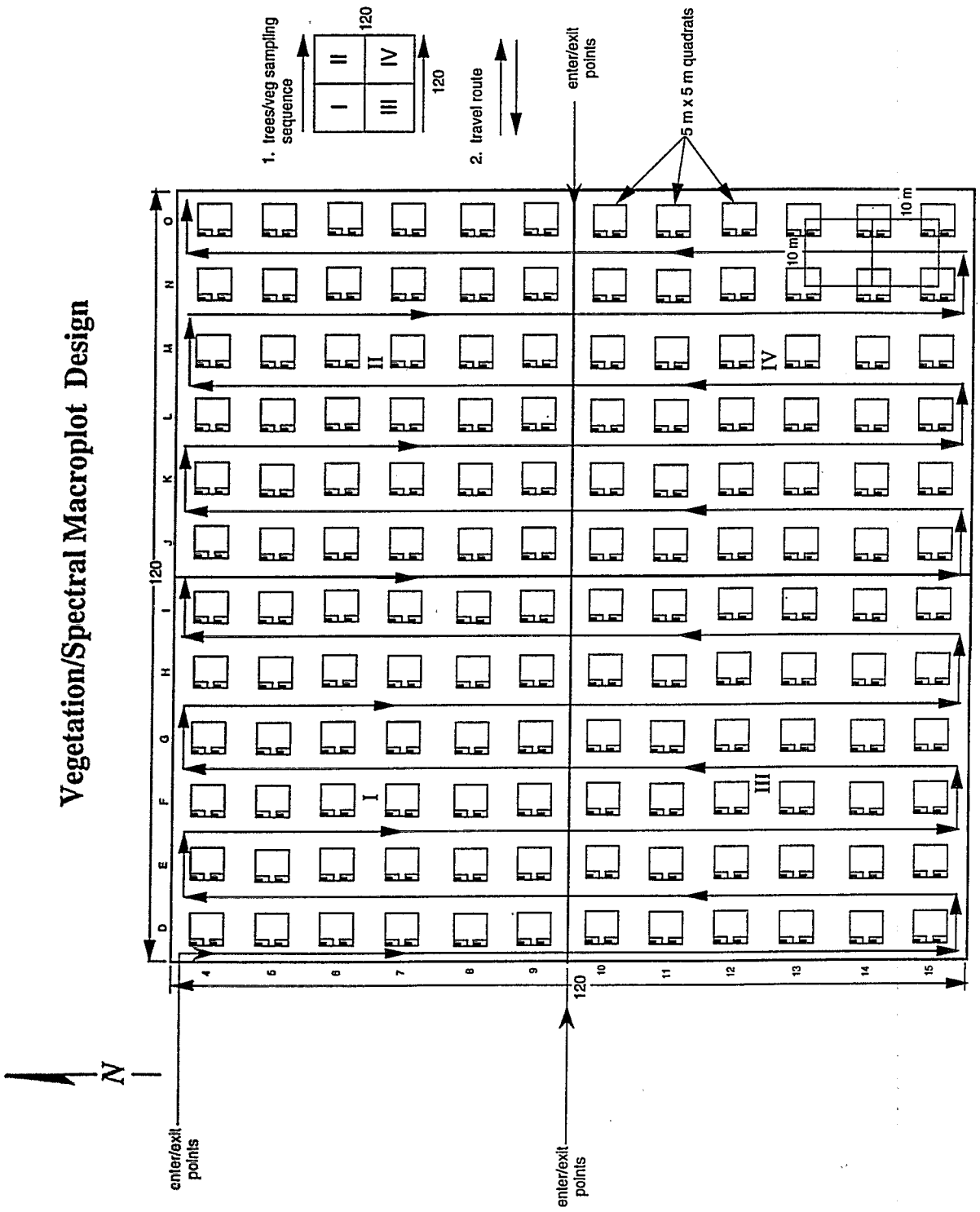

Figure 3-2. Vegetation and spectral properties macroplot design.

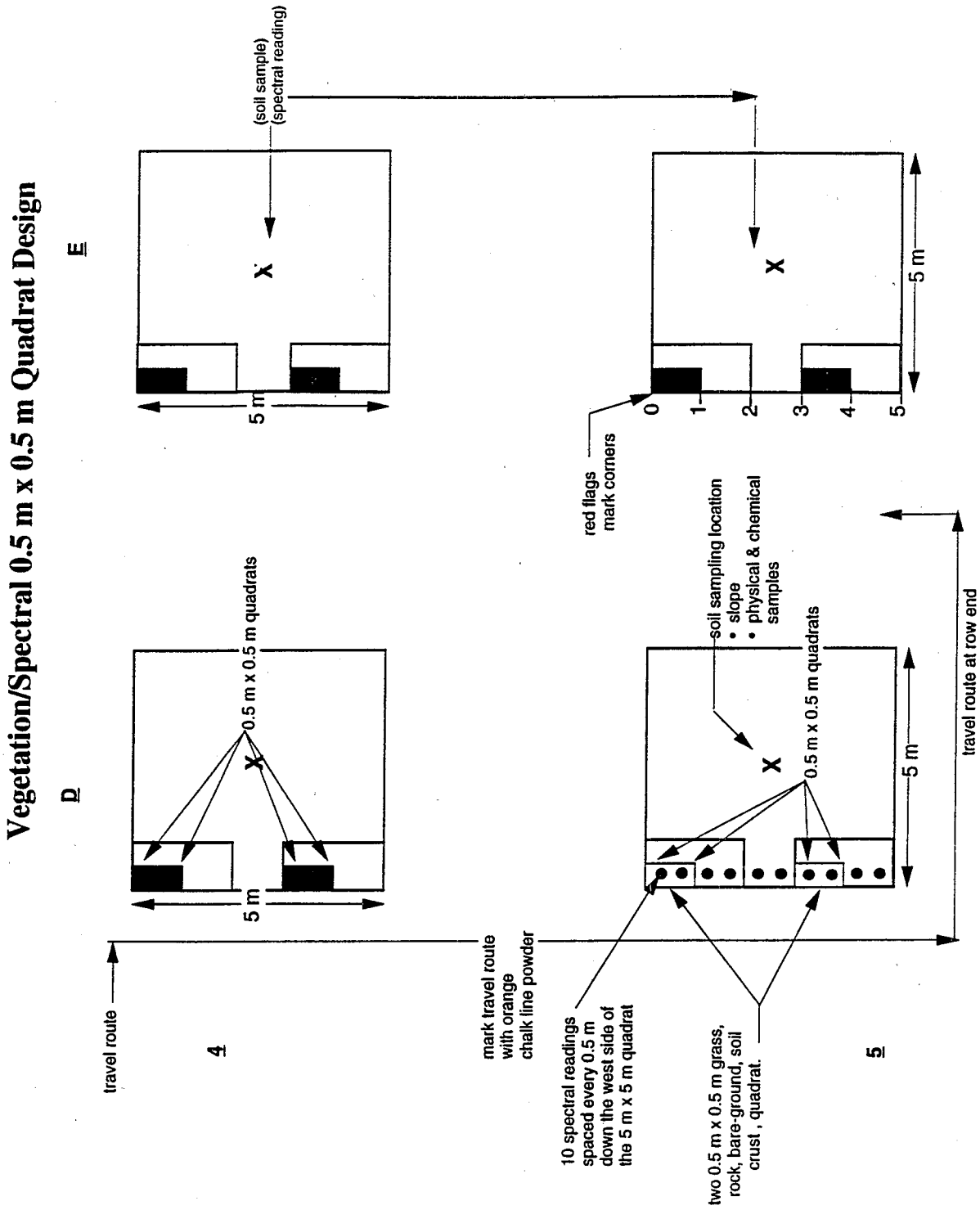

Figure 3-3. Quadrat design (0.5 m by 0.5 m) for vegetation and spectral properties indicators.

Measurements of total vascular plant cover, litter, rock, bare soil, and cryptogams will be made on two 0.5-m by 0.5-m quadrats located side by side within each 1-m by 2-m quadrat. This design results in a total of 576 (144 quadruples of 0.5-m by 0.5-m quadrats) of each of these measurements within the vegetation sampling area (figures 3-2 and 3-3).

3.3 HARVESTER ANT SAMPLING AREA

The macroplot design for harvester ants (*Pogonomyrmex* species) is the same area as for vegetation, i.e., the 120-m by 120-m sampling area (figures 3-2 and 3-3). A census of visible ant nests within each 5-m by 5-m quadrat will be tallied and compared with vegetative information. Specimens will be collected from each colony and preserved in alcohol for identification against appropriate keys.

3.4 SPECTRAL PROPERTIES SAMPLING AREA

The macroplot design for the spectral properties is also within the 120-m by 120-m sampling area (figures 3-2 and 3-3). A spectral reading will be taken every 0.5 m along the west side of the 5-m by 5-m quadrat unit (a total of 10 spectral readings). Each single spectral readout on the instrument represents an integration of 10 internal measurements taken by the instrument during its measurement period. This design results in a total of 1,440 spectral measurements taken from the 5-m by 5-m quadrats. Thirty-six additional spectral readings will be taken from the center of each 10-m by 10-m intensive soil sample basic unit, described in the following section, resulting in a total of 1,476 spectral readings taken on the macroplot.

3.5 SOILS

The macroplot design for surface soil measurements is an area measuring 180 m by 180 m. This area is overlaid on top of the 120-m by 120-m spectral and vegetation sampling areas with centers coinciding (figures 3-4 and 3-5). Within this larger macroplot sampling area, there are 36 basic units each measuring 30 m by 30 m on a 6 by 6 grid (figures 3-1 and 3-4). A surface soil sample and attendant surface measurements will be collected at the center point of each of the 30-m by 30-m basic units, i.e., 36 samples.

