EPA/620/R-94/015
March 1994

ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

ARID ECOSYSTEMS 1992 PILOT REPORT

by

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ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

Arid Ecosystems Resource Group

William G. Kepner, Technical Director

Arid Ecosystems 1992 Pilot Report

NOTICE

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Proper citation of this document is:

Kepner, W. G., R. O. Kuehl, R. P. Breckenridge, J. M. Lancaster, S. G. Leonard, D. A. Mouat, T. G. Reinsch, K. B. Jones, A. C. Neale, T. B. Minor, and N. Tallent-Halsell. 1994. Environmental Monitoring and Assessment Program: Arid Ecosystems 1992 Pilot Report. EPA/620/R-94/015. U.S. Environmental Protection Agency, Washington, D.C.

ACKNOWLEDGMENTS

The preparation of this plan has been a combined effort requiring the contributions of a number of scientists from various universities, research institutes, public interest groups, and federal agencies. Contributors are listed below. This manuscript has benefitted from the review and comments of Michael M. Borman, U.S. Department of the Interior, National Biological Survey; Charles F. Hutchinson, Office of Arid Lands Studies, University of Arizona; Richard Inouye, Idaho State University; Wesley M. Jarrell, Oregon Graduate Institute of Science and Technology; and Walter G. Whitford, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas; Brian A. Schumacher, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, and Gregory E. Huber, U.S. Soil Conservation Service. Appreciation goes to John R. Baker, Deirdre O'Leary, Rod L. Slagle, and Donna W. Sutton, Lockheed Environmental Systems & Technologies Co. for their contributions and technical editing; and Jan Aoyama and Pat Craig (Lockheed Environmental Systems & Technologies Co.) for document processing and production.

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ABSTRACT

The U.S. Environmental Protection Agency and its collaborators have initiated a long-term, policy-relevant research project, the Environmental Monitoring and Assessment Program, focused on evaluating ecological conditions on regional and national scales. In 1992 the Arid Ecosystems Resource Group (one of a number of EMAP ecosystem monitoring and research groups) conducted a pilot study in the southeastern Utah portion of the Colorado Plateau. This report describes this first field activity for arid ecosystems, an element of the Environmental Monitoring and Assessment Program. The 1992 pilot study was developed to evaluate sampling plot design and the sensitivity of selected indicators. The study focused on four objectives related to plot design, indicator development, sampling frame material, quality assurance, information management, and logistics. The primary categories of indicators selected for evaluation in the 1992 pilot study were vegetation composition, structure, and abundance; spectral reflectance; soil properties; and soil erosion. Data were collected on 29 sites within two major resource classes--desertscrub and conifer woodland. This report describes the indicator measurement methods and the study results for each of the four objectives. Each of these sections includes recommendations based on the 1992 study. The final section summarizes the major conclusions and recommendations drawn from the 1992 pilot study, draws implications from the study results, and discusses planned future studies.

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ABBREVIATIONS AND ACRONYMS

AVHRR	advanced very high-resolution radiometer
CEC	cation exchange capacity
CV	coefficient of variation
DQO	data quality objective
EC	electrical conductivity
EMAP	Environmental Monitoring and Assessment Program
EMAP-Arid	Environmental Monitoring and Assessment Program Arid Ecosystems resource monitoring and research group
EPA	U.S. Environmental Protection Agency
GAP	U.S. Fish & Wildlife Service Gap Analysis Pyrogram
GIS	geographic information system
GPS	global positioning system
IM	information management
INEL	Idaho National Engineering Laboratory
MLRA	major land resource areas
MQO	measurement-level quality objective
NDVI	normalized difference vegetative index
OC	organic carbon
PSII	personal spectrometer II
QA	quality assurance
RUSLE	revised universal soil loss equation
SAR	sodium adsorption ratio
SCS	U.S. Soil Conservation Service
SIR	soil interpretation record
TM	Landsat thematic mapper
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USLE	universal soil loss equation
WEPP	water erosion prediction project
WRD	water retention difference

SECTION 1
INTRODUCTION

The primary goal of the Environmental Monitoring and Assessment Program (EMAP) is to monitor status and trends in the Nation's ecological resources (Thornton et al., 1993). It is the intent and purpose of the EMAP Arid Ecosystems Resource Group (EMAP-Arid) to measure and report on the extent, condition, and trends of several resource classes in the biogeographical provinces of nearctic and neotropical North America within the United States (Brown et al., 1979; Figure 1-1). Two resource classes, desertscrub and desert conifer woodlands, are representative of resources in the EMAP-Arid program. These resources were studied in a 1992 pilot study conducted in the southeastern Utah portion of the Colorado Plateau. This pilot study was the first EMAP field study in arid ecosystems.

Regionally important issues in the Colorado Plateau and in other arid ecosystems (Kepner et al., 1991) have been identified as biodiversity, livestock grazing, desertification, water resource management, air quality, and global climatic change. Three societal values related to these issues 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 framing assessment questions and the selection and use of indicators. These values are:

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

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

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

Several assessment questions related to these values were developed by arid ecosystem researchers. These questions guided the development of the 1992 pilot study and provided overall direction. One such question was, "What proportion of desertscrub and conifer woodlands in the Colorado Plateau with unacceptable species (e.g., presence of exotic or unpalatable species) and/or have soils with unacceptable soil erosion or salinity values?" Questions of this type will be answered under full regional implementation.

1.1 1992 PILOT STUDY

The National Research Council (NRC, 1990) has defined an approach for designing and implementing program-level monitoring programs (Figure 1-2) that EMAP-Arid is using as

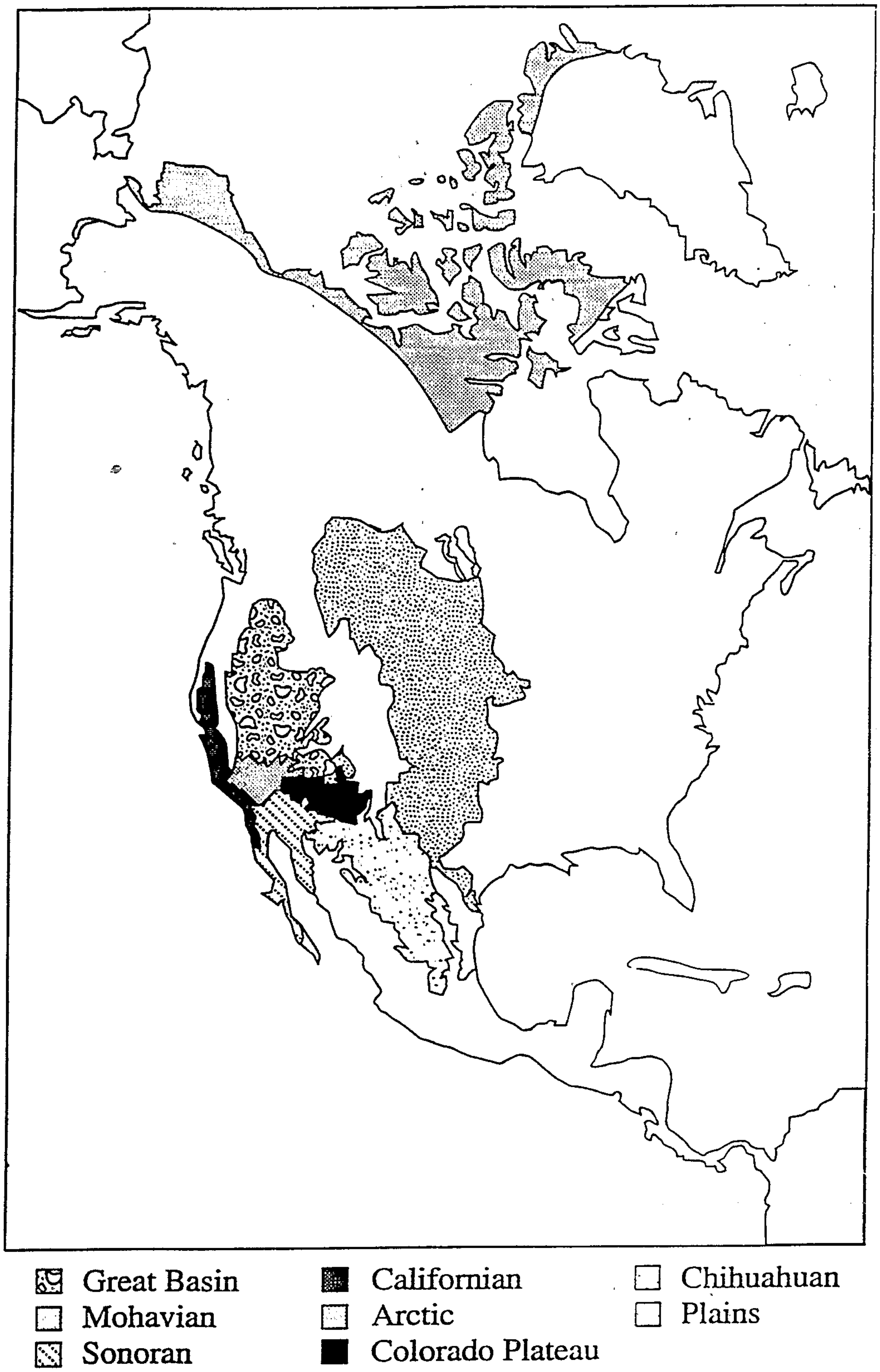

Figure 1-1. Biogeographic provinces of North America used in the EMAP-Arid Program.

a template. Pilot or exploratory studies, such as the EMAP-Arid 1992 pilot study, are an important beginning step in the interactive process of defining and redefining expectations, goals, and strategy for implementing a monitoring program (Figure 1-2). The EMAP-Arid 1992 study is at this critical step in the NRC approach and was undertaken to assess a common sample plot design and to evaluate indicator measurements recommended by the scientific community for arid ecosystems.

The EMAP-Forest plot design was selected for evaluation to determine if a common sampling design could be used across EMAP terrestrial resource groups. The EMAP-Forest researchers had previously evaluated the variance component of selected soil variables (e.g., particle size and carbon content) (Riitters et al., 1991) for plot design and these variables were similar to several of the soil properties under consideration by the arid group. However, there was no information about the EMAP-Forest sampling design related to the standard rangeland soil and vegetative sampling techniques and the spectral analysis approaches recommended by the scientific communities (Breckenridge et al., 1993; Mouat et al., 1992) as indicator measurements for EMAP-Arid.

The EMAP-Arid researchers selected a limited number of indicator measurements for testing. Indicator selection was based on review of the literature (Fuls, 1992; Bryant et al., 1990) and discussion with researchers who were conducting studies on arid ecosystems at Long-Term Ecological Research sites (Whitford, 1986) and in other areas with well-established data bases on ecological processes (e.g., experimental stations and U.S. Department of Energy sites). This indicator selection process, described in Breckenridge et al. (1993), led the EMAP-Arid resource group to focus on measurements or attributes of vegetation, spectral properties, soil properties, and soil erosion as measures of stress (e.g., from grazing) and as potential indicators of productivity and biological integrity (Schlesinger et al., 1990).

The 1992 pilot study was developed to evaluate sampling plot design and the sensitivity of selected EMAP-Arid indicators using the EMAP design for site selection. The design uses a randomly placed systematic grid to identify sampling site locations (White et al., 1992; Overton et al., 1990). Comprehensive assessment of the ecological condition of the Colorado Plateau, the ultimate goal for EMAP resource groups, was beyond the scope of this initial study. The pilot study was also not intended to derive conclusions about those values, issues and questions previously identified as significant in arid ecosystems.

1.2 REPORT OVERVIEW

The conceptual approach, objectives, rationale, and processes that led to the choice of study sites and selection of indicator measures to be tested are described in the EMAP-Arid Colorado Plateau Pilot Study--1992 Implementation Plan (Franson, 1993). The four objectives established in the implementation plan for the 1992 pilot study form the organizational basis of this report. These objectives are summarized in Section 2 which also includes a description of the pilot study area and the sampling plot design. Section 3 summarizes the indicator measurements. Sections 4 through 7 present results and recommendations relative to the four study objectives summarized in Section 2. The knowledge gained during the 1992 pilot has helped significantly

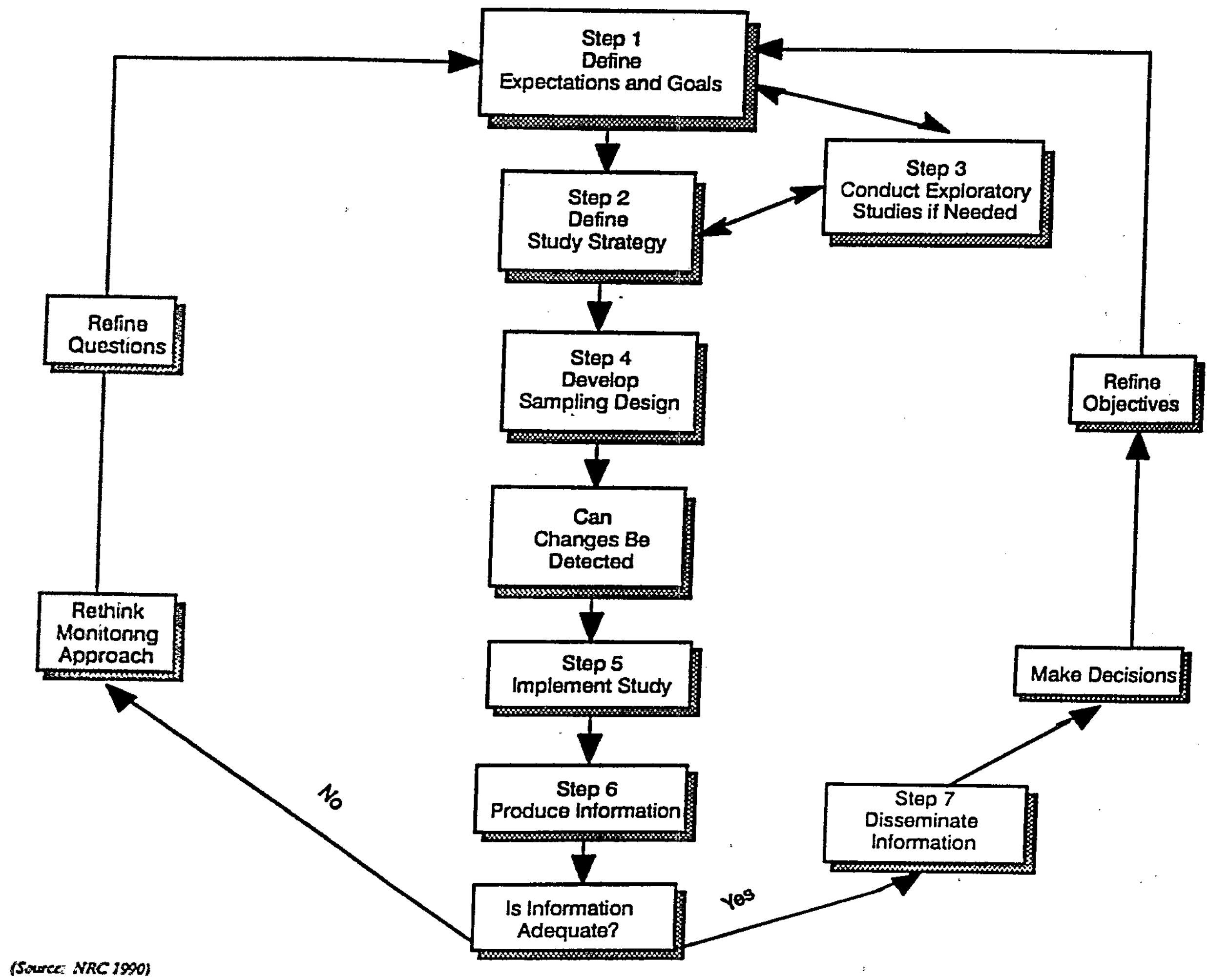

Figure 1-2. The elements of designing and implementing a monitoring program (NRC, 1990).

to define questions relative to these objectives and to establish new pilot study objectives. Section 8 summarizes the conclusions and recommendation from this study and describes ongoing and proposed studies.