Within one portion of the macroplot, intensive surface soil sampling will be carried out on 10-m by 10-m basic units on a 6 by 6 grid (i.e., a 60-m by 60-m area). For comparison purposes, this intensive grid is located on the northwest quadrant of the 120-m by 120-m spectral and vegetation macroplot sampling area (Figure 3-5). This intensive grid results in 36 surface soil samples (including the four surface soil samples) taken on the 30-m by 30-m basic units. Thus a total of 68 soil surface samples will be collected for analytical purposes.

A total of nine deep observation pits will be dug (with spade or auger) to a depth of 150 cm (as necessary) or to bedrock to evaluate characteristics of the soil profile and determine soil classification. These nine pits fall within nine of the 60-m by 60-m areas within the soil macroplot. These 60-m by 60-m areas are not basic units and are examined to provide a general characterization of the macroplot. This design results in four soil pits within the 120-m by 120-m macroplot sampling area coinciding with four of the surface soil collection points described above. In these cases, the soil surface sample will be taken from the top surface of the pit sample. The remaining five pits will be dug at the center of the 60-m by 60-m areas outside the 120-m by 120-m macroplot sampling area (but within the 180-m by 180-m macroplot sampling area). In at least one of the pits a detailed soil description will be made.

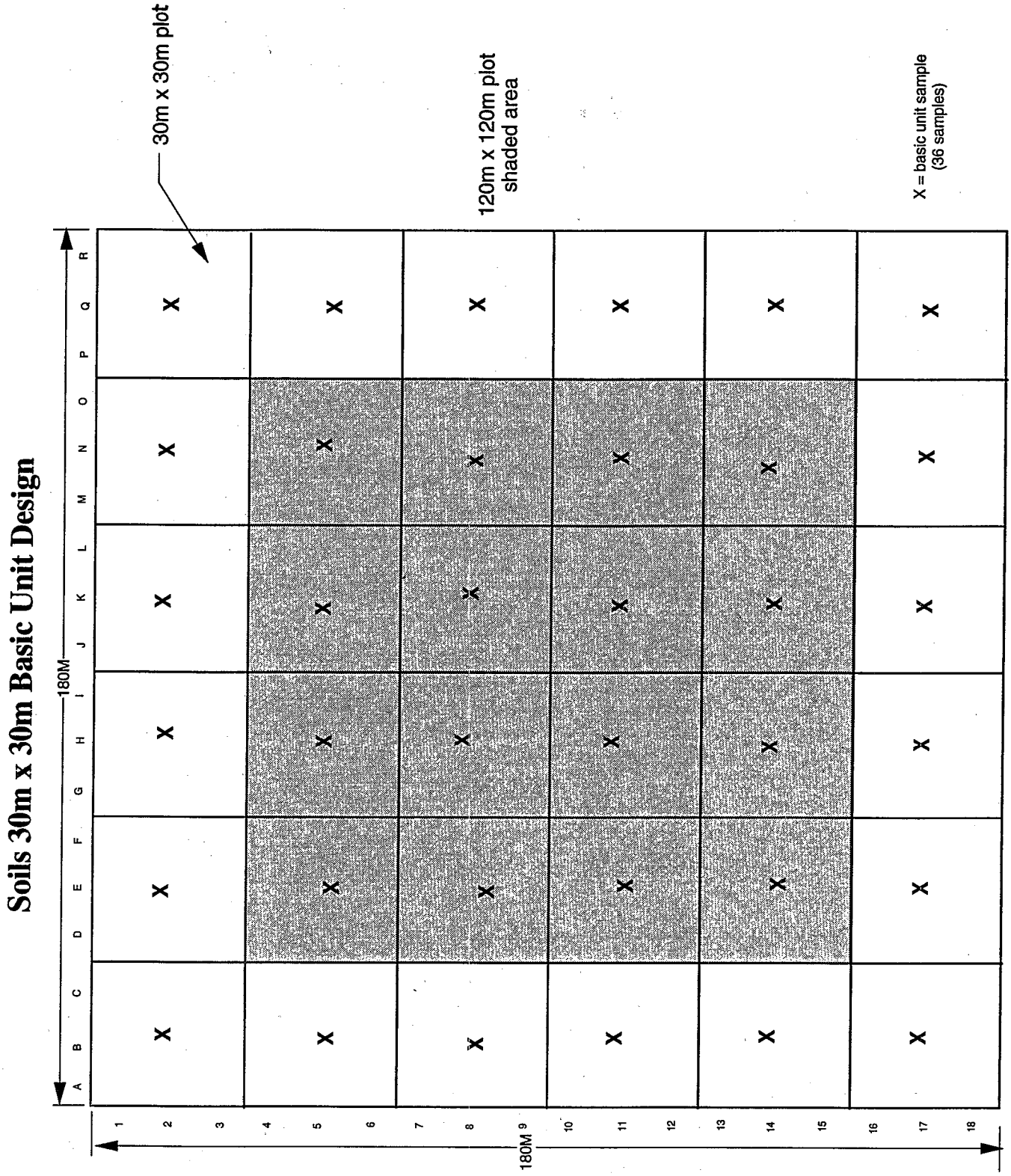

Figure 3-4. Soils macroplot design (30 m by 30 m).

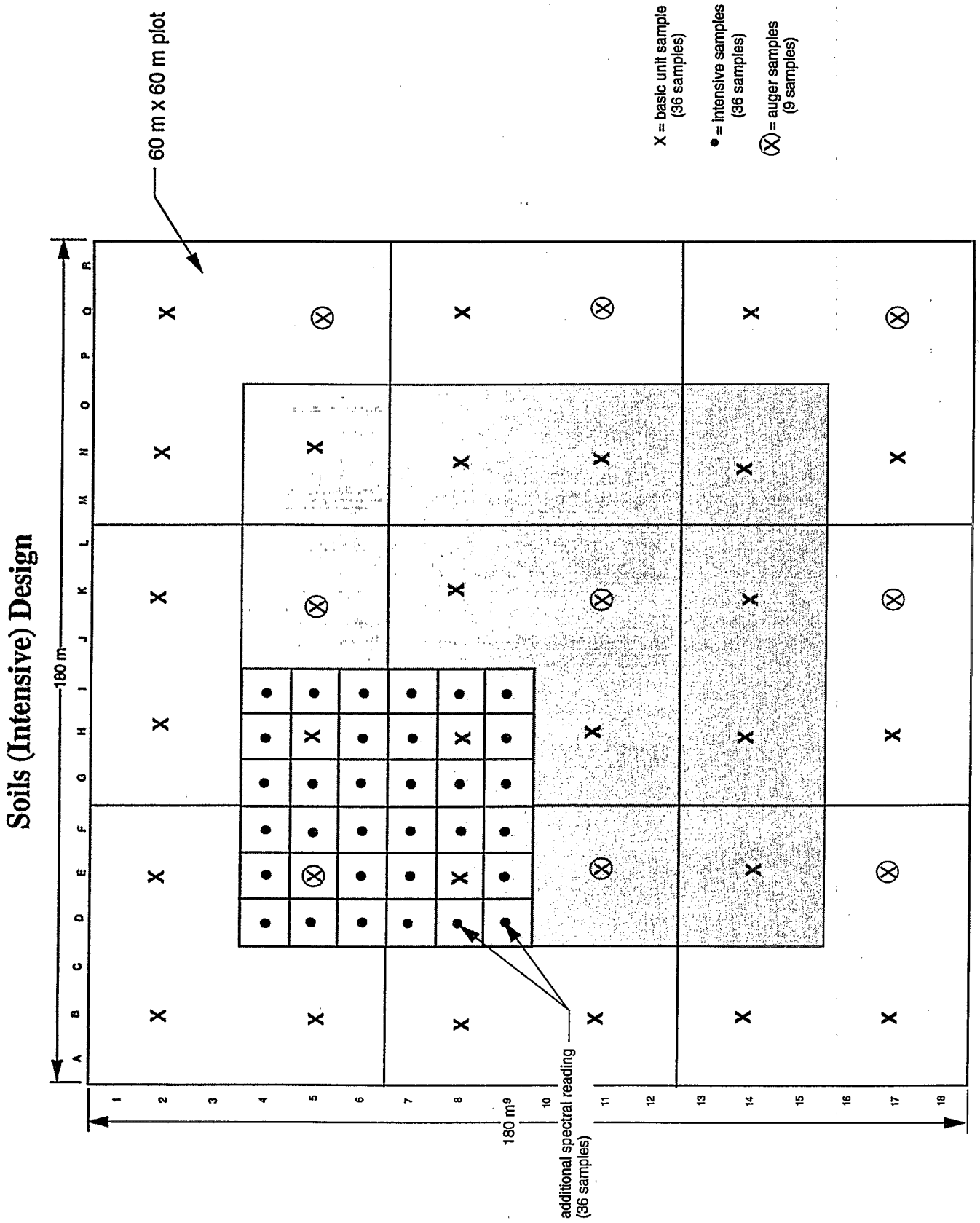

Figure 3-5. Intensive surface soil sampling design.

SECTION 4
INDICATORS

The EMAP indicators are being developed as characteristics of the environment that, when measured, quantify the magnitude of stress, habitat characteristics, degree of exposure to stressors, or the degree of ecological response to an exposure (Hunsaker and Carpenter, 1990). Indicators serve as the basis for quantification of the assessment endpoints (i.e., the actual measurements to be made). For example, water-holding capacity and bulk density are measurements that are being developed as indicators that serve to quantify the assessment endpoint of soil quality. A decrease in water-holding capacity and a decrease in bulk density indicate a marked decrease in the soil quality assessment endpoint and suggest poorer societal values related to productivity and biological integrity. In the 1993 EMAP-Arid Colorado Plateau Plot Design Pilot Study, the same three indicator categories and measurements used in the 1992 pilot will be studied to determine the optimum plot size for each. Also, a preliminary study of harvester ants will be performed to investigate their value as a possible new indicator in 1994.

4.1 VEGETATION COMPOSITION, STRUCTURE, AND ABUNDANCE

The composition, structure, and abundance of vegetation have been recognized as useful indicators of environmentally induced changes in arid vegetation. The proposed measurements for the determination of these indicators are estimation of (1) the percent cover and (2) the height of the green vegetation on the site by species. Together these measurements can provide an index of leaf area and serve as sensitive indicators of change in biological condition at the organism, population, community, and ecosystem levels. These indications occur through the relationships of cover and height to water availability and production (Nemani and Running,1989; Tausch and Tueller, 1990; Tausch and Nowak, 1991). Ground-based cover measurements can be related back to, and used to compare to remotely sensed spectral properties when specific timing requirements are met. The proposed vegetation measurement methods are rapid, have demonstrated levels of precision when used by personnel with proper training, and are familiar to all land management agencies.

Compatible data are available for many areas of arid and semi-arid vegetation. Similar methods are in wide use by the Inventory, Monitoring and Evaluation Program conducted by the USDA Forest Service, Intermountain Research Station (O'Brien and Van Hooser, 1983; Born and Van Hooser, 1988; Utah Forest Survey Field Procedures, unpublished; USDI Bureau of Land Management, USDI, 1985).

Details of specific vegetation indicator measurements are given below:

- Vegetation Cover--Percent of vegetation cover by species on a site provides information on abundance, relative composition, and dominance in the community. Samples are taken using the Daubenmire cover class method. The method described by Baily and Poulton (1968) is modified by adding a seventh cover class (less than 1%) to better indicate trace occurrences.

TABLE 4-1. MODIFIED DAUBENMIRE COVER CLASSES[a]

Class	Cover Range	Range Mid-Point
0	0	None
1	<1%	0.5%
2	1% - 5%	3.0%
3	5% - 25%	15.0%
4	25% - 50%	37.5%
5	50% - 75%	62.5%
6	75% - 95%	85.0%
7	95% - 100%	97.5%

[a] Modified from Baily and Poulton (1968)

- Vegetation Height--Average height of each species on a sampling location within the macroplot. Determined by species and quadrat, provides information on species dominance and vegetation structure in the community.

- Species Frequency--Quadrat sampling methodology provides for the determination of frequency by plant species for compatibility with ongoing collection of monitoring data by management agencies.

- Ground Cover--Ground cover by total vascular plant cover, litter, rock, bare soil, and cryptogams provides important information for soils and erosion analyses. Ground cover for all but total vascular plant cover will be determined both for the subcanopy and for the canopy interspace area.

- Species Composition--Through quadrat sampling, the species composition of each macroplot can be determined.

- Essential Complementary Data--Includes the description of topography and landforms surrounding the sample location, its slope and aspect, and information on land use in the area.

The following data for trees will be recorded within the 5-m by 5-m quadrat:

1. Species identification from National List of Scientific Plant Names (USDA, 1982, as amended) for each tree.

2. Widest crown diameter and the diameter at 90° for the same tree.

3. Height of tree (to nearest 0.5 m).

4. Basal trunk diameter for trees or diameter root crown for shrubs (greater than 1.5 m in height). When trees or shrubs have multiple trunks, measure all trunks.

5. The number of seedlings and saplings less than 1.5 m high.

The following data for shrubs will be recorded within the 1-m by 2-m quadrat:

1. Plant species identification for each shrub (less than 1.5 m in height) species.

2. Cover class of canopy for each shrub species.

3. Average height to nearest 0.1 m for each shrub species.

The following data will be recorded within the 0.5-m by 0.5-m quadrat:

1. Cover class (see Table 4-1) for:

   - Total vascular plant canopy cover

   - Surface features for subcanopy and for canopy interspace areas:
     - rock fragment cover by class:
       gravel (2-75 mm)
       cobbles (75-250 mm)
       stones (>250 mm)
     - litter cover
     - nonvascular cover by class: moss, lichen, cyanobacteria
     - bare soil

2. Plant species identification from National List of Scientific Plant Names (USDA, 1982, as amended) for each herbaceous grass or forb species.

3. Cover class of basal area for each herbaceous grass or forb species.

4. Average height to nearest 0.1 m for each herbaceous grass or forb species.

To fully characterize the vegetation composition of the sampling location with the macroplot, a general search of the area will be made to identify any species present on the site but not encountered in the vegetation quadrats.

4.2 HARVESTER ANTS

Ants are among the most ubiquitous invertebrates of terrestrial ecosystems. They occupy habitats from the driest deserts to subalpine regions. Ants play important roles in ecosystems. Most ants make nests in the soil and as soil animals are important modifiers of the chemical and physical nature of the soil. Although ant assemblages are diverse (Whitford and Gentry, 1981) in arid ecoregions, sample effort will be restricted to harvester ants (*Pogonomyrmex* species) because of the ease of identification and wide distribution. Ants can be censured by a number of

techniques which reduce the problems of sampling communities. A census of visible ant nests within each of the 5-m by 5-m quadrats will be tallied and compared with vegetative information. Identification of harvester ants is fairly simple because of their large size and blocky heads. Most harvest ants are either red or red and black. Harvester ant colonies in the Colorado Plateau will for the most part be single nest colonies and will be approximately 0.75 to 1 m across. Most of these will be fairly large colonies and can be identified by the deposits of vegetation material and gravel that have been extracted from the nest. Associations will be sought to determine how ant colony numbers vary with vegetation data. The idea behind sampling ant colonies is to determine if colony numbers increase or decrease with changes in site disturbance; hypotheses will be evaluated to determine if ant colonies increase with site disturbance.

4.3 SPECTRAL PROPERTIES

Electromagnetic radiation provides information about the physical and chemical properties of materials. While the spectral reflectance properties of objects tend to be wavelength dependent, the determination of these relationships is critical for characterizing or discriminating the objects. Vegetation, soils, and other materials have spectral responses that are a function of a diverse array of properties of those materials. These properties might include moisture content, shadowing, and presence of other materials. Nevertheless, the overall spectral response of a material is largely a function of the material itself. A number of researchers (e.g., Gholz, 1982; Waring et al., 1978) have shown very strong relationships between ecosystem structural (such as biomass or leaf area index [LAI]) and functional (such as net primary productivity [NPP]) features in reporting research on a transect of coniferous forest ecosystems in west central Oregon, and reported relationships between LAI and overstory NPP with a correlation coefficient (R^2) of 0.96 (see Arid Colorado Plateau Pilot Study--1992: Implementation Plan, Franson, 1992). For further information on typical spectral responses, see the 1992 Implementation Plan (Franson, 1992).

Spectral measurements will be made to determine if vegetation condition and soil properties can be related to spectral signatures collected by satellite, hand-held spectrometers, or both. The sensor collects data on the physical and chemical properties of the vegetation and soil. Tests will be conducted to determine whether Landsat satellite measurements (i.e., thematic mapper [TM] or multispectral scanner [MSS]), can be related to vegetation condition and soil properties in order to discriminate between them and possibly their condition from a synoptic perspective.

Ground spectra will be collected using a portable field spectrometer. Data will be analyzed to determine if satellite measurements can be related to ground spectral measurements to assess within-pixel spectral variability and evaluate its utility to EMAP-Arid. The ground spectral measurements will also be compared to data collected by the vegetation and soils group to develop a better understanding of the fundamental spectral properties of these objects.

The 1993 Plot Design Pilot Study will focus on correlating the spectral reflectance measured on the ground with that determined from various satellite platforms to estimate vegetation and soils features. The spectral data acquired from the 1992 Pilot Study are currently being assessed and will be statistically compared with vegetation and soils data. Data are being compared to determine statistical variance within and between plots for the ground and satellite scanners on three different formation types (desertscrub, woodland, and grassland). If the Landsat TM and MSS imagery can discriminate the vegetation and soils in a statistically acceptable

manner, at a scale relevant to EMAP, it will greatly reduce cost and increase area coverage for EMAP and other natural resource management programs.

4.3.1 Details for Specific Spectral Properties Indicators

The spectral properties indicator concept for the EMAP-Arid Plot Design Pilot Study proceeds from some basic assumptions which have been made by other investigators as to the relationships of vegetation structural and functional variables and spectral measurements.

The EMAP-Arid Plot Design Pilot Study will include the testing and evaluation of spectral properties of vegetation (primarily the normalized difference vegetative index but other indices may be used or developed and tested) and of soils (albedo) as determined by the use of satellite-hosted sensors. While these sensors will include the Advanced Very High Resolution Radiometer (AVHRR), and the Landsat TM and MSS, only the TM and MSS data will be used for subsequent analysis. Pixels extracted from the data sets will be chosen in such a way that they coincide with ground observations. The number of pixels needed to adequately characterize a given sample point will be tested and evaluated. It has been suggested (Mike Scott, pers. comm., 1992; Mike Spanner, pers. comm., 1992) that a 2 by 2 matrix may be adequate for the AVHRR pixels while a 3 by 3 or 4 by 4 matrix is probably necessary for the TM and MSS pixels.