SECTION 2
COLORADO PLATEAU PILOT STUDY

The Colorado Plateau Pilot Study was designed to consider issues critical to the success and implementation of the EMAP-Arid program. These issues included plot design, indicator development, sampling frame material, quality assurance, information management, and logistics. This section describes the objectives of the pilot study, provides an overview of the study area, and describes the site selection process and sample plot design.

2.1 STUDY OBJECTIVES

The assessments of sampling variance and indicator sensitivity were the primary objectives. Evaluation of the sampling frame and extent and of implementation activities related to logistics, quality assurance, and information management were also considered important issues and were established as additional objectives. The specific objectives were:

- Assessment of sampling variance. Evaluate the EMAP-Forests Resource Group sampling plot design relative to the selected EMAP-Arid indicators.

- Indicator sensitivity. Evaluate the sensitivity of selected indicator measures to independent evaluations of site condition as designated by various land management agencies.

- Sampling frame and extent. Evaluate the utility of using classified TM imagery and other data acquired from the U.S. Fish and Wildlife Service Gap Analysis Program (GAP) to select frame materials for the pilot study and future studies and to provide data for extent estimation of arid ecosystems.

- Quality assurance, information management, and logistics. Evaluate the quality assurance, information management, data analysis, logistical, and reporting requirements and constraints based on the pilot study area.

2.2 1992 PILOT STUDY AREA

The Colorado Plateau is an arid and semi-arid tableland in the southwestern United States (Franson, 1993). The entire 130,000-square mile region of the Colorado Plateau is much more extensive than needed to fulfill the requirements of the intended indicator evaluation pilot; therefore, only a portion of the Plateau was chosen for data collection (Figure 2-1). This

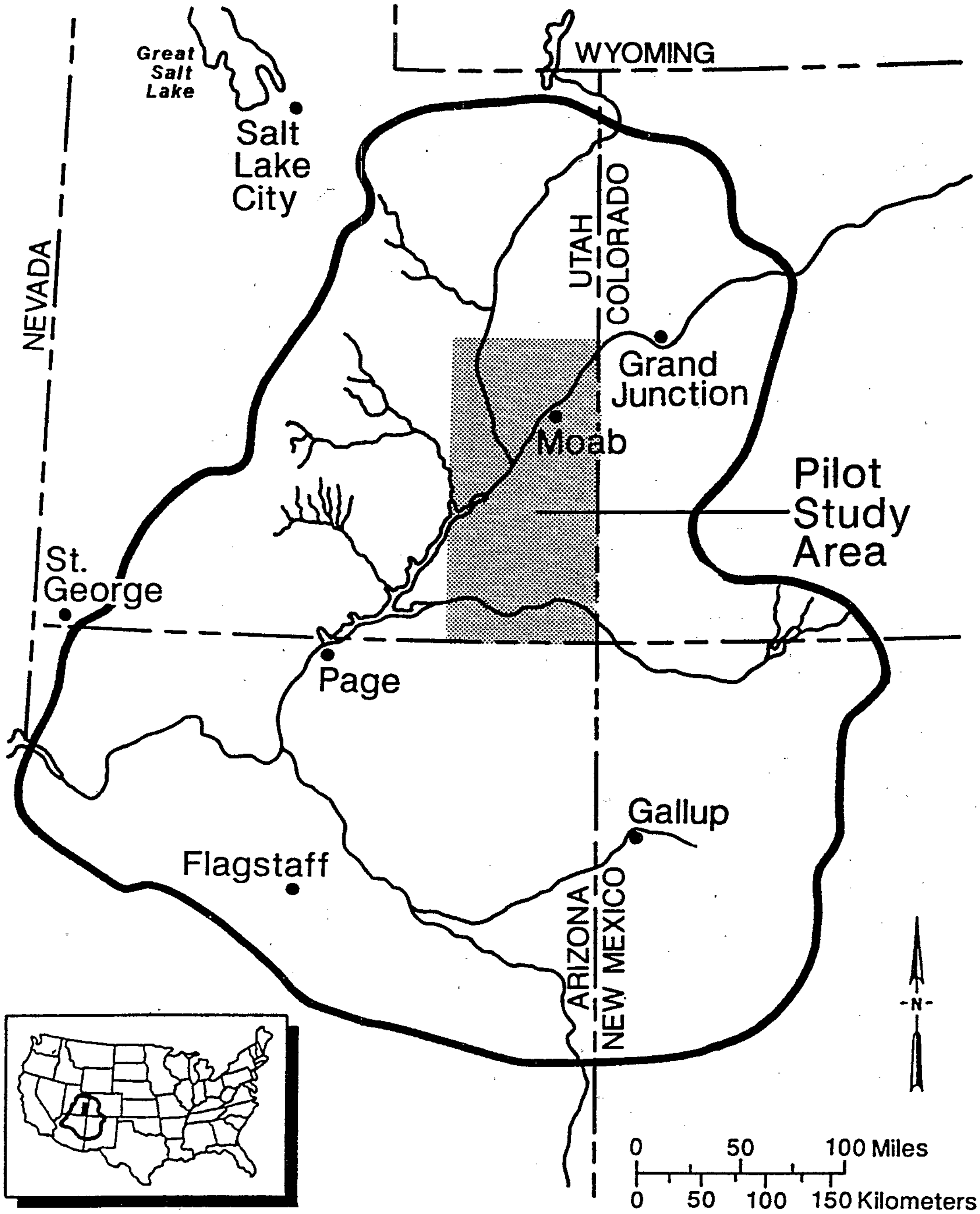

Figure 2-1. Location of the 1992 pilot study area within an outline of the Colorado Plateau.

region is predominantly managed as federal lands, i.e., Bureau of Land Management, National Park Service, and Forest Service, and part of Navajo Nation, state, and private lands. The diversity of ownership and jurisdiction promoted interagency participation in the pilot implementation. The area is bisected by the Colorado River and includes many canyon lands that allowed for evaluation of logistical requirements in some of the most difficult terrain that EMAP-Arid activities will likely face. The area includes two resource classes which are prevalant within the Colorado Plateau (i.e., desertscrub and conifer woodlands) that were chosen for indicator evaluation.

2.3 SITE SELECTION

Sampling points for the 1992 pilot were shifted approximately 13.5 km to the northeast of the original EMAP grid point. This strategy allowed the EMAP grid to be maintained, but did not compromise the original sampling points that will be used for full-scale implementation. This shift was performed using geographic information system (GIS) software to densify the original EMAP digital grid and select the new grid. The new grid was then overlaid onto a Landsat-derived vegetation plot developed by the GAP to identify which plant communities were associated with the new, shifted sample points.

The resultant shift of the original points yielded 63 points within the study area for the 1992 pilot study. The design was structured such that if the sample site fell within either desertscrub or conifer woodland, sampling would proceed. If the sample site fell into some other subpopulation (e.g., a grassland), it would not be sampled. It was expected that sampling would occur on approximately 30 sites, with about 15 in each subpopulation. In fact, the overall process resulted in 21 desertscrub, 12 conifer woodland, and 6 mixed vegetation (e.g., grassland, agriculture) or nonsites (e.g., water bodies) being selected for sampling in 1992. Of these 39 sites, 10 were identified as not fitting the resource class requirements, leaving a total of 29 sites included in the final study.

2.4 SAMPLE PLOT DESIGN

The sample plot design selected for evaluation during the 1992 pilot study resembled that in use by the EMAP-Forest resource group (Kucera and Martin, 1991). This design (Figure 2-2) was modified for the methods used for arid ecosystems (Franson, 1993). The sample plot consisted of specific plot designs for each indicator, overlaid on one another, resulting in a hexagon-shaped plot (approximately 1 hectare in area). A central circular subplot was centered on each designated sampling point. Six satellite subplots were located with their centers 40 m from the center point and oriented at 0, 60, 120, 180, 240, and 300 degrees relative to compass north. Each of these circular subplots was 7 m in radius, with an area of 154 m^2. Radial transects, AR, BR, and CR were extended from the center point to the centers of subplots A1, B1, and C1, respectively. Exterior transects, AE, BE, and CE were extended between centers of subplots A1 and A2, B1 and B2, and C1 and C2, respectively. Soil sampling locations were placed at AP, BP, and CP, each 20 m from the associated subplot center point and oriented to enhance association between soils and the two respective vegetation transects.

Shrubs and trees greater than 1.5 m in height within subplots MD, A1, B1, and C1 were identified and measured as a part of the vegetation composition, structure, and abundance indicator. Shrubs less than 1.5 m in height were measured in 1- by 2-m quadrats, aligned with

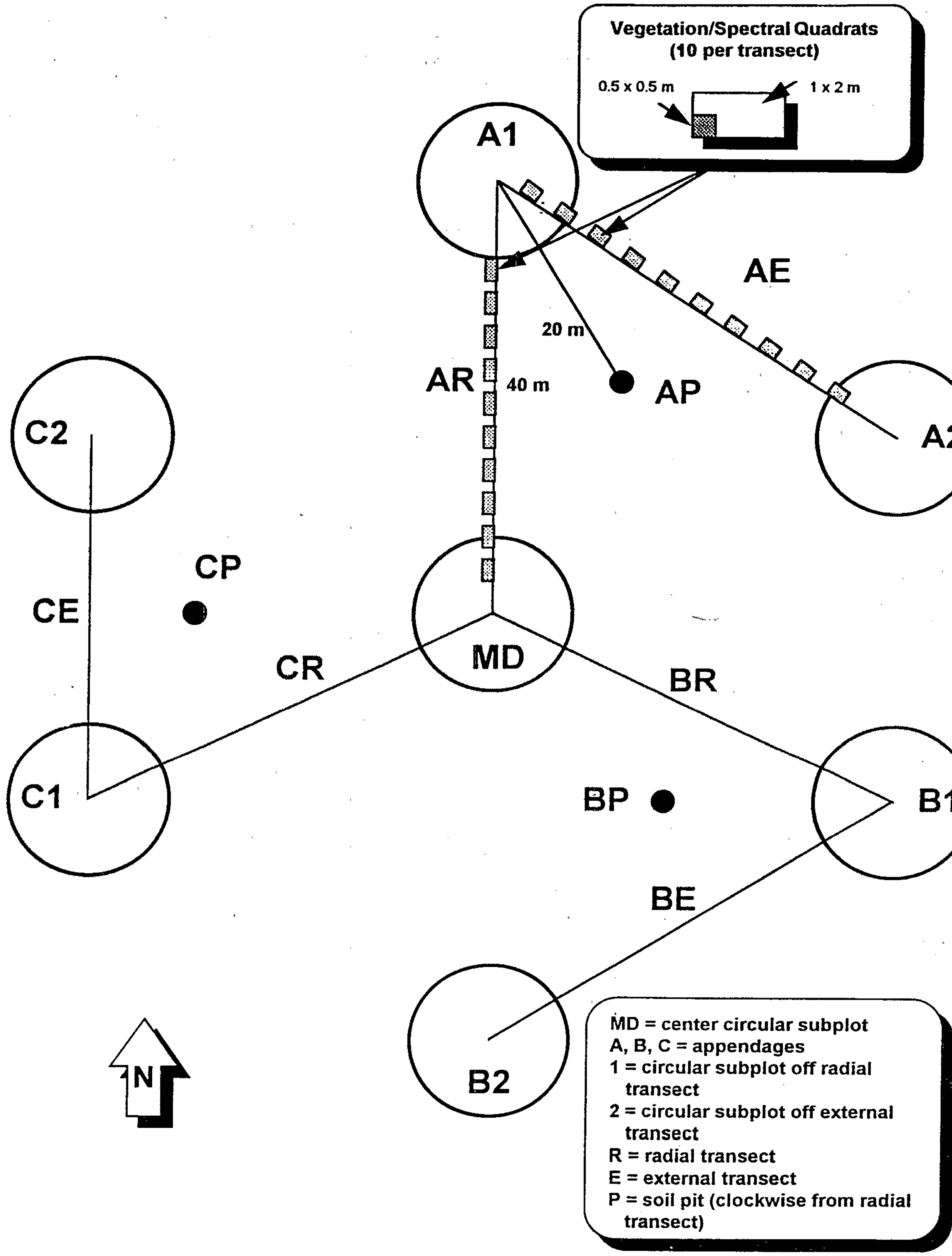

Figure 2-2. Diagram of indicator sampling areas at EMAP-Arid 1992 Pilot Study sites.

their long axis parallel to each of the six transects. The quadrats along each transect were separated by 1-m intervals, with 10 quadrats sampled along each of 6 transects, for a total of 60 quadrats sampled on the plot. Within each of the 1- by 2-m quadrats, a 50- by 50-cm subquadrat was measured for vegetation composition, structure, abundance of forb and grass ground cover, and surface soil attributes.

At one of the three soil sampling areas (AP, BP, and CP), a soil pit was dug to evaluate characteristics of the soil profile and collect samples to be sent to the laboratory for analysis of physical and chemical soil properties. At the two remaining areas, soil was extracted and described to 50 cm and augered and described below this depth to 1.5 m or bedrock. Soil samples were collected from the top two horizons for laboratory analysis. If one or both of these areas belonged to a different soil series than the first, then a soil pit was also excavated at that site. The above approach was used at 22 of the 26 study plots (permission was not granted for excavations at the remaining three sites). At the other four plots, all three soil sampling areas were excavated and described to a depth that included the top two horizons.

Information on spectral properties was collected at 13 sites. Because only one instrument was available for surface measurements, it was not possible to visit all the sites. Measurements were made within each of the seven circular subplots on a grid, with vertical and horizontal spacing between sampling points of 3 m, centered on the subplot center. In addition, along six vegetation transects, spectral measurements were evenly spaced in the 1- by 2-m area in every other quadrat, beginning with the first quadrat, for a total of 6 quadrats on a transect.

The entire sample plot represents a "conceptual hectare." If one imagines that each circular subplot represents an area surrounding it that has a radius of 20 m (one half the distance between the center points), then the entire plot represents either a circle of radius 60 m and area of 11,310 m^2 or a hexagon with 60 m from the center to each vertex, with an area of 9,350 m^2. This is an important conceptualization, especially for the spectral properties indicator, as Landsat Thematic Mapper pixels are 30 m on a side, so that a 3 by 3 cluster of pixels represents 8,100 m^2 and a 4 by 4 pixel cluster covers 14,400 m^2 (Franson, 1993). Thus, the conceptual hectare of the sample plot can be linked with remotely sensed spectral data. The plot structure represents a nested design with one plot at each site, several subplots for each indicator, and potentially several samples within each subplot. This structure allowed for estimation of the variance for sampling design components for each indicator (Franson, 1993).

SECTION 3
INDICATOR MEASUREMENT METHODS

Vegetation composition and structure have been evaluated for decades in arid ecosystems and are well established as important indicators of ecosystem condition. The difficult decision for the 1992 pilot was to determine what type of measurement technique best fit within the EMAP approach. Numerous vegetative sampling techniques were evaluated including plot sampling, belt transects, and line intercept techniques (Brower et al., 1989). Most of the vegetative sampling techniques have been developed for measuring forage supplies for big game and other herbivores. The literature was reviewed and the EMAP-Arid researchers decided to use a modified Daubenmire (1968) approach because it provides the ability not only to measure vegetation attributes about species richness and diversity, but also to keep open options for relating this information to wildlife habitat in future pilots (Anderson and Ohmart, 1986).

A remote sensing approach to collect information about a site offers a number of advantages for indicator development such as producing spatially explicit estimates of ecological condition over entire regions in a cost-effective manner. A number of researchers have developed strong relationships between measurements and indices derived from remote sensing and ecosystem variables. The Normalized Difference Vegetation Index (NDVI) is such an index and researchers have shown very high relationships between NDVI developed from satellite and ground measurements and leaf area index. The leaf area index correlates strongly with a number of other extremely important ecosystem variables such as primary productivity and biomass (Hobbs and Mooney, 1990; Running, 1990). The NDVI was selected as a candidate indicator for the 1992 pilot study because it has both a demonstrated relationship to vegetation parameters and a lack of sensitivity to atmospheric conditions (Anderson et al., 1993; Holben et al., 1980; Holben and Fraser, 1984; Holben, 1986; Hobbs and Mooney, 1990; Peters et al., 1993); in addition, it has been used to monitor phenological (vegetation) variables on regional, continental, and global scales (Tucker et al. 1986; Townshend and Justice, 1986; and Justice et al., 1985). The Landsat TM satellite data were used to determine NDVI because the waveband location for deriving information concerning vegetation parameters is superior to multispectral scanner (MSS) data and the pixel size of 30 by 30 m correlates more easily with field-based measurements than does the 1.1- by 1.1-km pixels of the Advanced Very High Resolution Radiometer.

Soil properties were selected because they were determined to be critical in evaluating ecosystem health and interpreting vegetative information. Articles by Schlesinger et al. (1990), Fuls (1992), Holmgren (1988), Lugo and McCormick (1981), Grossmat and Pringle (1987), and West (1990) provided the rationale for looking at soil parameters (physical, chemical, and biological [i.e., crusts]) and focusing on their implications to management options, plant growth and the water balance. Soil erosion was also included in the 1992 pilot because most of the data required for estimating errosion were collected in the soil profile. These data could then be used as inputs to the Revised Universal Soil Loss Equation (RUSLE) erosion models for evaluating the relationship between soil erosion and site condition. Several researchers have identified a positive correlation between increased runoff and erosion with decrease in the seral stage of arid ecosystems (Schlesinger et al., 1990; Renard and Simanton, 1991) and evaluated the sensitivity of the models (Renard and Ferreira, 1993).

The following sections provide a summary of the field methods used in the 1992 pilot study. Sections 3.1 and 3.2 discuss vegetation and spectral methods respectively. Section 3.3 discusses methods for soil properties and soil erosion. For those cases where published references are available for the method, discussion is limited and the reader is referred to the primary reference.

3.1 VEGETATION MEASUREMENTS

The composition, structure, and abundance of vegetation have been recognized as important measures of the condition of arid ecosystems. These measurements are considered diagnostic in determining changes in biological condition at the organism, population, community, and ecosystem levels. They particularly reflect the relationships of cover and height to water availability and production in the arid West (Nemani and Running, 1989; Tausch and Tueller, 1990; Tausch and Nowak, 1991). In addition, ground-based cover measurements can be used to assess the accuracy of remotely sensed spectral properties. During the 1992 survey, related site and soil characteristics were observed and recorded simultaneously with vegetation sampling. Specific measurements included:

- Vegetation Cover--Percent vegetation cover by species was determined using the Daubenmire cover class method. The method was modified as described by Baily and Poulton (1968) by adding a seventh cover class (<1 percent) to estimate trace occurrences of ground cover (Table 3-1).

- Species Frequency--Quadrat sampling methodology provided for the determination of frequency by plant species.

- Ground Cover--Ground cover as total vascular plant cover, litter, rock, bare soil, and cryptogams was measured and provided important information for soils and erosion analyses. Ground cover for all but total vascular plant cover was determined both for the total quadrat and for the canopy interspace area.

- Species Composition--Through both quadrat sampling and site survey, the species composition of each site was determined and recorded.

- Essential Complementary Data--Information collected included the description of topography and landforms surrounding the sample location, the slope and aspect of the site, and land use in the area.

Vegetation sampling followed a procedure adapted from Rangeland Monitoring Trend Studies (USDI, 1985). Trees greater than 1.5 m in height and widely spaced and large shrubs greater than 1.5 m in height were measured in four fixed area subplots. Subplots were 14 m in diameter with one centered on the plot center and the centers of the remaining three placed 40 m

TABLE 3-1. MODIFIED DAUBENMIRE COVER CLASSES

Class	Cover range %	Range mid-point %
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

from the plot center on radial transects spaced 120° apart. All individual trees and large shrubs in each subplot were measured for two crown diameters (Meeuwig, 1979), height, and either diameter root crown or diameter breast height. For each tree species within each 14-m circular subplot, the number of seedlings and saplings less than 1.5 m in height were also recorded. Table 3-2 summarizes data recorded within the quadrats and subplots as illustrated in Figure 2-2.

TABLE 3-2. INFORMATION RECORDED WITHIN QUADRATS AND CIRCULAR SUBPLOTS

50- by 50-cm subquadrat:

1. Cover class (Table 3-1) for:
   - Total vascular plant canopy cover
   - Surface features for total plot and for canopy interspace areas:
     - rock fragment cover by class: gravel (2 - 75 mm), cobbles (75 - 250 mm), and stones (>250 mm)
     - litter cover
     - surface type by class (Eckert et al., 1986): I, II, III, IV, and unclassified
     - cryptogamic 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 and forb species.
3. Cover class of basal area for each herbaceous grass and forb species.

1- by 2-m quadrat:

1. Plant species identification for each shrub (plants less than 1.5 m in height) species.
2. Cover class of canopy for each shrub species.

14-m circular subplots (MD, A1, B1, and C1, Figure 2-2) for each individual tree and shrub greater than 1.5 m in height:

1. Species identification from National List of Scientific Plant Names (USDA, 1982, as amended).
2. Longest crown diameter and the longest one perpendicular to it.
3. Height.
4. Basal trunk diameter for trees or diameter root crown for shrubs. When trees or shrubs have multiple trunks, all trunks were measured.

Voucher specimens for any unknown species were collected and preserved in a plant press for later identification. Such species were assigned a sample number for use on data forms until species identification could be confirmed.

To fully characterize the vegetation composition of the site, a general search of the area was made to identify any species present on the site but not encountered in the vegetation transects or circular subplots. These species were only listed and no other data was recorded for them.

3.2 REMOTE AND GROUND-BASED SPECTRAL MEASUREMENTS

In the 1992 pilot study, spectral data from the Landsat Thematic Mapper (TM) were compared with concomitant ground-based spectral measurements of vegetation and soils obtained through the use of a portable handheld spectroradiometer. A TM digital image file from an overpass on August 20, 1992, was acquired for the 1992 pilot study from path 036, row 034. The file is geocoded and covers all but the most southerly two sites of the pilot study sampling area in southeastern Utah.

The Landsat TM sensor collects data, which can be converted to indicate radiance from the Earth's surface, every 16 days at the same time of day, about 10:00 a.m. in the case of southeastern Utah. Data are collected in pixels, which measure 30 by 30 m on the ground, as a radiance value for each of seven broad wavebands. Bands 1, 2, and 3 correspond to blue, green, and red visible light. Band 4 is a near infrared band, Bands 5 and 7 are in the middle of the infrared spectrum, and Band 6 is in the thermal part of the spectrum (Figure 3-1, Table 3-3). During the developmental phase of the TM sensor, a deliberate decision was made to position wavebands in such a way as to derive the maximum information possible concerning vegetation parameters (Lillesand and Kiefer, 1987). As a result of this decision, five of the seven wavebands are located in wavelengths where significant vegetation information may be obtained (Table 3-3).

All natural objects reflect solar radiation to varying degrees at different wavelengths, resulting in a spectral curve that may contain distinctive features and may be used to identify certain physical properties of the object (Lillesand and Kiefer, 1987). Healthy green vegetation produces a spectral curve that is characterized by a reflectance peak at about 550 nm, a narrow absorption trough at 680 nm, a sharp increase in reflectance between 680 and 760 nm (the "red edge"), a plateau between about 760 and 1,100 nm, and then two broader absorption features at 1,400 and 1,900 nm, with interspersed peaks of diminishing reflectance (Figure 3-1).

Red soil, a characteristic of the sites investigated during the 1992 Pilot Study, also has a distinctive spectral curve, gradually increasing in reflectance from 400 to about 750 nm and then leveling into a plateau. The chemical composition of soil is varied and will usually be mirrored by the peaks and troughs in reflectance at specific wavelengths that are characteristic of the different chemicals involved.

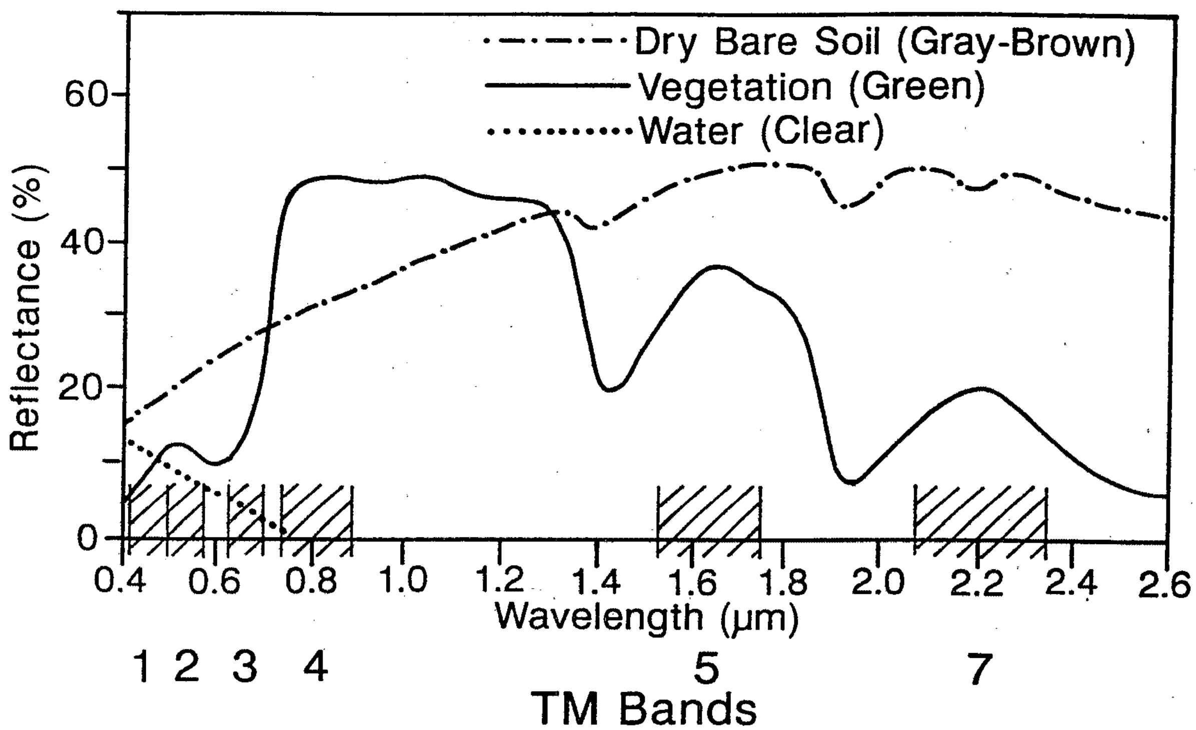

Figure 3-1. Typical reflectance curves for vegetation, soil, and water with Landsat TM wavebands (numbered). Band 6 (10.5 to 12.5 μm not shown). (After Lillesand and Kiefer, 1987).

TABLE 3-3. PRINCIPAL APPLICATIONS OF LANDSAT TM SPECTRAL BANDS
(from Lillesand and Kiefer, 1987)

Band	Wavelength (μm)	Nominal spectral location	Principal applications
1	0.45-0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52-0.60	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63-0.69	Red	Designed to sense in a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76-0.90	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55-1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6[a]	10.4-12.4	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7[a]	2.08-2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

[a] Bands 6 and 7 are out of wavelength sequence because band 7 was added to the TM late in the original system design process.

Thematic mapper wavebands vary in width between 60 and 270 nanometers, and radiance values are averaged within each band to give a single value. Several factors affect the quality of data collected by the sensor, some of which, such as spacecraft motion, are corrected on board the satellite. In addition, atmospheric conditions greatly affect data quality, especially for shorter wavebands, and it is necessary to radiometrically calibrate radiance values before any image processing or interpretation takes place (Sabins, 1987). The sensor collects radiance values at 256 levels of brightness, which can, in turn, be used to discriminate the objects being sensed.

Chavez (1989) has developed two methods to perform radiometric calibration of Landsat data, one using ground-based measurements of calibration targets and the other using a relative power law model to predict the atmospheric haze values for the multispectral bands, based on a starting band haze value that is selected for each image on an individual basis. The Landsat images used for the 1992 Pilot Study were radiometrically calibrated using the second method developed by Chavez (1989). Bands 1 through 4 were calibrated individually, based on their maximum reflectance for a specific pixel and with a different stretching parameter applied to each, in order to optimize the dynamic range of radiance. These converted numbers (for example, in band 1 an input radiance of 100 was reset to 79 and an input of 230 was reset to 251) were then multiplied by a constant to convert them to reflectance. For Band 1 this constant was 10, for Bands 2 and 3 it was 7, and for Band 4 it was 5. The conversion to reflectance values was carried out in order to enable Landsat TM data to be directly comparable to ground-based spectrometer measurements, which were obtained in a reflectance rather than radiance mode.

The ground-based spectral measurements were made between late June and late August with a portable Personal Spectrometer II (PSII). The instrument incorporates a PC-compatible computer with an LCD screen, to allow for real-time data display, and a battery that lasts 2 hours. Calibration procedures followed those given in the Personal Spectrometer Procedures Reference Manual (Analytical Spectral Devices, 1993). Measurements are made using an optical fiber 2 m in length, terminating in a hand-operated gun with an adjustable field of view that permits measurements of targets from 1 mm to many meters in size depending on the instrument height above object level. For the pilot study, the instrument was held 1 m above the surface to be measured resulting in the acquisition of reflectance values from a circular area 28 cm in diameter. In the case of pinyon and juniper trees or large shrubs where it was impossible for the gun to be held 1 m above the target, a surrogate branch or shrub of the same species was chosen in the same phenological state as the original target. Reflectance data from the PSII were collected in 4,095 brightness levels in 512 wavebands, each about 1.4 nm in width, between 350 and 1,050 nm.