In the 4 by 4 matrix, an assumption will be made that the center of that matrix will coincide with the given site centerpoint. In the 3 by 3 matrix, the assumption is that the center pixel contains the site centerpoint. That grid point, and its surrounding area, will be examined by the vegetation sampling team for vegetation composition, structure, and abundance and surface attributes (e.g., extent of bare soil).

4.3.2 Ground-Based Measurements of Spectral Properties

Ground-based spectral measurements will be made for two basic reasons: to characterize the spectral measurements made by the satellite sensors (Landsat TM and MSS) and to determine relationships between ground-based vegetation and soils measurements and their concomitant spectral responses. A measurement made by a remote sensor integrates or "mixes" the heterogeneity of the ground area being sensed. In the case of the Landsat TM, this area is 30 m by 30 m. The ground area or "pixel" may be quite uniform or homogeneous or it may consist of a diverse array of cover types. In southeast Utah, for example, these areas could involve highly dissected terrain (and widely varying soils and rock types), scattered shrubs, varying surface organic matter content, shadows, and other factors. Ground-based spectral measurements of these materials will determine the spectral composition of the integrated spectral measurements made by the satellite. These measurements, made in the context of an appropriate ground sampling strategy, will also help to determine the nature of spectral variance within pixels.

Ground spectral data will be obtained for the five macroplots during the field sampling activity. A Personal Spectrometer II (PS-II) will be employed in the field. This instrument, with a spectral range of 400 to 900 nm and a spectral resolution of 2 nm, is a highly portable (3 kg) instrument capable of acquiring spectra in as little as 1/23 second. The PS-II will be used to acquire spectra within the 5-m by 5-m quadrats along transects of plants, litter, shadows, surface soils, and surface lithology for the purpose of characterizing the sample site. This information will in turn be used to correlate the satellite-derived information with the other ground measurements.

The PS-II measurements will also be used to determine the basic spectral properties of the materials themselves. Spectral analysis software, together with other statistical packages (Quattro Pro), will be used to determine the spectral properties of the ground materials being examined.

Sampling for spectral properties will proceed at each vegetation 5-m by 5-m quadrat (see Section 3 for pilot design description, Figure 3-3). At each point the PS-II will be positioned approximately 1 m above the surface and a set of 10 spectra acquired, averaged, and recorded. The PS-II has a field of view approximately 30 cm in diameter from a height of 1 m.

The 1,440 spectral measurements made on the macroplot (120 m by 120 m) will be used to estimate the value and spectral variance for the macroplot as well as 16 TM pixels. The spectral properties indicator portion of the Plot Design Pilot Study will then evaluate the relationship between on-ground spectral and satellite spectral measurements.

The spectral measurements for the entire basic unit (10 m by 10 m) can be combined and related to the vegetation composition and abundance and surface attributes of that basic unit. The 1,476 spectral measurements for the entire macroplot (120 m by 120 m) can be combined and related to the vegetation composition and abundance and surface attributes of the entire macroplot. Similarly, the spectral properties measured from satellite imagery (TM, MSS, or AVHRR) for the entire macroplot can be related to the vegetation composition and abundance of the macroplot. Thus, vegetation properties and surface attributes can be related to spectral properties determined from both on-ground measurements and satellite imagery.

As time permits, a catalogue of spectral measurements of individual plants and surface materials will be made. A botanist will work with the spectrometer technician to record species identification, phenology, and condition (e.g., flowering, dead, withered, healthy) information for individual plants for which spectra are acquired. Surface features will also be recorded and spectra acquired. Such a catalogue of spectra for individual plants and surface features will be extremely useful in expanding the use of remotely sensed spectral properties for vegetation mapping and determining condition. This information, linked with information on the spectral variance averaged into TM and MSS pixels, will help to further develop spectral properties indicators for future use in EMAP-Arid activities.

4.4 SOIL PROPERTIES

Selected soil properties will be measured in the field and lab as indicators of soil erosion, productivity, and moisture-plant growth indices. Local soil characteristics and soil surface and subsurface samples will be obtained using established methods from the U.S. Soil Conservation Service (SCS) (USDA, 1975). Local soil characteristics will be used to evaluate type of soil and to calculate an erosion index.

Surface physical and chemical soil attributes are obtained from samples collected at the surface. Surface soil properties are one of the first attributes to respond to natural and anthropogenic stress. Deep soil profile observations will be collected to classify the soil. Most of the measured soil properties provide baseline data that would only be resampled if notable changes occurred in other indicators. The data can then used for comparison extrapolation and interpolation of long-term change.

Soil properties directly influence the amount, timing, and distribution (lateral and vertical movement) of soil moisture available for plant growth. Soil infiltration properties and surface characteristics also directly affect erosion processes, including overland flows (runoff) and transport of suspended and dissolved solids. Disturbances and stresses to surface and subsurface soil can influence flow velocity, routing, soil detachment, and deposition. The result is accelerated soil erosion that further affects moisture infiltration rates and patterns. Ultimately, physical changes to vegetation communities may result. An altered soil moisture regime, in conjunction with changes in other soil properties through erosion, can result in degradation to soil productivity, landscape features, and vegetation composition and abundance. Consequently, biological integrity, productivity, and the degree of desertification of arid ecosystems are highly dependent on soil condition.

Soil property measurements will be incorporated with vegetation and spectral properties data to allow application of the Water Erosion Prediction Project (WEPP) (Lane and Nearing, 1989; Flanagan, 1990, 1991), Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), or the revised USLE (RUSLE) (Mills et al., 1985) and Wind Erosion (WE) equation (Fryrear, 1991). A description of these indexes is provided in this section. Also included is a description of external data requirements.

4.4.1 Soil Property Measurements

The field crew will measure three soil property measurements:

1. surface soil attributes--description of attributes of the topmost soil surface including vascular and nonvascular vegetation, rock fragments, bare soil, and litter

2. surface soil (a) description and (b) analysis of the A horizon

3. soil profile observation and classification of a vertical section of the soil through all its horizons and extending into the parent material.

Soil properties encompassed by these three measures control both soil moisture and susceptibility to erosion processes. Table 4-2 summarizes the field measurements and laboratory parameters measured on the surface soil sample. In addition, soil pits will be excavated to a depth of 150 cm (as necessary) or bedrock for soil profile classification at nine of the surface soil locations. Two clods will be collected from the A horizon at these sample locations to determine bulk density.

TABLE 4-2. SURFACE SOIL MEASUREMENTS

Field Measurements	Soil Sample Laboratory Measurements
- % Slope - % Bare Soil - Permeability - % Rock Fragments in Soil - Structure - Textural Class - Soil Surface Roughness Factors - Length of Unshielded Distance - Particle Size Separation - Thickness of A Horizon - Soil Crust Thickness - Soil Color/Surface Erosion - Soil Depth - Soil Classification - Infiltration	- Particle Size - Bulk Density - Water Retention - Organic Carbon - Total Nitrogen

4.4.2 Infiltration Rate

Soil infiltration rates govern the rate at which rain and irrigated water enter into the soil. When the rate of water addition exceeds the intake capacity of the soil, overland flow (runoff) and transport of suspended and dissolved solids begin. Environmental changes which decrease infiltration rates decrease the amount of water stored in the soil and increase the runoff rates. Changes in runoff rates directly affect the erosion process.

The objectives of measuring the infiltration rate are to:

1. determine if infiltration rates can be measured by tension infiltrometer in an efficient and timely manner,

2. measure the infiltration rate at a known tension for 36 basic units, and

3. determine the optimum size and shape of the plot to measure the infiltration rate.

Infiltration rates can be measured for saturated or unsaturated conditions. Saturated infiltration rates are measured by ponding water on the soil surface and recording the time required and amount of water that flows into the soil through a known cross-sectional area. Saturated conditions occur when the soil is completely covered with water or sufficient water has entered the soil as to fill all pore space. Unsaturated infiltration rates are measured by adding water through a

semi-permeable membrane at a known tension. The time required and amount of water flow through a known cross-sectional area are recorded. Unsaturated infiltration occurs at the inception of water added to the soil and when water has not filled all soil pores. In arid ecosystems, water movement into the soil is primarily at unsaturated conditions.

4.4.3 Erosion Index

Soil erosion is universally recognized as a serious threat to the sustainability of arid ecosystems and man's well-being (Kral, 1982). This recognition is shown by the fact that most governments in the world give active support to programs of soil conservation.

The objectives of measuring the erosion index are to:

1. calculate water erosion rates based on field measurements for the basic unit and

2. determine optimum size and shape of the plot for the erosion index.

Soil erosion from wind and water can be measured directly or calculated using a variety of models. To obtain accurate field measurements, extensive instrumentation and sampling of a plot are often required (Larson et al., 1983; Breckenridge et al., 1991). Because of cost and time constraints, the EMAP-Arid team has decided to use modeling as an alternative approach to determine site erosion. Three models will be evaluated as part of the study: (1) the Universal or Revised Universal Soil Loss Equation (USLE/RUSLE); (2) the Water Erosion Prediction Project (WEPP); and (3) the Wind Erosion (WE) equation. These models will be evaluated for their ability to construct an erosion index for a site. The erosion index (presented in tons per acre per year) will be specific to a soil series and map unit. The calculated index will be a combination of the water and wind contributions to the total site erosion rate. The index will be compared to the erosion factors (T) found on the physical and chemical properties of soils table (Table 12 in all soil surveys) in each of the published USDA soil surveys for the various counties of the pilot area. The T factor is an estimate of the maximum average rate of soil erosion by wind or water that can occur over time without affecting vegetative productivity over a sustained period. This value is in tons per acre per year.

By comparing the calculated T for a site to the established nominal T from the soil survey, the EMAP-Arid team hopes to make statements about the relative erosion condition of the site on a regional basis. Thus, the expression for the soil index for a specific soil series could be as follows:

Site calculated values (Tons/ac/yr)	**SCS recommended Values**	**EMAP association**
Water erosion + Wind erosion	$\leq T$	= nominal
	$> T$	= subnominal

The remaining discussion in this section describes the various equations and their inputs.

The USLE is a well-established equation for water erosion originally developed in 1940 to predict long-term soil loss through sheet and rill erosion. USLE is widely used by the SCS and conservation planners to determine appropriate soil management strategies. The 1977 National

Resource Inventory data base on erosion was derived from the USLE (water erosion component) and WE (wind erosion component) models. The USLE is a simpler equation than the WEPP. The USLE calculates soil loss as a product of six factors.

A = R x K x L x S x VM x P (Israelsen et al., 1980) where:
A = estimated soil loss in metric tons/hectare/yr
R = rainfall (a function of local rainstorm characteristics)
K = soil erodibility (a function of soil properties)
L = slope length
S = degree of slope
VM = Erosional Control Factor (vegetative and mechanical measure) (% ground cover of grasses and stone, forb density)
P = erosion control (practices such as contouring, strip-cropping, or terracing)

The RUSLE is essentially identical to the USLE but incorporates additional parameters addressing gully erosion.

The WEPP is a new project designed to generate improved erosion prediction technology on rangelands for use by multiple federal agencies. The EMAP-Arid team will collect the required inputs for WEPP that include climate, soil properties, topography, and land use. WEPP (Lane and Nearing, 1989; Flanagan, 1990, 1991) is being designed to ultimately replace USLE/RUSLE, at present, it is in the trial stage.

Wind erosion is important and often the main cause of erosion in large flat arid regions. Many of the soils deposited in arid areas are aeolian materials (parent material accumulated through wind actions). The WE equation is:

E = I x C x K x V x L (Israelsen et al., 1980) in which:
E = soil loss by wind in tons/acre/yr
I = soil wind erodibility factor
C = local wind erosion climatic factor
K = soil surface roughness factor
V = vegetative factor
L = length of the unshielded distance parallel to wind in the direction of the wind fetch.

The inputs to these parameters will be obtained from field data or by using standard values (Israelsen et al., 1980). Details of field collection techniques are given in the 1993 Field Operations and Training Manual (O'Leary and Byers, 1993).

The EMAP-Arid team will collect the required input for the USLE, RUSLE, WEPP, and WE for those pilot sites that have published soil surveys (an exception could be bare rock). Based on current plans, field data will be input to the three equations and erosion values calculated. These values will then be compared to published T values from the soil surveys. Data evaluation will be conducted to determine cost effectiveness of different models and precision between USLE, RUSLE, and WEPP.

4.4.4 Data Sources and Additional Data Requirements for Soils Indicator Development

In order to assure the quality standards necessary for EMAP indicator data collection, the procedures and methods identified in the National Soils Handbook (USDA, 1983) as part of the National Cooperative Soil Survey (NCSS) will be used. Copies of the National Soils Handbook, Soil Survey Manual, Soil Taxonomy, and Soil Survey Investigations Report No. 1 will be obtained from the USDA-SCS or the U.S. Government Printing Office.

Existing data pertinent to the sample sites in the pilot area for 1993 will be obtained from the Utah State SCS. Additional data specific to the pilot study area will be obtained from SCS field offices, Bureau of Land Management (BLM) State or District Offices, and the Forest Service Forest or Range District Offices. The SCS offices will be the main source of soil data because they are charged with soil correlation, soil data base maintenance, and manuscript publication responsibilities.

The soil data required for proper soil series identification at the sampling sites are available for San Juan County except for the southern section including the Navajo Nation. Soil surveys for San Juan County can be obtained from the Moab SCS office (801-587-2481). This information includes the soil maps, map unit identification legend, map unit descriptions, table of soil classification, typical soil pedon descriptions, soil laboratory data, and soil interpretation tables or form SCS-SOI-5 for each soil component in a map unit where the sample sites are located.

Soil data collected on site will be compared with existing data to determine similarities or dissimilarities and to provide support for erosion calculations. The soil data from laboratory analyses will be stored in the SCS National Database and transferred to the EMAP-Arid data base management system.

SECTION 5
LOGISTICS

The sites selected for the 1993 EMAP-Arid Plot Design Pilot Study of the Colorado Plateau were not drawn from the EMAP Stage 2 sample. In order to simplify logistical operations and facilitate meeting the objectives of this study, members of the EMAP-Arid team handpicked five sites on the Colorado Plateau to sample and measure. The macroplot size for the 1993 study of 180 by 180 m is designed to allow the collection of a quantity of data to assist in determining and refining the optimum size plot for each indicator. Information collected this year will help to specify the size plot that is sampled in future years. Thus, in future years plot sizes should be significantly reduced from the size of the 1993 macroplot and associated logistical problems should be simplified. Logistical efforts for the 1993 field operations will focus on procedures related to laying out the plots, the sequence of sample and data collection, data recording, and sample tracking and shipping.

5.1 1993 SITE SELECTION

In June 1993 the EMAP-Arid team met in Moab, Utah, to select the five sites. All five macroplots were selected using the following criteria:

1. The five monitoring sites are on land managed by the BLM.

2. Sites are readily accessible by two-wheel drive vehicles and must be at least 100 m from any road.

3. Slope at the site does not exceed 6% and the site is void of canyons, steep cliffs, rivers, or human or domestic animal impact.

4. The five monitoring sites represent five combinations of productivity and biomes:

   - 1 desertscrub--low production
   - 1 desertscrub--medium production
   - 1 desertscrub--high production
   - 1 grassland--medium production
   - 1 woodland (pinyon juniper--medium-high production)

5. Vegetation type represents a uniform distribution of the desired plant community over a constant landscape type.

6. The macroplots selected do not contain artifacts of archaeological interest or known threatened or endangered species.

5.2 FIELD CREW

During the 1993 field season, one field crew will sample all five sites. This crew will be composed of trained qualified personnel selected from the permanent staff of the National Park

Service, SCS, BLM, EPA, other federal agencies, cooperators, and contractors (Table 5-1). The field crew will consist of one soil scientist, one soil technician, two botanists, two botanical technicians, and one spectral technician. A number of these individuals participated in field operations during the 1992 Colorado Plateau Pilot.

TABLE 5-1. 1993 PILOT STUDY EMAP-ARID CREW COMPOSITION

Position	Affiliation
Soil Scientist	Soil Conservation Service
Soil Technician	Soil Conservation Service
Botanist	Bureau of Land Management
Botanist	National Park Service
Botanical Technician	Contractor or EPA
Botanical Technician	Contractor or EPA
Spectral Technician	Cooperator or Contractor
Logistics Aide	Contractor

Specific crew members will be responsible for collecting the data and samples for each indicator. All crew members must understand how the macroplots are laid out and follow the protocol for movement on the macroplot to ensure that the integrity of each indicator is not compromised. Crew member responsibilities are listed in Table 5-2. The Crew Leader and the Logistics Aide have other responsibilities in addition to sampling.

Before the field crew reaches a site, the Logistics Aide and an assistant will establish the soils and vegetation macroplots, mark the sites where pits will be placed in the area outside the vegetation macroplot, and mark the beginning of the quadrat lines on the northern boundary of the vegetation macroplot (Section 3). A detailed protocol for establishing the macroplot, basic units, and quadrats is given in the 1993 Field Operations and Training Manual (O'Leary and Byers, 1993).

5.3 TRAINING AND FIELD OPERATIONS

Training of field crews and sample and data collection will begin in late August and continue through September. An additional training macroplot has been established near Moab. This training macroplot has all three vegetation types (grass, desertscrub, and pinyon-juniper woodland). Training in Moab, Utah, is scheduled to begin on August 23, 1993, and will include an introduction to EMAP and the Arid Lands Resource Group, background information provided by the indicator leads, and training in specific protocols. Sampling protocols will ensure consistency, comparability, and integrity of all samples. A dry run, debriefing, and proficiency test will ensure that crew members understand the significance and sequence of collecting data.

Field work will begin on August 30 and conclude September 29. A debriefing of the field crew will take place on September 22, 1993. The objective of the debriefing will be to gather information from the field crew on how to improve field operations and field data collection

TABLE 5-2. CREW MEMBER RESPONSIBILITIES FOR EMAP-ARID 1993 PILOT STUDY

Crew member	General duties
Field Crew Leader	· Makes final decision concerning in-field protocol deviations · Conducts and records daily debriefings · Transmits information for weekly reports · Inspects field forms for completeness and condition of samples prior to transfer to Logistics Aide · Interacts with Logistics Aide
Soil Scientist (1)	· Collects soil samples and directs technician in soil measurement activities · Assists in laying out the sampling area (basic units) · Verifies and transmits soil data collected · Maintains field equipment for soil sampling
Botanist (2)	· Performs and directs vegetation sampling protocols · Assists in laying out the sampling area for vegetation measurements · Verifies and transmits vegetation data collected · Maintains field equipment for vegetation sampling
Soil or Botanist Technician (3)	· Assists soil scientist or botanist as needed · Assists in laying out sampling area (basic units) · Assists botanist in recording vegetation data and sample collection · Assists in excavating soil pits, soil data recording, and sample collection · Maintains field equipment
Spectral Technician (1)	· Performs spectral property measurements · Maintains Personal Spectrometer (PS-II) and downloads data from PS-II · Takes Global Positioning System (GPS) readings and records GPS data
Logistics Aide	· Establishes macroplots · Assumes custody of samples; processes and ships samples · Photocopies and transmits completed data forms and computer disks weekly · Maintains inventory of supplies · Assists Field Crew Leader in communications with EMAP-Arid management, indicator leads, and visitors · Arranges for repairs or replacement of equipment

measurement in the future. During the field season indicator leads or coordinators will visit the field operation sites to ensure that the field crew is following sample collection protocols. The field crew will also remeasure certain elements within one macroplot for each biome for quality assurance protocols. As time allows, remeasurements will be made at the remaining two macroplots.