The NDVI was calculated for both Landsat TM and PSII reflectance data collected for the 1992 pilot study and is discussed in the results in sections 4 and 5. The NDVI makes use of the contrast between the high reflectance of vegetation in the near infrared (760 to 900 nm) and the low reflectance in the visible red wavelengths (630 to 690 nm). It is normally derived from either Landsat TM or Advanced Very High Resolution Radiometer (AVHRR) satellite data. For Landsat TM, this index uses data collected in Bands 4 and 3; thus,

$$NDVI = b4 - b3/b4+b3$$

3.3 SOIL MEASUREMENTS

Soil quality directly influences 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.

3.3.1 Soil Properties

Soil quality was not measured directly, but it is associated with a number of soil properties measured during the pilot study. The three soil property measurements or attributes were: (1) soil profile (description and analysis)--the characterization of a vertical section of the soil through all its horizons and extending into the parent material; (2) the top two mineral soil horizons (description and analysis); (3) and soil surface attributes--description of attributes of the topmost soil surface including vascular vegetation, rock fragments, cryptogams, bare soil, litter, surface type, and surface roughness. The three soil properties that were measured in the pilot study control both soil moisture and susceptibility to erosion processes. The following soil indicator measurements were collected during the 1992 pilot study:

- Full soil profile description and analysis from one hole dug to 1.5 m or bedrock.
- Auger hole description of soil profile and soil-surface description and analyses of surface soil at remaining two locations.
- Description of selected surface soil attributes along six 40-m transects (these data were collected by the vegetation group).

Soil scientists used materials extracted from soil pits and auger holes at each site to describe soil characteristics, draw a soil map, collect samples, and compare the described soils to the soil survey map unit and components previously developed for the site. The soil series or family at each site shown in Appendix A was determined from the soil descriptions. The soil series phase was used as a key to access the soil interpretation record (SIR) of the USDA Soil Conservation Service. The SIR contains estimates of soil properties and interpretive information. A soil series may have multiple SIRs, and thus the soil series must be matched to the appropriate critical phase criteria on the SIR. Because the appropriate SIR number was not recorded at the time of sampling, a match was made later according to the scientist's best judgment. In the future, the critical phase criteria should be recorded at the time of sampling along with the appropriate SIR and phase identification. Soil maps were used to determine the percentage of soil at each site. When different soil series were noted for the site, data were weighted by multiplying values by the percent soil of the series at the site.

Soil samples were collected from at least one soil pit. When possible, the soil pit was located at the edge of a canopy boundary. This location was chosen to provide consistent sampling protocol and to try to obtain a mixed sample of interspace and undercanopy soil. Table 3-4 summarizes the soil sample analyses methods used in the laboratory.

TABLE 3-4. METHODS FOR SOIL SAMPLE ANALYSES IN THE EMAP-ARID PROGRAM

Parameter	Selected method[a]
Sample preparation	1B1
Carbonate clays[b]	3A1d
Cation exchange capacity	5A8
Electrical conductivity	8I
Organic carbon	6A2
Sodium adsorption ratio	5E
Bulk density	4A1
Particle size analysis	3A1
Water retention difference	4C1
pH soil-water suspension	

[a] United States Department of Agriculture-Soil Conservation Service. 1992 Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42. Version 2.0. U.S. Government Printing Office, Washington, D.C.

[b] Carbonate clay analysis only performed when indicated by effervescence in 1 N HCl drop test.

3.3.2 Erosion Index Indicator Measurements

Soil erosion is almost universally recognized as a serious threat to the productivity and sustainability of ecosystems as evidenced by the fact that most governments in the world give active support to programs of soil conservation. Soil erosion from wind and water can be measured directly or calculated using a variety of models. Because accurate field measurements often require extensive instrumentation and sampling of multiple plots (Larson et al., 1983; Breckenridge et al., 1991), EMAP-Arid researchers decided to use modeling as an alternative approach to determine site erosion. The Revised Universal Soil Loss Equation (RUSLE) (USDA-ARS, 1991) was selected to evaluate erosion during the pilot study. This model was evaluated for the ability to construct an erosion index for a nonagricultural site. The EMAP-Arid researchers used the RUSLE formula to determine soil erosion rates. The RUSLE formula (USDA-ARS, 1991) is:

$$A = R \times K \times LS \times C \times P$$

where:

A = average annual soil erosion (t/ac/yr)
R = rainfall and runoff factor
K = soil erodibility factor
LS = slope-length and slope-steepness factor
C = cover and management factor
P = support practice factor.

The R factor was determined using nearby climatic stations. The P factor used for all sites was 1. The LS factor was measured at each site. The K and C factors were calculated from measured and estimated data (Table 3-5). The K factor can also be obtained from the USDA-Soil Conservation Service soil interpretation record (SIR). The range of SIR K factors values are 0.15 to 0.45.

TABLE 3-5. MEASURED AND ESTIMATED DATA NEEDED TO CALCULATE K AND C FACTORS

Measured	Estimated
Slope length	Permeability
% slope	Field roughness
% very fine sand	Root mass in top 4 in.
% silt	
% clay	
% organic matter (1.72 x organic carbon)	
Surface structure	
Rock fragments within the soil	
% ground cover (with lichen and moss)	
% canopy	
Above ground biomass	

SECTION 4
ASSESSMENT OF SAMPLING VARIANCE

The primary resource classes that must be sampled by the EMAP-Arid group can be broadly identified as extensive or as resources that do not have distinct boundaries. Extensive resources such as desert woodlands are generally not easily identified as populations. The geographic distribution of extensive resources can be fragmented and discontinuous over the regional landscape. The geographic continuity of extensive arid resources is frequently interrupted by urban areas, areas of agricultural development or other natural systems such as forests; thus, these resources do not always have well-defined boundaries.

Two extensive resources, conifer woodlands and desertscrub, were studied during 1992 to assess indicator measurement variance. Table 4-1 summarizes those sites selected and sampled. A variance component for a resource condition indicator, estimated from the sample data, describes the variability in the resource condition over its geographic extent. Various other statistical descriptors such as the cumulative distribution function and quartile frequencies can be used to depict that variability for assessment and interpretive purposes. The spatial variability of the measured indicator among the sampled sites expresses the actual variability in the resource condition if no other extraneous variation interfered with the sampling process.

The process of collecting samples can produce extraneous variability in the indicator measurements in addition to the variability associated with the resource condition. The EMAP survey design protocols include annual visits to sampling sites throughout the region and will require multiple sampling crews to procure the measurements within adequate time frames. The utility of indicators of resource condition to some extent depends upon the degree to which these extraneous sources of variation inhibit the ability of the indicator measurement to describe resource characteristics. Knowledge of these variance values is necessary not only to construct confidence intervals for the measured indicators but also to evaluate the viability of the measurements as indicators. The magnitude and influence of each of these components of variability must be evaluated by the EMAP-Arid program as it progresses through the indicator development process. Variance components that continue to require a high level of investigation include those associated with the year, crew, measurement, and plot design.

Year Variance--The year component of variance arises from yearly fluctuations of the indicator measurements about some central value that may be expected regardless of the presence or absence of an overall trend in the condition of a resource from year to year. Evaluation of this natural variation in the condition of a resource as a result of climatic and other associated natural changes will be important to the detection of trends of a more fundamental nature to the systems.

The graphs in Figure 4-1 illustrate how high extraneous variability can inhibit the utility of a condition indicator that has some response to yearly transient climatic fluctuations. The dashed

TABLE 4-1. SITES SELECTED AND SAMPLED IN THE 1992 COLORADO PLATEAU PILOT STUDY

Site	Resource Type	Indicator Measurements Sampled*
20752	Conifer woodlands	V SL
20753	Desertscrub	V SL SP
20755	Conifer woodlands	V SL SP
20758	Desertscrub	V SL SP
20907	Conifer woodlands	V SL
20908	Conifer woodlands	V SL SP
20911	Conifer woodlands	V SL SP
20913	Desertscrub	V SL SP
21059	Desertscrub	V
21060	Desertscrub	V SL SP
21061	Desertscrub	V SL SP
21062	Desertscrub	V SL
21064	Conifer woodlands	V SL
21065	Desertscrub	V
21210	Desertscrub	V SL SP
21211	Conifer woodlands	V SL
21212	Desertscrub	V SL
21213	Desertscrub	V SL
21214	Conifer woodlands	V SL
21215	Conifer woodlands	V SL
21216	Conifer woodlands	V SP
21217	Desertscrub	V SL SP
21361	Desertscrub	V SL
21362	Desertscrub	V SL
21363	Conifer woodlands	V SL
21364	Desertscrub	V SL SP
21365	Conifer woodlands	V SL
21366	Desertscrub	V SL
21367	Desertscrub	V
COF101		V SL SP

* V = Vegetation
SL = Soils
SP = Spectral

line shows a fundamental trend in the resource condition via the indicator. The solid line shows the trend in the indicator measurement from field observations. The cyclical nature of the measured indicator around the trend in panel B as a result of yearly fluctuations greatly exceeds that shown in panel A. Although the measured indicator in panel A fluctuates around the fundamental trend, a general trend is still evident from the observations. In panel B, the response of the measured indicator to the climatic cycles is sufficient to mask evidence of a fundamental change. Each of the other sources of extraneous variability in the following discussion can have equally important effects on the measured indicator.

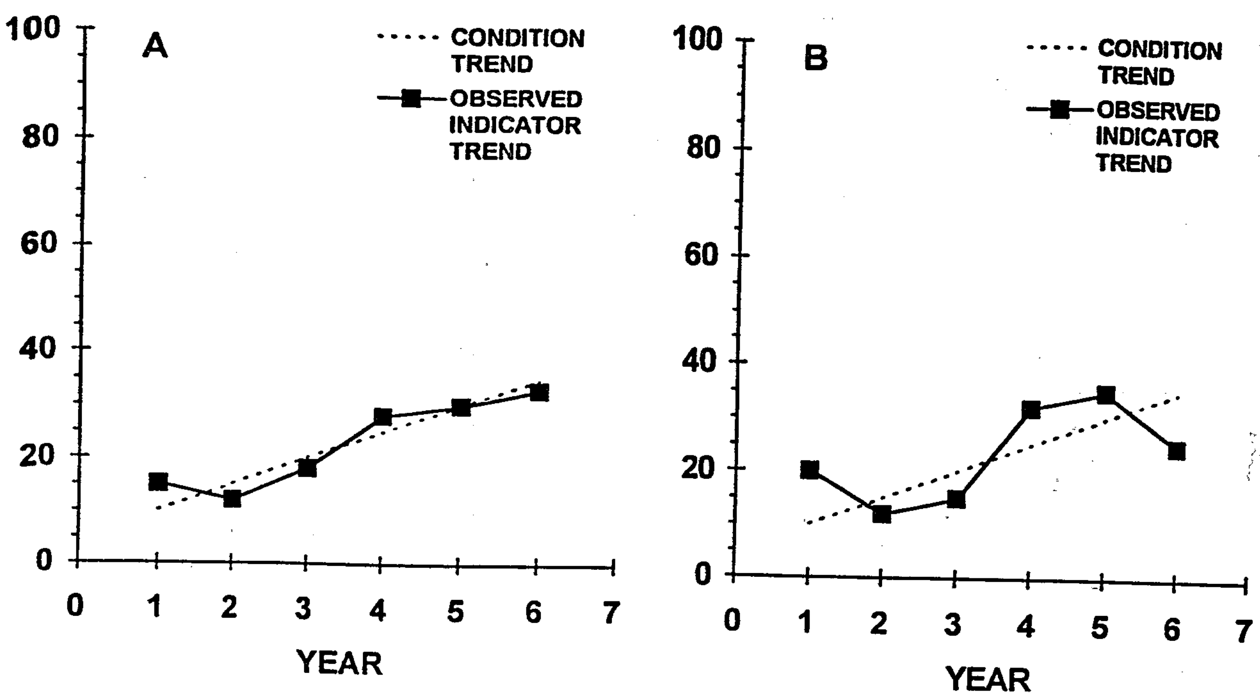

Figure 4-1. Theoretical effects of extraneous variability on indicator response illustrating how high extraneous variability can inhibit the utility of a condition indicator that has some response to yearly transient climatic fluctuations.

The annual variation in indicator value may differ among subregions in the monitored region. This variation is a response of the resource to local climatic and other effects that differ among subregions of the resource and is indicative of subregion variation in addition to that associated with annual fluctuations over the entire region. These differences in the annual variations among the subregions are represented as a location-by-year interaction component of variance in the monitoring program that must be evaluated for its effect on the detection of overall trends in the resource condition.

The activities associated with acquisition of data for indicator measurements produce variability beyond that associated with the natural transient variability in the condition of a resource over years or subregions. These sources of variation also must be evaluated for the magnitude of their influence on the statistical confidence of indicators. The following is a partial list of those components of the sampling system that can be targeted to reduce overall variance.

Crew Variance--The magnitude of the monitoring program will require multiple field crews with each crew collecting data at different sites than those visited by the other field crews using the same sampling protocols. The magnitude of crew-to-crew variability can be controlled through training, experience, and crew evaluation during the sampling period in addition to using as few crews as possible to complete the field work within the required time period.

Measurement Variance--Measurement variances are produced during measurement of the physical sampling units. Quality assurance and quality control protocols address measurement variance. These protocols track and sequence activities from sample correction to the validated and verified data base and incorporate procedures to minimize this component of variation.

Plot Design Variance--The measurements of indicators at each site require a response design at each sampling site. The response plot design consists of sampling units of various sizes and orientations from which to collect the observations required at a monitoring site to measure the response of a resource to the environment. The sampling units for extensive resources may consist of subplots or transects, such as those used in the 1992 EMAP-Arid pilot study, within which subsamples or quadrats are used for measurement purposes. The variability among these physical measuring units affects the precision of the indicator measures at the site. Thus, a characterization of the variance properties of these sampling units is essential to the development of a response design at monitoring sites that provides efficient statistical estimates of indicator measurements.

4.1 ANALYSIS AND RESULTS

The evaluation of indicator measurement variances associated with the sampling units that potentially could be used in a common plot design for monitoring EMAP-Arid extensive resources was a primary objective of the 1992 pilot study. Year and crew components of variance were not considered for investigation in the 1992 pilot study and will be determined from larger and long-term studies in the future. Measurement variances are discussed in Section 7.

Measurements considered most influential for the spectral, vegetation, and soils indicator categories were selected as candidates for evaluation of their variance properties. A single spectral measure, the Normalized Difference Vegetation Index (NDVI), was selected for the analysis. The variables selected for vegetation measurements were total vascular plant cover, shrub cover, and tree cover. Soil variables analyzed were the clay, silt, sand, and very fine sand percentages; organic matter; the soil erodibility factor (K); and the length-slope (LS) steepness factor.

The variables for this analysis also were selected to represent measurements acquired from different components of the plot design. The basic sampling units in the plot design at the sites were the 50- by 50-cm quadrats, 1- by 2-m quadrats, circular subplots, and soil subplots. The selected variables are each representative of uniquely different types of statistical variables which affect how the indicator variables are used in the analyses. Each category of indicator measurements will be discussed separately.

4.1.1 Vegetation Measurements

The three vegetation cover measures (total vascular plant, shrub, and tree cover) were measured on different measurement units in the plot. Total vascular plant cover was measured on 50- by 50-cm quadrats nested along the 10 quadrats. Shrub cover was measured on ten 1- by 2-m quadrats nested within each transect. Tree cover was measured in the fixed area circular subplots (see Figure 2-2).

Total vascular plant cover and shrub cover were scored in one of seven Daubenmire cover classes (see Table 3-1). Thus, the discrete random variables have seven possible values, expressed as the Daubenmire cover range midpoint. The linear statistical model to describe the variation for these two variables is a nested effects model:

$$Y_{ijk} = \mu + s_i + t_{j(i)} + q_{k(ij)} \qquad (1)$$

where $i = 1, 2, \dots, s$ sites; $j = 1, 2, \dots, t$ transects per site; and $k = 1, 2, \dots, q$ quadrats per transect. Y_{ijk} is the measurement (shrub cover or total cover) on the quadrat, μ is the average cover for all sites in the study, s_i is the difference of a particular site from the overall average cover, $t_{j(i)}$ is the difference of a transect on a site from the average for a site, and $q_{k(ij)}$ is the difference of a quadrat on a particular transect from the average for a transect.

The sites, transects within sites, and quadrats located on the transects are considered random samples of their respective representative populations for the purpose of this analysis. The objective of the analysis was to estimate the components of variance for the respective random effects in the model s_i, $t_{j(i)}$, and $q_{k(ij)}$.

Estimates of the components of variance are useful for planning future sampling strategies at the monitoring sites. The estimates are only useful if they exhibit some consistency in magnitude across the sampled population. Thus, an assumption of homogeneous variance of quadrats on transects and of transects within sites is necessary for useful component estimates. Both shrub cover and total cover are discrete variables measured in the seven Daubenmire categories on the quadrats. Discrete variables tend to have strong relationships between means and variances and can be expected to exhibit heterogeneous variance.

The residuals from an analysis of variance, where the residual equals the observed value minus the fitted model value, reveal the characteristics of the observations on the basic sampling unit. In the case of shrubs and total cover, the basic sampling unit is the quadrat. The plots of residuals versus fitted values for shrub and total cover on quadrats shown in Figure 4-2 reveal the patterned residuals for each of the measurements. Clearly the patterned residuals preclude the assumptions necessary for valid variance component estimates for the quadrats. Regardless of the magnitude of cover, represented by fitted values, only several categories of values appear for the residuals. The total cover residuals most clearly reveal the pattern of seven categories of cover. A patterned residual plot occurs regardless of whether the measurements were made on 1- by 2-m quadrats for shrubs or 50- by 50-cm subquadrats for total cover.

Ten quadrats were measured on each of the transects. The variability patterns for transects within sites can be evaluated from the transect means by using the average of the ten quadrats as a transect observation. An analysis of variance was conducted on the transect means with the nested model

$$Y_{ijk} = \mu + s_i + t_{j(i)} \qquad (2)$$

where Y_{ijk} is the transect mean, μ and s_i have the same interpretation as the model in equation (1), and $t_{j(i)}$ is the difference of the transect mean from the average for a site. The residual plots from the analysis of transect means for shrub cover and total cover shown in Figure 4-2 reveal a considerable contrast to those for the quadrat measurement. The patterned residual plot has been dispersed through the smoothing provided by the means. In addition no distinct variance pattern is apparent from the plot. A test of transect variance homogeneity among the sites with the Levene (median) test (Brown and Forsyth, 1974) did not reject the hypothesis of homogeneous variance; P = 0.12 for total cover and P = 0.07 for shrub cover.

These results indicate that a useful measure of shrub cover or total vascular plant cover for development of sampling plans is the average of groups of quadrats rather than the individual quadrat.

Tree cover was measured on four 7-m circular subplots at each site. Tree cover was determined from height and crown diameter measurements; thus, cover is a continuous measure on the plot. A box plot of the residuals by site from an analysis of variance of tree cover is shown in Figure 4-3. Although some sites exhibited what appeared to be considerably large or small dispersion among the four subplots, a Levene (median) test for homogeneity of subplot variances among the sites did not reject the hypothesis of homogeneous variances (P = 0.49). Suitable estimates for subplot variances can, therefore, be obtained to plan sampling designs for tree cover.

4.1.2 Ground Spectral Measurements

Spectral measurements with the portable spectrometer were obtained in two different plot designs at each of the sites. One design used the quadrat sample design for vegetation cover. The second design used the circular subplots used for tree cover. The indicator measurement derived from the spectral reflectance measures was the NDVI. The spectral data are of questionable quality

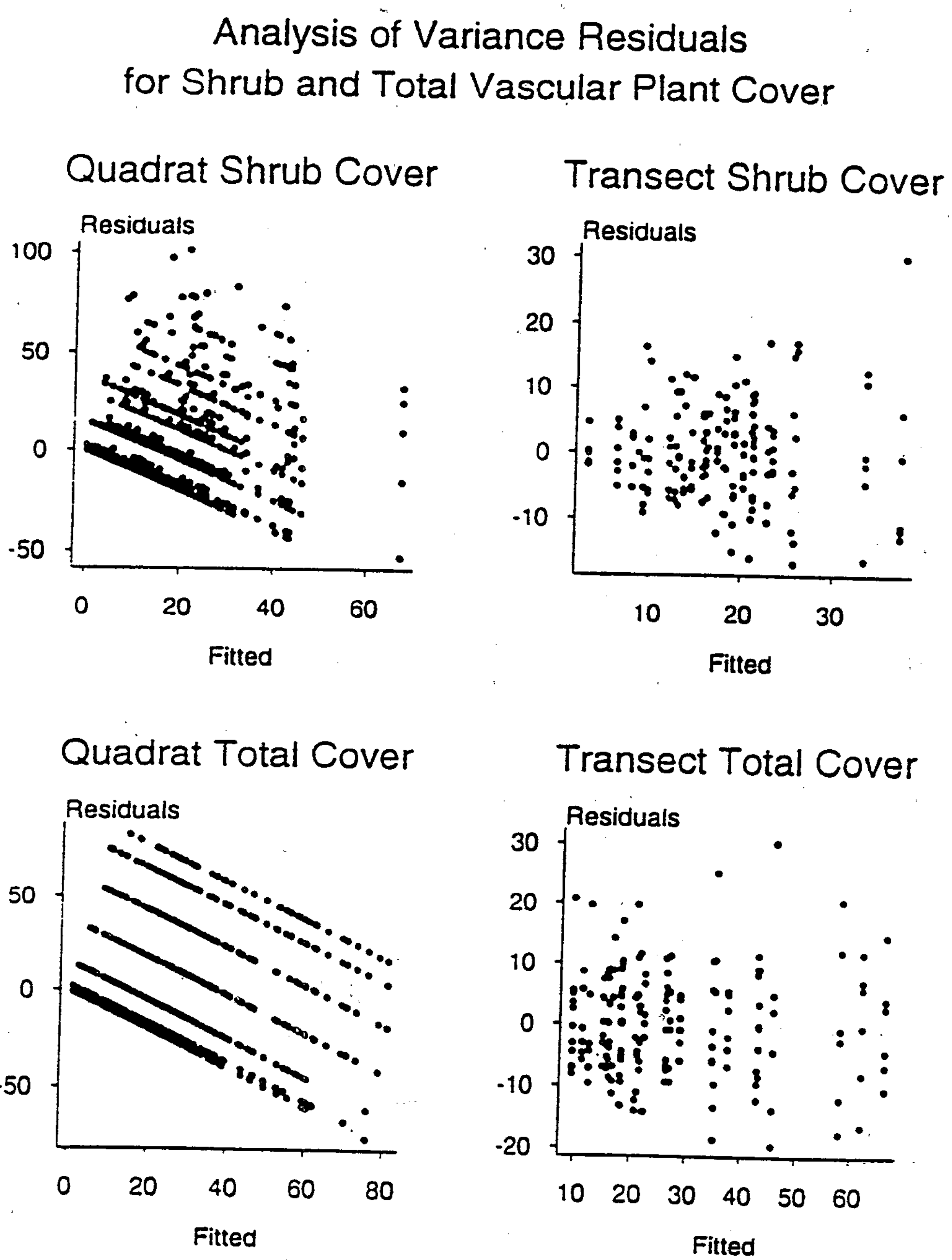

Figure 4-2. Analysis of variance residual plots for shrub cover and total vascular plant cover using quadrat measures or transect means.

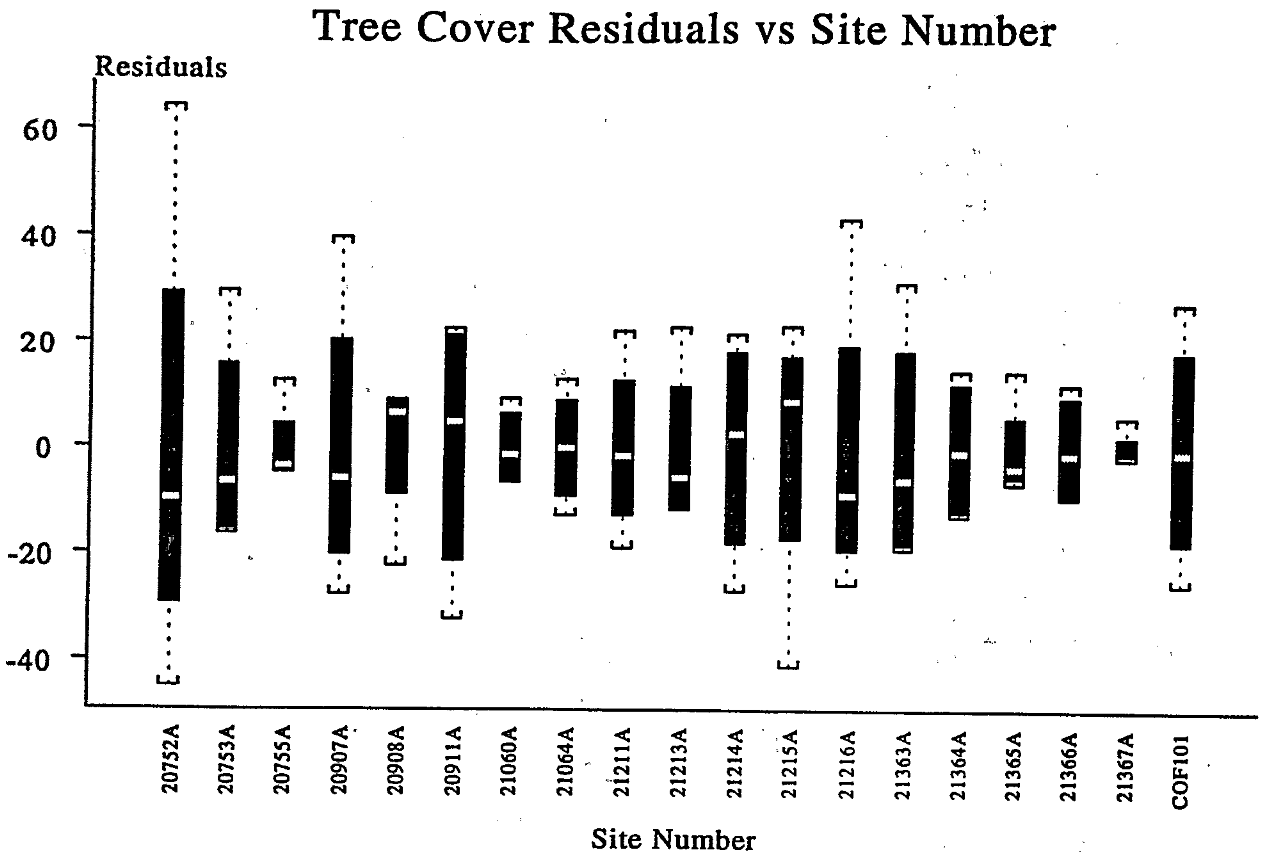

Figure 4-3. Box plot of tree cover analysis of variance residuals by site. Brackets indicate range, shaded areas are 25th and 75th percentile values, and the central white area is the median.

because the field calibrations of the spectrometer to a white reference standard were performed incorrectly. This problem and its effect on data quality are discussed in more detail in Section 7.1.

The NDVI variable is a bounded continuous variable with $0 \leq \text{NDVI} \leq 1$. Histograms of all observations collected on circular plots and the linear transects in the study are shown in Figure 4-4. The NDVI observations are highly skewed with most observations near the lower boundary value for NDVI.

Three NDVI measurements were obtained from each of the quadrats located on the vegetation transects. The linear statistical model for these NDVI measurements is

$$Y_{ijkl} = \mu + s_i + t_{j(i)} + q_{k(ij)} + e_{l(ijk)} \qquad (3)$$

where Y_{ijkl} is a single NDVI measurement and all other components have the same description as those for the model in equation (1) with the additional component $e_{l(ijk)}$ for the difference of a single NDVI measurement within a quadrat from the quadrat value.

Sixteen NDVI measurements were made in a 4 by 4 array with a 3-m spacing within each of the circular plots. The linear statistical model is

$$Y_{ijk} = \mu + s_i + p_{j(i)} + e_{k(ij)} \qquad (4)$$

where Y_{ijk} is the NDVI measurement, μ is the overall average for all sites, s_i is the site average deviation from the overall mean, $p_{j(i)}$ is the difference of the subplot mean from the mean of all subplots on the site and $e_{k(ij)}$ is the difference of an individual measurement from the subplot mean.

Residual plots from an analysis of variance for NDVI measured on transects or circular plots are shown in Figure 4-5. The variance patterns for the individual measurements within the circular plots exhibit a typical pattern for bounded variables when many of the observations are near the lower bound. The observations from quadrats on the vegetation transects exhibit an even more extreme residual variance pattern than those from the circular plots. The more extreme pattern is the result of having only 3 NDVI measurements within each basic measuring unit (the quadrat) as opposed to 16 NDVI measurements within the circular plots.

If the average of all NDVI measurements on the circular plots or the transects is used for the analysis (see Equation 2), a much different variance pattern is apparent in Figure 4-5. The means possess a distribution more amenable to analysis for estimation of variance components similar to that for vegetation cover. Thus, planning for sampling designs must be based on the means of groups of NDVI measures in either the transect or rectangular sampling arrays rather than the smaller sampling units.