Specific daily activities for the EMAP-Arid field crew are detailed in the EMAP-Arid 1993 Field Operations and Training Manual (O'Leary and Byers, 1993). The crew will begin each morning by checking and calibrating instruments and ensuring that all necessary equipment and supplies are loaded into the vehicles.

At the macroplot, the field crew will review their notes from the previous sampling day to refresh their memories of where the previous day activities ended. The crew will also hold a crew conference to discuss the day's activities for each crew member and the time set to leave the macroplot. Sample protocols will remain consistent.

At the conclusion of a sampling day, the crew will remove all equipment from the site. Tape measures may be left on the ground for reference points for the next day's activities. Equipment should be securely and properly packed into the vehicles for the return to the lodging. A second pass should be made to ensure that no equipment is left behind.

Upon returning from the field, the Field Crew Leader will debrief the crew members and check data forms, sample labels, and the condition of the samples. The crew members will clean and prepare equipment and supplies for the next day. The Field Crew Leader will perform administrative tasks as they arise.

When all sampling has been completed on a site, the field crew will backfill all soil excavations and pack them down. The field crew will also remove all survey flags, stakes, and flagging tape, and, insofar as possible, return the site to its natural condition before field activities occurred.

Base site operations for the 1993 Colorado Plateau pilot will be located at the BLM district office in Moab, Utah. The district office will provide a desk area for data analysis and a storage area for equipment. Shipping and receiving will also be handled through the BLM office. Any items being shipped must be clearly marked EMAP-Arid or EPA. Procedures to be followed by EMAP personnel at the BLM facility will be distributed to all individuals at the training session during the week of August 23, 1993.

5.4 INFORMATION MANAGEMENT

The Field Crew Leader will hold data forms until they are submitted to the Logistics Aide. The Logistics Aide will review the data forms, make photocopies, and mail or fax the copies weekly to the Information Manager for data entry. Original data forms will remain on file in the field office individually for each site. The Logistics Aide will ship soil samples to the analytical laboratory every two weeks or as often as necessary by freight.

The portable data recorders (PDRs) will be downloaded each night by the Botanist and Logistics Aide. The Botanist is responsible for charging the PDR battery. The Spectral Technician is responsible for downloading and charging the Personal Spectrometer (PS-II).

5.5 SAMPLE SHIPMENT

The Logistics Aide is responsible for contacting shipping carriers and shipping data forms and soil samples. The Soil Scientist is responsible for ensuring the completeness of the samples that are to be shipped. The Soil Scientist is also responsible for packing the soil shipment. Soil samples will be shipped to the SCS in Lincoln, Nebraska. Data forms and a computer backup disk will be shipped to the Information Management Center in Las Vegas, Nevada, once a week.

SECTION 6
QUALITY ASSURANCE

The Arid Ecosystems Resource Group, as a component of EMAP, will participate in the EPA mandatory quality assurance (QA) program (Stanley and Verner, 1985). Accordingly, the EMAP-Arid team is developing a QA program to ensure that all data collected under the auspices of this resource group are scientifically valid and of known, documented, and acceptable quality to achieve research objectives.

The QA program for EMAP-Arid is based on a philosophy of guidance and assistance rather than enforcement. There must be a commitment of personnel at all levels, from the program managers providing guidance to the field technician taking measurements, to the philosophy of quality management. Quality assurance is not the responsibility of any one person in the program. Rather, the responsibility is distributed among all personnel, each of whom has a specific role. Those roles must be clearly defined and organized to ensure that an adequate level of quality is attained.

The study that the EMAP-Arid group will conduct in 1993 is intended primarily as a plot design study for selected indicator measurements. The level and scope of QA for this study will be considerably less comprehensive than will be necessary for the larger scale efforts to be carried out in the future. Information obtained in this study will be crucial in further developing the QA program for future activities.

6.1 QUALITY ASSURANCE PERSONNEL AND RESPONSIBILITIES

The following personnel are in key positions in the structure of the QA personnel (QA-related positions) for EMAP and EMAP-Arid:

- Quality Assurance Coordinator for EMAP
  L. Kirkland, Quality Assurance, EPA, Washington, DC

- Technical Director for EMAP-Arid
  W. Kepner, EPA, Las Vegas, Nevada

- Quality Assurance Coordinator for EMAP-Arid
  A. Neale, EPA, Las Vegas, Nevada

- Quality Assurance Officer for EPA Environmental Monitoring Systems Laboratory, Las Vegas
  L. Williams, EPA, Las Vegas, Nevada

- Indicator Development Coordinator for EMAP
  C. Barber, EPA, Athens, Georgia

- Indicator Development Coordinator for EMAP-Arid
  R. Breckenridge, INEL, Idaho Falls, Idaho

- Indicator Leads and Joint Leads for EMAP-Arid
  Spectral - Dave Mouat, Desert Research Institute, Reno, Nevada
  Vegetation - Steve Leonard, DOI, BLM, Reno, Nevada and
  Robin Tausch, USDA, Forest Service, Reno, Nevada
  Soils - Tom Reinsch, Soil Conservation Service, Lincoln, Nebraska

- Methods Coordinator for EMAP
  Gary Collins, QAMS, Cincinnati, Ohio

Responsibilities of the above 11 personnel are provided in Section 3 of the 1993 Quality Assurance Project Plan (QAPjP) for the 1993 plot design pilot study. The indicator leads play an important role in planning and implementing quality assurance for their respective indicators. Indicator leads, working closely with QA personnel, are responsible for the data quality for their indicator. This responsibility will ultimately include defining data quality objectives (DQOs), developing standard operating procedures, training and certifying personnel, verifying data, assessing data quality, and planning audits and performance evaluations.

6.2 QUALITY ASSURANCE OBJECTIVES

The mission of the EMAP-Arid QA program is to ensure that the data and statistical products collected by the EMAP-Arid group are documented and of sufficient quality to meet and satisfy the needs of the users of the data. More specifically, for the 1993 EMAP-Arid pilot study in Utah, the mission is to establish criteria to control and assess the quality of data collected in the field and laboratory and evaluate the quality assurance procedures implemented in the 1993 pilot study for application to future arid ecosystems activities. This mission can be partitioned into two objectives:

1. Establish data quality objectives (DQOs) for precision, accuracy, and completeness for all field and analytical laboratory data.

2. Develop, conduct, document, assess, report, and evaluate for future use all aspects of training, field activities, laboratory activities, information management, and quality assurance to ensure that the EMAP-Arid data for 1993 collected from the field and the analytical laboratory satisfy the established DQOs.

These two objectives can be accomplished using various approaches and actions as follows:

- Ensure that all field evaluation and sampling techniques, analytical methods, and data management procedures are documented, printed, and distributed to the appropriate participants prior to commencement of the field season.

- Conduct training workshops on field procedures for all participants (field crews, trainers, experts) prior to the field season. Document all test results on these procedures for assessment and accreditation of field crews.

- Use field evaluation techniques and procedures and laboratory assessment samples and procedures to verify and assure the quality of the data.

- Conduct various audits and field check techniques during the field season and conduct a post-season debriefing workshop to ensure that all activities and procedures are properly performed and that discrepancies are identified and resolved.

- Establish adequate data verification and validation techniques for all data.

- Evaluate the QA data using established statistical methods and document data quality in reports to management.

At present, DQOs are considered to be specific statements of the level of uncertainty a data user is willing to accept in a body of environmental data, with respect to the kind of scientific or policy question that motivated the data collection activity. The DQOs are definitive, quantitative or qualitative statements developed jointly by data users (e.g., scientists, policy makers, interest groups) in conjunction with the QA staff. The DQO process uses an iterative approach that balances costs versus uncertainty to achieve a desired or acceptable level of quality.

EMAP is committed to the use of DQOs as a means of assuring data quality. The DQOs for EMAP-Arid data will be defined in accordance with overall EMAP objectives and ecosystem data requirements. Data quality, and thus DQOs, may be defined for several levels of EMAP data collection:

- Measurement-level DQOs (MQOs) for specific measurement parameters, estimated using existing or initial baseline data

- Indicator-level DQOs (IQOs) derived from aggregated parameter data for ecological indicators

- Resource-level DQOs (RQOs) derived from aggregated indicator data to provide an overall EMAP-Arid assessment of arid resource condition

- Ecosystem-level DQOs (EQOs) derived from aggregated resource data for overall ecosystem assessments.

The EMAP-Arid group has not yet collected enough information to establish DQOs on an indicator level. Therefore, the focus for this plot design pilot study will be on MQOs. MQOs are defined for specific measurements and may address the following attributes of data quality:

- Detectability--the lowest concentration of an analyte that a specific analytical procedure can reliably detect.

- Precision--the level of agreement among multiple measurements of the same characteristic.

- Accuracy--the difference between an observed value and the true value.

- Representativeness--the degree to which the data collected accurately represent the population of interest.

- Completeness--the quantity of data collected with respect to the amount intended in the experimental design.

- Comparability--the similarity of data from different sources.

6.3 1993 QUALITY ASSURANCE PROJECT PLAN

The details of the EMAP-Arid QA program for 1993 are described in the arid plot design pilot study--1993 Quality Assurance Project Plan (QAPjP) (Appendix A in the Field Operations and Training Manual, O'Leary and Byers (1993). The 1993 QAPjP describes (1) the EMAP-Arid program, organization, and objectives; (2) the EMAP-Arid data quality objectives; and (3) the QA activities and assessment criteria used to satisfy the data quality requirements. The 1993 QAPjP will be completed and signed by appropriate QA personnel before field activities begin in August 1993.

6.4 COMPONENTS OF THE QA PROGRAM FOR THE 1993 PLOT DESIGN PILOT STUDY

The following sections address QA components that apply to all of the indicators for the 1993 plot design pilot study. Subsequent sections will address QA issues related to specific indicators. As previously stated, the QA program is described more thoroughly in the QAPjP.

6.4.1 Field Training and Debriefing

A crucial element of quality control is sufficient training for the field staff. An overall EMAP orientation and EMAP-Arid task-specific training program will be conducted before the field study begins to ensure that the field crew is technically competent and individuals fully understand the standard operating procedures for the three indicators. Training will be provided primarily by the indicator leads and support personnel on a pre-established training plot at the training site near Moab, Utah.

Training and proficiency testing of the crew will cover all vegetation, soils, and spectral reflectance parameters to be measured in the field. Training and testing will also cover the use and maintenance of PDRs. All proficiency testing for crew members will be documented on either PDRs or hard copy with copies passed on to the Arid QA Coordinator for assessment and archiving.

The indicator leads will be responsible for evaluating members of the field crew after training and for certifying that they are able to do the necessary tasks. A brief session will be held after training to discuss the results of the proficiency testing and to give crew members the opportunity to provide feedback to the trainers prior to field activities. A post-training protocol check and accuracy audit on the field crew will be conducted after they complete the training workshop.

A debriefing workshop will also be held after the field season to review all field activities for 1993 and receive feedback from the crew members. Results of the debriefing will be documented and distributed to the EMAP-Arid Technical Director, Indicator Coordinator, Indicator Leads, QA Coordinator, Information Manager, and other key team members as appropriate.

6.4.2 Measurement Quality Objectives

Each indicator lead is responsible for defining the MQOs for the measurements made for each indicator. The MQOs for precision, accuracy, and completeness are documented in the 1993 QAPjP.

6.4.3 Standard Operating Procedures

The use of written standard operating procedures (SOPs) for sampling and analysis helps to ensure consistency in planning, implementation, and analytical activities over time and among personnel for routine activities within an organizational unit. All methods for 1993 field activities are documented in the Field Operations and Training Manual (O'Leary and Byers, 1993). In some instances, the manual refers the reader to specific users guides, e.g., the Spectrometer II Users Guide.

6.4.4 Analytical Laboratory Operations

All of the laboratory analytical work will be performed by the Soil Conservation Service in Lincoln, Nebraska. Their methods are documented in the laboratory methods manual (USDA, 1992). All laboratory personnel are trained and proficient in the current soil methods. A separate QA program for laboratory analyses is described in the QAPjP.

6.4.5 The Audit Program

A technical systems audit is an on-site visit used to verify conformance to the QAPjP and to established SOPs in the generation of the environmental data. The audit ensures that all data collection participants are adhering to protocols in a consistent manner. Audits also help determine whether the QAPjP and SOPs are adequate for the objectives of the project. These audits are documented in reports to management. The indicator leads, coordinating with the QA Coordinator, are responsible for developing, conducting, and reporting these audits.

Field data collection activity for each indicator (soils, spectral reflectance, and vegetation) will be audited at least once during the pilot study. The auditors will interview members of the crew to ensure that they have a clear understanding of the SOPs and are complying with them. Auditors will also review data forms and logs to verify that data are being recorded and documented properly. The results will be reported to the Technical Director, the QA Coordinator, and the Indicator Leads.

The SCS analytical laboratory will also be audited at least once during the sample analysis phase of the project.

Corrective actions that will be taken, if the audits reveal problems, include additional staff training and reviewing and improving the SOPs. Determining and taking the appropriate action will be the responsibility of the Indicator Lead in consultation with the Technical Director and the QA Coordinator. The QA Coordinator is responsible for tracking problems or discrepancies, the corrective actions taken, and the remedial effects. If necessary, a follow-up audit will be performed to verify that the problem has been remedied.

6.4.6 Information Management and Logistics

Absolutely integral components of quality control are an adequate information management system and a well-coordinated logistics program. The information management system to be employed for the 1993 field activities is discussed in Section 7. Logistics is discussed in Section 5. Both information management and logistics are discussed further in the QAPjP.

6.5 VEGETATION INDICATOR QA COMPONENTS

Data quality for the vegetation indicator is really a function of how well the botanists measure and record information in the field. The following data quality attributes will be addressed for the vegetation component of the 1993 field activities:

- Within-crew (botanist) precision--the ability of a botanist to produce the same result for multiple measurements of the same characteristic.
- Between-crew precision--the ability of different botanists to produce the same result for multiple measurements of the same characteristic.
- Crew accuracy--the ability of a botanist to measure the actual or true value of a characteristic.

6.5.1 Between-Crew and Within-Crew Precision

Remeasurements will be performed to assess precision. Each botanist will measure all parameters on 12 of the 0.5-m by 0.5-m, 12 of the 1-m by 2-m, and 6 of the 5-m by 5-m quadrats previously measured by the other botanist. These remeasurements will provide an assessment of between-crew variability.

Each botanist will also remeasure all parameters on 12 of the 0.5-m by 0.5-m, 12 of the 1-m by 2-m, and 6 of the 5-m by 5-m quadrats that individual previously measured. This procedure provides an assessment of within-crew variability.

Ideally, these remeasurements will be performed at each of the five macroplots visited. If time does not allow for this number of remeasurements, then the remeasurements will only be performed at three macroplots--the conifer-woodland, the grasslands, and at one of the desertscrub macroplots. All remeasurements will be performed on the plot where soil measurements are not being performed.

6.5.2 Crew Accuracy

Remeasurements will also be performed by a "reference expert botanist" to attempt to assess accuracy of the crew. The reference botanist will measure 24 of the 0.5-m by 0.5-m, 24 of the 1-m by 2-m quadrats, and 12 of the 5-m by 5-m quadrats previously measured by the two botanists. This accuracy check will be done at the first and last macroplots visited.

6.5.3 Precision and Accuracy Remeasurements

An attempt will be made to have the precision within-crew, the between-crew precision, and the accuracy measurements performed on the same quadrats. The botanists will mark the location of the first measurements so that the remeasurements are made as close as possible to the first measurements. This will minimize the spatial variability associated with locating the quadrats.

All QA data resulting from the remeasurements will be evaluated as soon as possible so that any problems encountered can be resolved early in the pilot study.

6.5.4 Data Verification and Validation

The vegetation data will be entered on PDRs in the field. The PDR program will allow a certain amount of error checking to be performed when the data are entered. For example, the program will be able to identify incorrect species codes entries, incorrect classification of shrubs, forbs, and grasses, and incomplete entries for a given quadrat.

6.6 SPECTRAL PROPERTIES INDICATOR

Elements affecting the quality of the spectral data include within-crew precision, crew accuracy, variability introduced by sun angle, shadowing, atmospheric haze and cloud cover, and calibration of the instrument. Spectral measurements will not be taken if cloud cover exceeds 50 percent to minimize variability caused by cloud cover. Spectral readings will generally only be taken between 10:00 am and 3:00 pm to minimize the variability from sun angle and shadowing. Atmospheric clarity and amount of cloud and wind will be recorded in the comments section of the header for each group of quadrats.

6.6.1 Precision

Precision of the instrument will be tested and documented before the study begins. This procedure includes taking repeated measurements of both a woody plant and a green plant. If there is a backup instrument available in the field, precision for the two instruments will be checked before the study begins.

As there will only be one spectral technician, between-crew variability is not an issue for the spectral indicator. Within-crew precision will be assessed by the spectral technician remeasuring a group of 20 spectral quadrats immediately following the first measurement of that same group of quadrats. The spectral technician will also remeasure the same group of 20 quadrats at the end of the same day. This procedure will provide an estimate of diurnal variation between the measurements.

6.6.2 Accuracy

To assess accuracy, the reference expert spectral technician will remeasure a group of 20 spectral quadrats immediately following the spectral technician's measurement of the group. This procedure will be performed during the first and last weeks of the study.

6.6.3 Precision and Accuracy Remeasurements

An attempt will be made to have the within-crew and the accuracy check measurements performed on the same quadrats. The spectral technicians will leave the flags after their first measurements so that the remeasurements can be performed as close as possible to the location of the first measurements. This procedure will minimize the spatial variability associated with locating the quadrats.

All QA data resulting from the remeasurements will be evaluated as soon as possible so that any problems encountered can be resolved early in the study.

6.6.4 Instrument Calibration

A stringent methodology for calibration of the spectrometer with reference to atmospheric conditions, internal calibration, and a black-and-white reference standard will be applied to the instrument prior to measurement of a group of quadrats. This rigorous calibration will be performed every three basic units.

6.6.5 Data Verification and Validation

For each file of data created, spectra are automatically assigned a three-digit suffix. Spectral measurements must be taken in a consistent and careful order to ensure that it is possible to associate spectral measurements with exact location of collection. Each file of data will consist of three basic units of spectral measurements. The file name will consist of site identification and column and row number of starting basic unit.