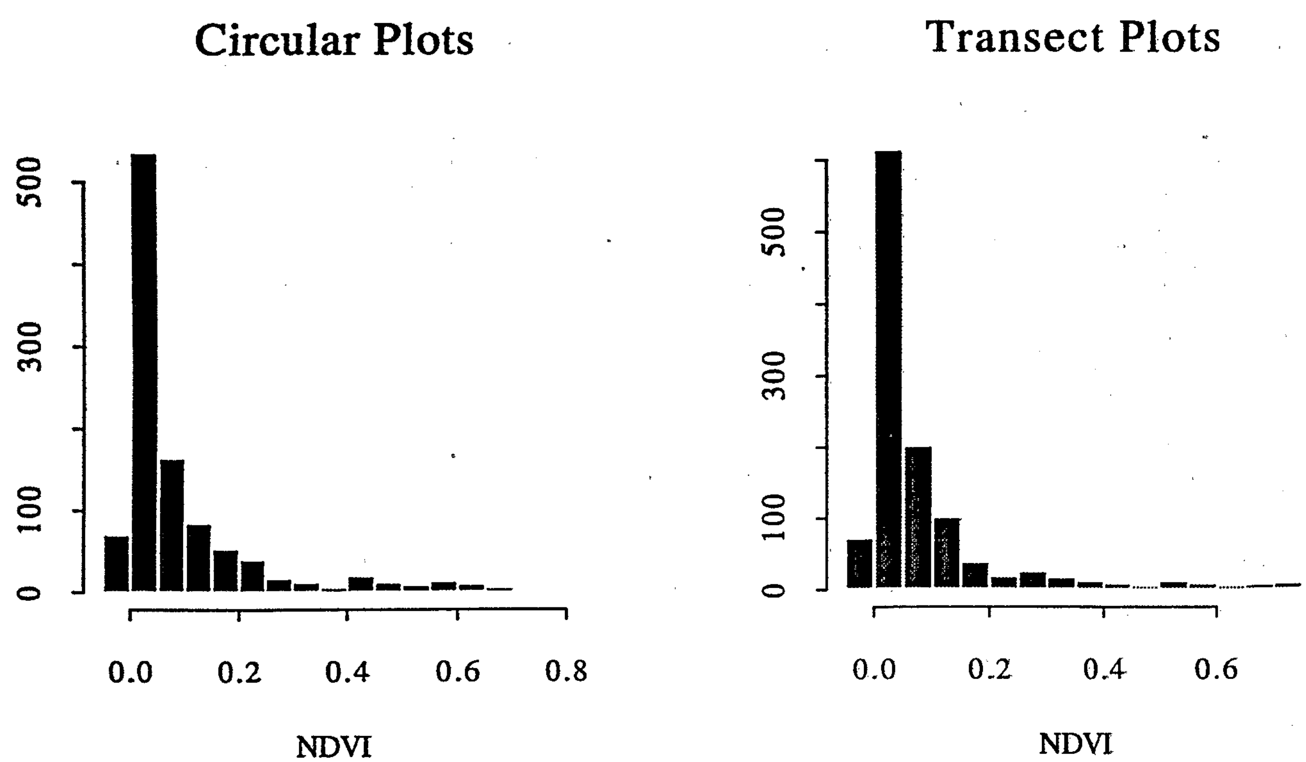

Figure 4-4. Histogram of NDVI measurements from circular plots and transects.

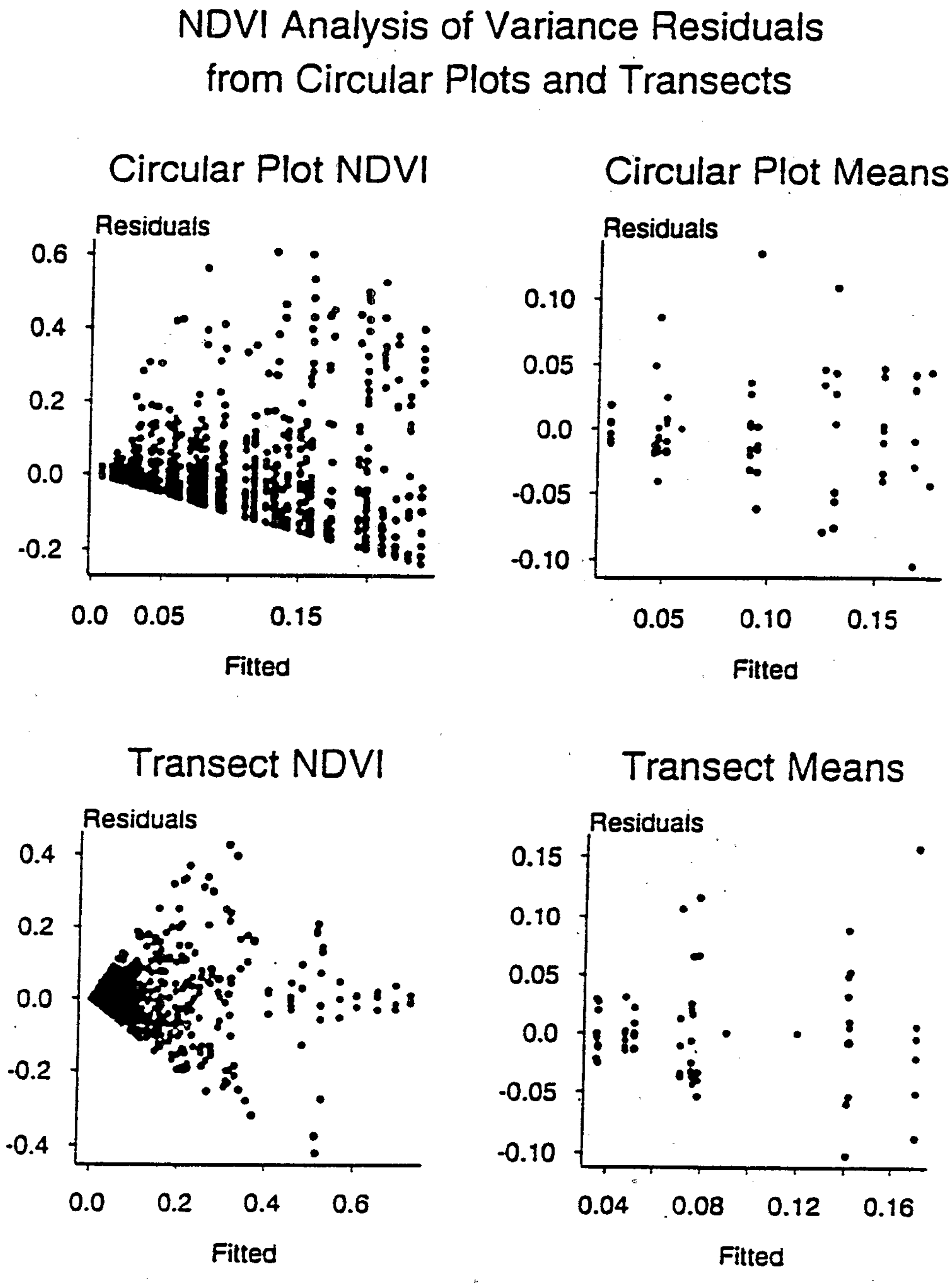

Figure 4-5. Analysis of variance residual plots for NDVI measurements on circular plots, transects, and for means of circular plots and transects.

The Levene (median) test for homogeneity of circular plot or transect plot variances among sites did not reject the null hypothesis for homogeneous variance; P = 0.46 for circular plots and P = 0.21 for transects.

4.1.3 Soils Measurements

The soils data were collected in three subplots (pits) at each site. The measurements considered for variance analyses were the percentages of clay, silt, sand, very fine sand and organic matter as well as the soil erodibility factor, K, and the length-slope and steepness factor, LS. The statistical model for the soil measurements is

$$Y_{ij} = \mu + s_i + p_{j(i)} \qquad (5)$$

where Y_{ij} is the soil measurement, μ is the overall mean, s_i is the difference of the site mean from the overall mean, and $p_{j(i)}$ is the difference of the subplot value from the site mean. The component of variance of interest for a soils measurement is the variance among subplots within sites. The analyses of variance residuals did not exhibit any unusual properties and the analysis of variance estimates of the variance components were computed for each of the soils measurements.

Residual plots for the seven soil measurements are shown in Figure 4-6. The Levene (median) tests for homogeneity of subplot variances were nonsignificant for percent clay (P = 0.47), percent sand (P = 0.16), percent very fine sand (P = 0.30), organic matter (P = 0.41), erodibility (P = 0.13), and length-slope (P P = 0.16), with percent silt somewhat significant (P = 0.03).

4.1.4 Variance Component Estimates

The vegetation, soils, and spectral measures used for the variance component estimates are shown in Table 4-2. In most cases the variables are averages of measurements on the subplots. The subplots for the vegetation measures were the transects for all cover measures. Subplots for the spectral measure, NDVI, were the transects or circular subplots. Soils measures were used from the three soil pit subplots at each site.

The linear statistical model for the analysis of variance is

$$Y_{ij} = \mu + s_i + p_{j(i)} \qquad (6)$$

where $i = 1, 2, \ldots, s$ sites; $j = 1, 2, \ldots, R_i$ subplots at site i; μ is the overall mean; s_i is the difference of the site mean from the overall mean; and $p_{j(i)}$, is the difference of the subplot from the average of subplots at a site. It is assumed the subplot effect, $p_{j(i)}$, is a random effect with mean 0 and variance σ_p^2 .

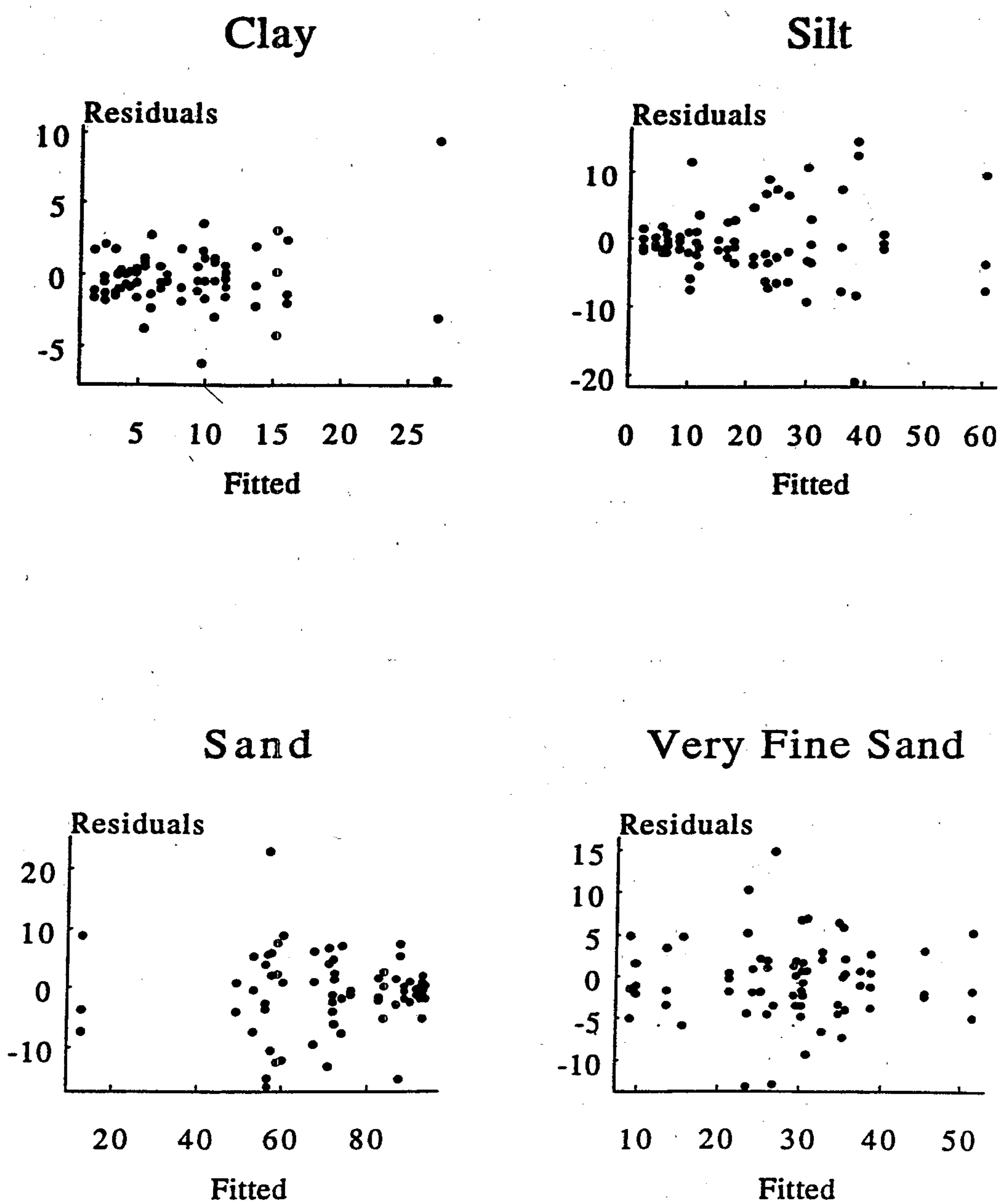

Figure 4-6. Analysis of variance residual plots for soils measurements (Page 1 of 2).

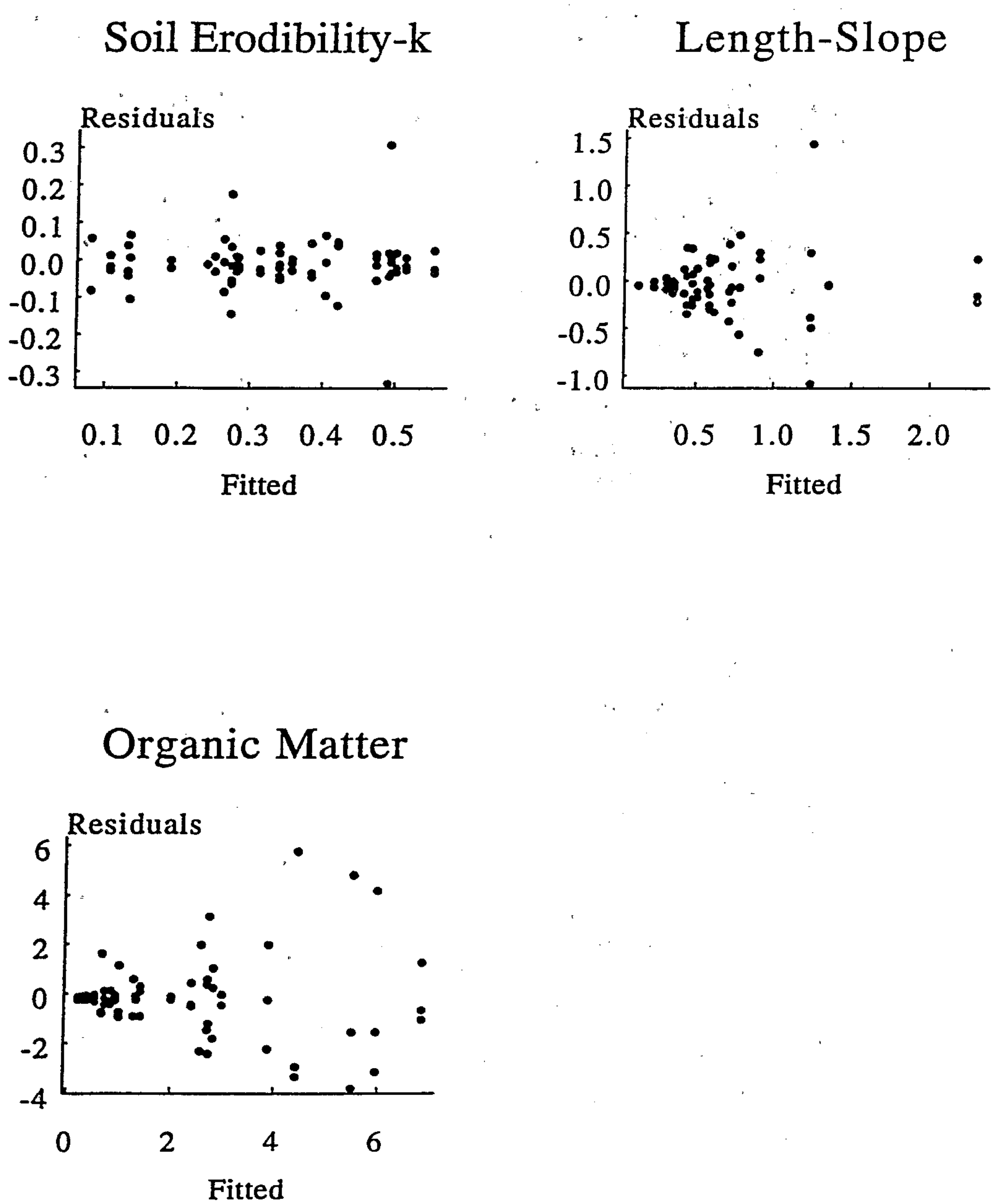

Figure 4-6. Analysis of variance residual plots for soils measurements (Page 2 of 2).

TABLE 4-2. VARIABLES, MEASURING UNITS, AND MEASURES USED FOR VARIANCE COMPONENT ESTIMATES

Variable	Measuring unit	Variance estimate
Total vascular plant cover	50- by 50-cm quadrat	Transect average
Shrub cover	1- by 2-m quadrat	Transect average
Tree cover	7-m circular plot	7-m circular plot value
NDVI	3 samples on 50- by 50-cm quadrat	Transect average
NDVI	16 samples on circular plot	Plot average
All soils measures*	1 to 3 soil pits	Soil pit average

* Clay, silt, sand, very fine sand, organic matter, K (soil erodibility), and LS (length-slope and steepness)

The variance components were estimated from the analysis of variance for each variable. The analysis of variance in Table 4-3 shows the source of variation degrees of freedom and expected mean squares. Variance components can be estimated by equating observed mean squares to expected mean squares. The variance component of interest for the current study is that for subplots within sites. Thus, the component estimate is the observed mean square for subplots within sites (MSW) for each of the measures in Table 4-2 or σ_p^2 = MSW.

The subplot variance component estimates for the vegetation, spectral, and soils measures are shown in Table 4-4. The standard deviation for subplots, the overall study mean, and the percent coefficient of variation for each measure is included in Table 4-4. Also included in Table 4-4 are the half lengths of the 95 percent confidence interval estimates for a site mean for each of the measurements. The half length of the interval was computed as:

$$t\sqrt{\frac{s^2}{n}}$$

where t is the Student t for a two-sided 95 percent confidence interval, s^2 is the estimate of the subplot variance, and n is the number of subplots at a site for the 1992 pilot study. The degrees of freedom for the Student t are those shown for the subplot variance estimate in Table 4-3.

The measured variable exhibited a considerable range in percent coefficients of variation. They ranged from 10.9 percent for percent sand to 88.1 percent for soil organic matter. However, a majority (seven) of the variables had coefficients of variation between 19.9 percent and 46.7 percent. The half lengths of the 95 percent confidence interval estimates in the last column of Table 4-4 showed differences analogous to those of the coefficients of variation among the variables as expected. As a percentage of the overall mean, the half lengths ranged from 13 percent of the mean for percent sand to 102 percent of the mean for soil organic matter. Again a

TABLE 4-3. ANALYSIS OF VARIANCE FOR MEASURES ON SUBPLOTS AT EACH OF SEVERAL SITES[a]

Source	Degrees of freedom	Mean square	Expected mean square
Among sites	$S - 1$	MSA	$\sigma_p^2 + K_1\sigma_s^2$
Subplots within site	$\sum_{i=1}^{s}(R_i - 1)$	MSW	σ_p^2

$$K_1 = \frac{1}{S-1}\left(N - \sum_{i=1}^{s} R_i^2/N\right), \qquad N = \sum_{i=1}^{s} R_i, \qquad \sigma_p^2 = MSW$$

[a] S = number of sites in pilot study.
MSA = mean square among sites.
σ_p^2 = estimate of population.
R_i = number of repetitions within site$_i$.
MSW = observed mean square for subplots within sites.
N = total number of samples collected for all sites.

majority of the variables, seven, had half lengths between 23 percent and 38 percent of the mean. They were total cover, shrub cover, NDVI circular plots, percent clay, percent silt, percent very fine sand, and soil erodibility.

These results indicate considerable differences in precision among the measured variables with the 1992 plot design. In some cases an increase of 50 percent more observations would be required to obtain confidence interval lengths of a more modest nature of 15 percent of the mean, whereas other variables would require at least a doubling of the number of observations to achieve a decent order of precision to estimate the site mean.

4.2 RECOMMENDATIONS

The variance patterns exhibited by the discrete vegetation measures and the bounded NDVI measure indicate that viable variance component estimates for response design planning can only be obtained from the averages of clusters of measurements such as the transects or circular plots. Valid variance component estimates were obtained for those variables, such as tree cover and soils measures, whose basic measurement unit was the subplot. They in turn can be used for usual sample size considerations.

TABLE 4-4. SUBPLOT VARIANCE COMPONENT ESTIMATES FOR THE VEGETATION, SPECTRAL, AND SOILS MEASURES

Variable	Subplots	Degrees of freedom	Subplot variance	Standard deviation	Overall mean	Coefficient of variation	Interval half length
Total cover	6	145	87.78	9.37	27.78	33.7	7.57
Shrub cover	6	129	67.93	8.24	17.63	46.7	6.66
Tree cover	4	57	467.62	21.62	34.36	62.9	21.62
NDVI transect	6	52	0.002398	0.049	0.086	57.2	0.04
NDVI circular	7	54	0.001954	0.044	0.095	46.3	0.033
Clay	3	48	7.04	2.65	8.31	31.9	3.08
Silt	3	48	44.45	6.67	20.33	32.8	7.74
Sand	3	48	60.93	7.81	71.36	10.9	9.06
Very fine sand	3	48	30.93	5.56	28.01	19.9	6.45
Organic matter	3	48	3.69	1.92	2.18	88.1	2.22
K[a]	3	48	0.007495	0.087	0.335	26.	0.1
LS[a]	3	48	0.13724	0.37	0.634	58.4	0.43

[a] K = soil erodibility
LS = length-slope and steepness

The measurements considered for this variance study showed considerable discrepancy in precision among the variables with the current plot design. Considerable increases in the numbers of observations would be required to have more precise estimates of site means for many of the variables. Clearly, the adaptation of the EMAP-Forest plot design to site sampling for arid resources needs to be reconsidered in light of these results.

The patterns of spatial variation for sampling units are not well known for arid communities and may differ considerably from other types of natural communities. In addition, a response plot design that integrates measurements for three indicator categories--vegetation, spectral and soils needs to be determined. This need necessitates a study to determine efficient clusters of units to obtain measurements for the discrete vegetation and bounded NDVI variables that can be integrated with those measurements which already provide viable variance component estimates.

Such a study would require the ability to evaluate the variabilities associated with different sizes and shapes of the measurement unit clusters, more so than was possible with the current response plot design. Some insight into the behavior of variances was obtained with the current design, especially with measurements on NDVI. Clearly clusters of three observations from quadrats on the linear transects were inferior to clusters of all 18 observations on the linear transects. Also, some differences of variability were evidenced in the clusters of 18 NDVI measurements on the linear transects from those with clusters of 16 NDVI measurements in a rectangular array from the circular plots.

It is recommended that a study be conducted to determine an optimal integrated response design for EMAP-Arid monitoring. Such a study should be conducted in the manner of a uniformity sampling study that allows a wide range of arrangements of the basic measurement units from linear transects of varying lengths to varying shapes and sizes of rectangular arrays of the units. The relationships of the arrangements to their respective variances can be used to craft efficient sampling designs at a site. Also, this type of study would result in data to estimate the level of spatial correlation that can be expected from the measurements. Knowledge of the spatial correlation would indicate the need for any spatial separation among the measurement units to increase the amount of independent information acquired from the units.

SECTION 5
INDICATOR SENSITIVITY

One of the primary aims of the indicator evaluation process is to evaluate the degree to which individual indicators represent a range of ecological condition (Hunsaker et al., 1990; Frost et al., 1992). This is often referred to as evaluation of indicator sensitivity. Two general types of indicator sensitivity are commonly evaluated: the grouping or clustering of indicator values across an environmental gradient (Ludwig and Reynolds, 1988) and the degree to which an indicator varies within a known range of conditions (NRC, 1994).

The first type of sensitivity analysis normally involves recognition of patterns or clusters (e.g., pattern recognition or detection) of values of indicators across an environmental gradient. The study is designed to determine if indicator values will separate or cluster into one or more groups and whether the groups correspond to the environmental gradient. This design allows an evaluation of indicator sensitivity to a range of environmental conditions, even if standards (e.g., desired conditions) for evaluating condition are not known.

The second type of sensitivity analysis generally involves selecting sample sites based on a range of "known" or "desired" conditions and evaluating the degree to which indicators vary across those conditions. This type of sensitivity analysis requires an a priori agreement on what constitutes condition (e.g., nominal, marginal, subnominal) and knowledge of the geographic range of the condition (so that representative sites can be selected).

Initially, the EMAP-Arid researchers had intended to evaluate indicator sensitivity relative to known or desired conditions as determined by existing information available from federal land management agencies. The EMAP-Arid team decided to conduct this initial pilot study in the Colorado Plateau due to the wealth of information available from this area (Kepner, 1991). Discussions were held with a number of management agencies and these discussions led to the understanding that EMAP-Arid could obtain congruous determinations of site condition for the Colorado Plateau area. However, the EMAP team discovered significant differences in agency descriptions of the condition of a site. This difference was substantial enough in several cases that no consistent rating of a site could be established. Recently, similar concerns have also been reported by the NRC in their review of rangeland health (NRC, 1994). As a result of these factors, the 1992 pilot study was not able to address the objective to evaluate indicator sensitivity against sites of "known" condition. Results presented in this section are only indicative of patterns in the Colorado Plateau and the range in condition, delineated in these patterns is not known. However, it is reasonable to assume the sites were different and represented at least a partial range in condition.

5.1 VEGETATION INDICATOR

As noted above, different agencies value different components of arid ecosystems and condition ratings are not consistent among agencies. However, given the assumption that different condition classes would be encountered in data collections at 29 different sites, some evaluation of indicator sensitivity is possible from this pilot study. It is expected that the parameters measured in the vegetation component of this study can serve as indicators of condition whether alone or combined into ratios or indices.

5.1.1 Analysis and Results

This analysis is limited to the preparation of plots of site data to illustrate the applicability of some vegetation parameters and their comparative ratios as indicators. The plots are of three basic types, i.e., plots of total vascular cover on a site with other vegetation parameters or ratios, plots of total vascular cover with soil parameters, and plots of total number of species on a site with other vegetation parameters.

For instance, Figure 5-1 contrasts the number of species encountered at a site with total vascular plant cover on a site. Of the sites examined in the 1992 pilot (Table 4-1) two sites were notable deviations from the general pattern (outliers) suggesting that these sites may have been subjected to stress. These sites are 21210 and 21062. Each had a large amount of cover (greater than 60 percent foliar cover) and a considerable exotic species component in terms of cover.

These two sites plus site 20758 also appear as outliers in the plot in Figure 5-2. This plot contrasts total vascular plant cover and exotic plant cover. The desertscrub site, 21210, is dominated by Halogeton glomeratus, an introduced annual forb that is poisonous to sheep. Both desertscrub sites, 20758 and 21062, have large amounts of Bromus tectorum, an introduced annual grass which can cause soremouth in livestock and wildlife species due to stiff awns in its seedhead.

Figure 5-3 contrasts total vascular plant cover with a ratio of poisonous and physically injurious plants to total plants on a site in terms of relative frequency. The ratio of poisonous and physically injurious plants to total number of plants is generally expected to remain low in a relatively undisturbed site. This plot discriminates the same three sites as do plots in figures 5-1 and 5-2, thereby suggesting these parameters may be good discriminators of subnominal versus nominal sites in a regional index. When palatable (for cattle and sheep only) species cover is considered (Figure 5-4), the relationship still held up as well because some exotic species are highly palatable at some time of the year. These three outlier sites have several things in common. Each has a relatively high amount of vascular plant cover. At site 20758 vascular plant cover is the lowest of the three, which is why this site is not an outlier in Figure 5-1. Each has a high ratio of exotic species which can be harmful or highly palatable to sheep or cattle at some point during the plant growth cycle.

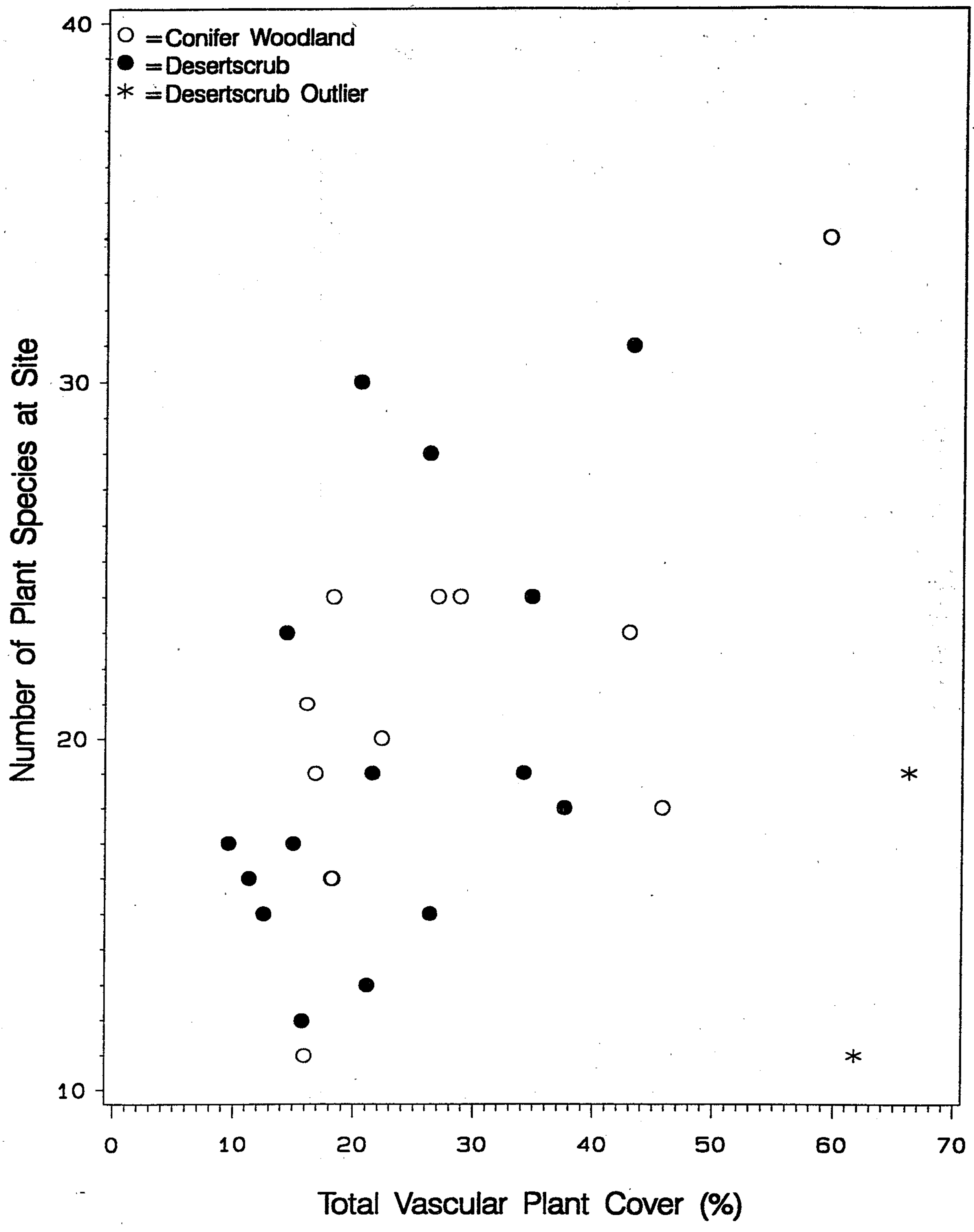

Figure 5-1. Total number of plant species versus total vascular plant cover.