The comments for each file will include whether the technician is working from north to south or from south to north (the direction will alternate depending on what column the technician is working in). The four 0.5-m by 0.5-m quadrats will be measured first from left to right (determined as the individual faces east within the basic unit) and then the bare soil measurement will be taken. This procedure allows individual spectral measurements to be associated with exact location of collection.

6.7 SOILS PROPERTIES INDICATOR

Data quality for the soils properties indicator is a function of both the field work and the analyses in the SCS Laboratory. The QA Program will address both of these components.

6.7.1 Precision for Field Measurements

Remeasurements will be performed to assess within-crew precision. Between-crew precision is not an issue as there is only one soil scientist. The soil scientist will remeasure all area characteristics (e.g., percent slope, length of slope) and soil characteristics (e.g., soil color, rock fragments, soil structure, infiltration) for a specified number of the basic units. This procedure will be performed three times during the study; i.e., once at each formation type.

6.7.2 Field Accuracy

Measurements by a reference expert will be performed to assess crew accuracy. A reference soil scientist will perform all surface soil measurements for 12 of the basic units. The reference soil scientist will also classify the soil at the nine soil pits. This procedure will be performed at least once during the study.

6.7.3 Laboratory Accuracy and Precision and Quality Control

Quality assurance samples will be inserted into each batch of samples analyzed to assess precision and accuracy. For the purposes of this study, a batch will consist of all soil samples from one macroplot. The preparation laboratory at the SCS in Lincoln, Nebraska, will insert the QA samples into the batches so that they are double-blind to the analyst, i.e., the analyst does not know the location of the QA sample in the batch, nor its contents analytically.

Several types of QA samples will be used to assess laboratory accuracy and precision. These include a pure sand sample taken to the field site to assess field contamination, split samples at the preparation laboratory to assess homogenization efficiency, reference samples and duplicate pairs at the analytical laboratory to assess accuracy and precision, respectively. A separate quality control program is also being monitored at the analytical laboratory.

SECTION 7
INFORMATION MANAGEMENT

Information management (IM) plays a critical role in EMAP, EMAP-Arid activities, and the Colorado Plateau Plot Design Pilot Study. The activities and functions performed by IM are integrally connected with the study objectives, statistical design, logistics, field and laboratory measurements, quality assurance and quality control (QA/QC), data analysis, and product and report generation. Properly designed and implemented, IM functions as a cohesive and consistent thread which ties together each of these components of the research effort and provides the infrastructure necessary for turning scientific concepts into defensible results and products.

The efforts of IM in this study will not be as extensive as those expected in later pilot or demonstration studies or in full implementation. Other EMAP resource groups have had the opportunity to work through some of the same IM functions that will be tested during EMAP-Arid activities, and this group will attempt to use the lessons learned where they are applicable. These techniques and approaches will need to be modified and adapted to meet the specific requirements of the EMAP-Arid group but will be of value as initial designs and system components.

The prime objective of the Colorado Plateau Plot Design Pilot Study is to gather extensive data on relatively few sites (five) to be able to evaluate the results and determine the optimal plot design and size for further implementation. This objective overrides any secondary objectives to test and demonstrate IM concepts and prototype systems for full-scale implementation. However, a fully functional IM system that performs critical requirements from data collection to data base development and data analysis support will be implemented. To this affect, the IM system will demonstrate the following key functions:

- data collection effort using field forms, portable data recorders, and electronic field portable instruments;
- use of global positioning system (GPS) and postprocessing of location information;
- coordination and transfer of data between the field office and EPA laboratory (Arid Information Center);
- automation of data verification (i.e., QC/QA) checks;
- relational data base and scientific documentation (metadata) development;
- support to data analysis efforts through the creation of data extracts and data transfers;
- validation and confirmation of the Arid Information Management (AIM) System requirements of each research component from design through analysis and reporting;
- general requirements for interacting with collaborating agencies regarding data set development and data transfer;

- field and information center hardware and software requirements; and

- integration of the Geographic Information System (GIS) with traditional tabular and statistical driven IM systems design and operation.

The focus of IM will be to design, implement, and perform these functions, and to generate and make available data for evaluating the results of the pilot study. The objective of EMAP-Arid Information Management will not include testing the distribution of the study data outside of EMAP-Arid; however, preliminary discussions will be conducted to coordinate with the EMAP-wide information management efforts.

7.1 OPERATIONAL ASSUMPTIONS

The following assumptions are the basis for the modes of operation described in the field procedures:

1. Portable Data Recorders (PDRs) will be the primary method of recording vegetation and spectral data and paper forms will be used for all other plot and measurement data (i.e., soils). Paper forms will be designed as a backup mechanism for PDRs.

2. Transfer of information from the field to the central office can be on a weekly basis rather than daily basis.

3. Changes to field sampling procedures will be kept to a minimum after the beginning of the field season.

4. The data collected will not be considered suitable for distribution as EMAP assessment data. They will be used to evaluate indicators and to establish the optimum plot design for each indicator.

7.2 OVERVIEW OF INFORMATION MANAGEMENT FUNCTIONS

The functions carried out by IM in this study fall into four categories: prefield, field, data base development, and data verification, validation, and distribution.

The prefield IM functions relate to the design, preparation, and acquisition of IM tools required for data collection. The field functions include the use of equipment relevant to IM, procedures and methods for tracking the collected information, backup of information collected, and transfer of information from the field to the Information Center. Information Center data base development includes the tracking of information received, organization and archival of data sets, and transfer of information to the data base. The verification, validation, and distribution of data transform raw data into defensible data products and support the extraction and distribution of those products.

7.2.1 Prefield Functions

The functions in this category are developed before the field activities begin. The following functional descriptions generally address these IM activities.

The development of paper forms for data collection and instructions for completing those forms is a combined effort of the Information Manager, Logistics Aide, indicator leads, and statisticians. Forms must be designed to capture all information efficiently in the field and set up to allow for efficient data entry. All forms are placed in individual macroplot packets with the assigned macroplot and sample numbers.

Software programming for both PDR and data entry systems involves the definition of requirements, development and testing of prototype systems, development of protocols for running and using the programs, tracking versions of a program, and documentation (mostly internal, minimal external) of programs.

Hardware set-up activities primarily include developing protocols for the testing of the GPSs, spectrometers, personal computers (PCs), and PDRs; the charging or replacement of batteries; reloading software; and replacement of PDR memory cards.

Identification and coding schemes must be developed to allow for the tracking of soils data forms and soil samples.

7.2.2 Field Functions

The IM functions in this category are carried out directly in the field at the base site after field activities by the field crews or the field coordinator. These include use of equipment, methods for tracking collected information, backup of information taken, and transfer of information from the field to the Information Center. The following description addresses the types of functions in this category for which procedures or documentation will be developed.

Protocols must be developed for proper use of the electronic equipment. These include testing or calibration of equipment before use (GPS, spectrometer, and PDR); collection of measurements with the GPS, spectrometer, and PDR; downloading of measurements from the GPS, spectrometer, and PDR; and uploading new programs from the PC to the PDR.

Tracking information collected in the field is accomplished in part by providing forms and predetermined site and sample numbers. Instructions for recording vegetation composition, structure, and abundance data, with the PDR will be developed. These procedures will cover basic data collection, saving the data and transferring the data from PDR to PC. Similar procedures for collecting spectral properties data with the PS-II will be developed along with procedures for naming data files and transferring the data from the PS-II to the PC.

Tracking of soil samples is provided by means of a preprinted soil sample shipping form included in each site packet with the basic site number and sample identification included. The shipping form is used to track the number of samples sent in a given shipment.

A backup of the information collected in the field is accomplished by providing protocols for downloading data from the PDR, spectrometer, and GPS to the PC; downloading data from the PC to disk; backup of disks; backup of forms; and printout verification of data collected on the PDR.

Protocols for transferring information from the field to the Information Manager include: online modem transfer, mailing of disks and forms, and mailing sample tracking information to the Information Manager and to the analysis laboratory with the samples.

7.2.3 Information Center - Data Base Development

Functions in this category are carried out by the IM staff after information is received from the field. Materials, forms, and disks are logged as received. Data received on forms are computerized and data received on disks are uploaded to the main system with checks on the files and their sizes. Data in the main system will be reviewed with computerized checks for completeness and consistency.

Information, forms, and original, edited, and combined files will be catalogued and archived. The GPS information will be combined with site information in the data files. Relationships between files in a GIS context will be developed by incorporating and integrating combined files into a GIS data base covering the entire study area.

Transfer of information to the EMAP data base involves the development of record structure, a data dictionary, a data set catalogue, and a data base scheme with defined relationships. Protocols will be developed for the addition and correction and retrieval of data in the data base.

7.2.4 Information Center - Data Verification, Validation, and Distribution

Following the field activities of the pilot, the main task of information management is to provide support for the data verification, validation, and distribution of datasets.

Each data set will be processed for quality assessment to verify that the contents accurately represent measurements taken in the field, all measurements are within scientifically acceptable ranges, and coded values are valid and to calculate the measurement quality attributes as defined by the QA plan. The result of this process is a verified data set.

Once the data sets are verified, then the data can be used in analysis for its designed and intended purpose. This process of using the data further analyzes and evaluates the data set, and validates its appropriateness for scientific use. The result of this process is a validated data set.

These verified and validated data sets will be managed at the Arid Information Center as an integrated data base. All data sets will be linked and documented to facilitate management, access, and distribution. The access and distribution of the data from these data bases will initially be restricted to team members of the Arid resource group. A record will be kept that tracks the distribution of this data within the group.

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