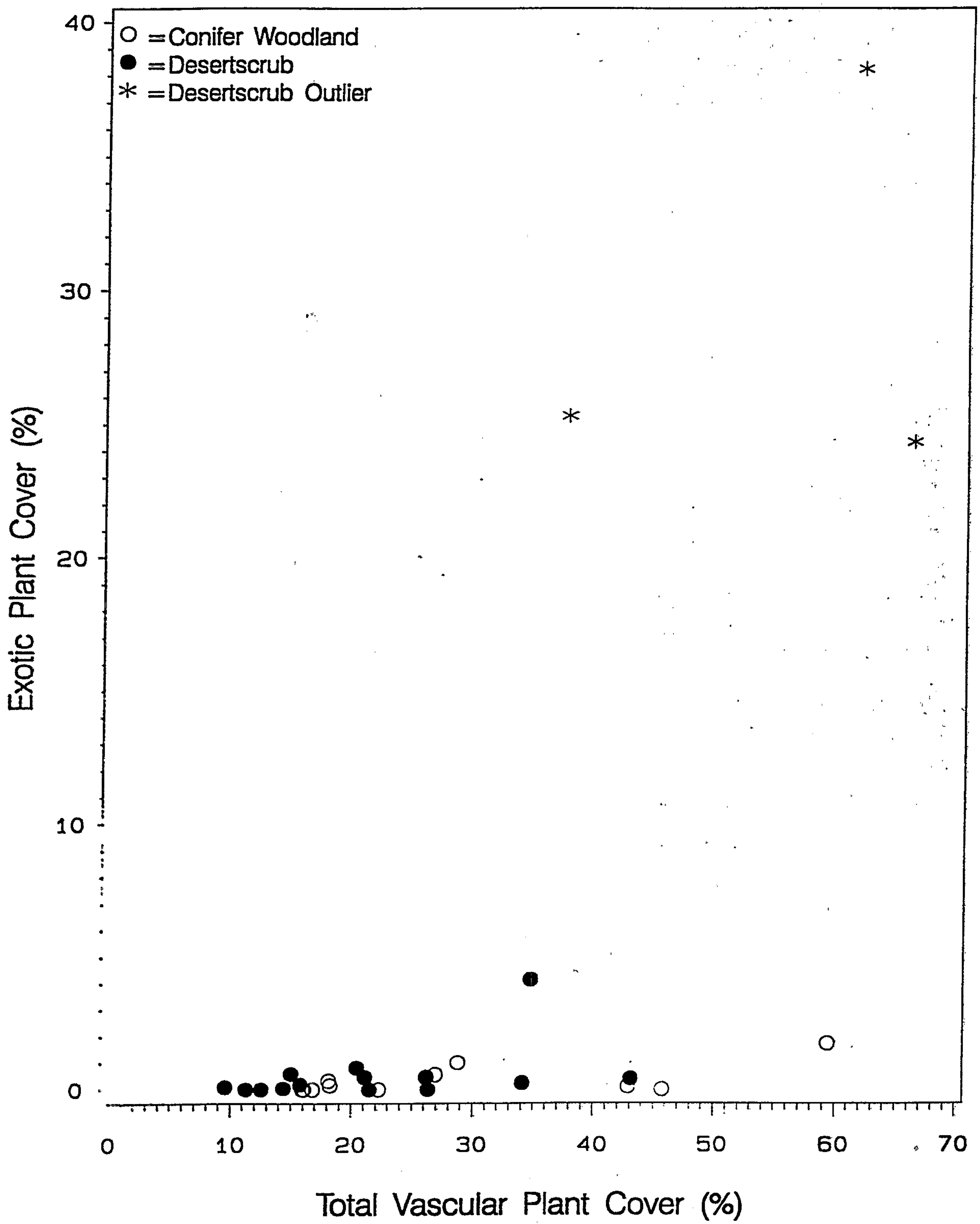

Figure 5-2. Exotic plant species cover versus total vascular plant cover.

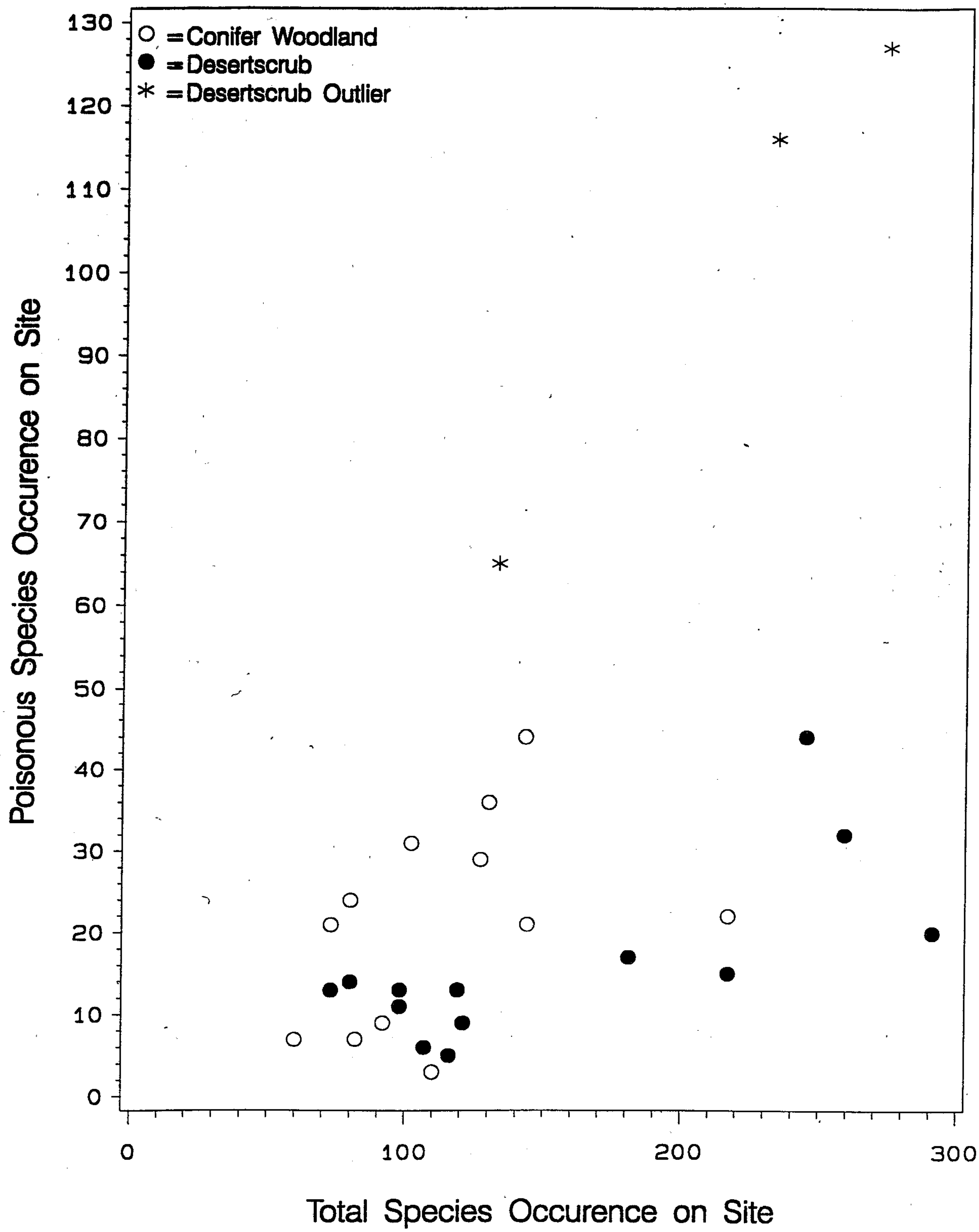

Figure 5-3. Number of poisonous plants versus total number of plants at a site.

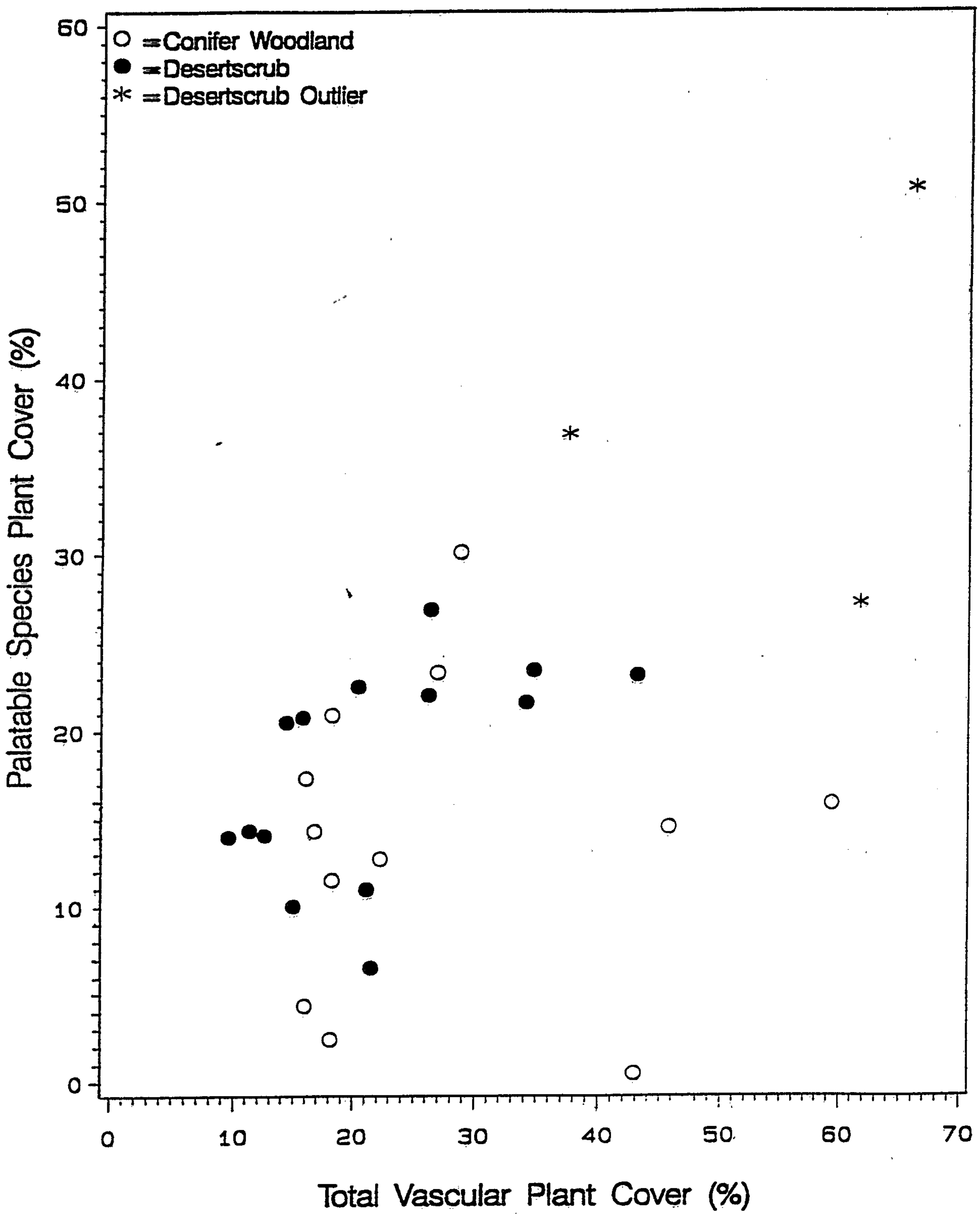

Figure 5-4. Palatable plant species cover versus total vascular plant cover.

Comparisons of total vascular plant cover with soil organic carbon showed a general pattern of increasing total vascular cover with increasing levels of organic carbon for desertscrub sites. This pattern was not evident for conifer woodland sites. Electrical conductivity versus total vascular plant cover discriminated site 21210 which is the desertscrub site dominated by Halogeton glomeratus. This forb is tolerant of saline and alkaline conditions so the parameter is somewhat descriptive in that sense.

Figure 5-5 is a comparison of the sand/clay ratio with total vascular plant cover on each site. This plot discriminates several groups. Lower values of desertscrub and pinyon-juniper on the x axis indicate decreasing sand percentages at the sites. Sites that have a ratio greater than 20 (i.e., high sand relative to clay content) are interesting. Sites with more sand relative to clay had about the same total vascular cover, but sites with higher clay content fell into three groups. The sites with the highest vascular plant cover were sites with lower sand-to-clay ratios and were dominated by exotic annuals. The sites with moderate vascular plant cover, 37 to 45 percent, were mixed as to species composition. Site 20758 was dominated by Bromus tectorum; the other two sites had virtually no exotic species.

Each of these ratios indicates differences between some sites in this study. The ratios also indicate that disturbance has occurred on some sites. Deviation from expected values in any one analysis is not necessarily an indication of unacceptable conditions; however, deviations in multiple parameter ratios are probably indicative of criteria that will distinguish nominal conditions from subnominal ones. It should be noted that soil erosion (Section 5.3) was not excessive on any of the sites using the current erosion indicator.

5.1.2 Recommendations

The analyses of the data from the 1992 pilot study demonstrate that some of the kinds of data collected are useful as indicators. It is recommended that additional sensitivity studies be conducted. With a larger data base and calibration data sets from sites of known condition, the kinds of analyses presented in this report will be expanded to include multivariate techniques and robust analysis based on non-normal distributions.

Existing soils, plant, and ecological site ancillary data should be compiled as part of this larger data base. This data base would include data such as palatable species for livestock and wildlife, poisonous plants, rare plants, soil maps, soil chemistry, and other pertinent data that are available. These types of data will be important in indicator development and interpretation of results.

5.2 SPECTRAL PROPERTIES INDICATOR

Investigations for the spectral properties indicator were conducted by different methods aimed to test and evaluate the use of spectral measurements to derive information about the spectral properties of vegetation and soils in arid ecosystems. The purpose of this study was to compare Landsat TM spectral data with concomitant spectral measurements obtained through the use of a portable handheld spectroradiometer (PSII). Thus, spectral properties of objects in arid and

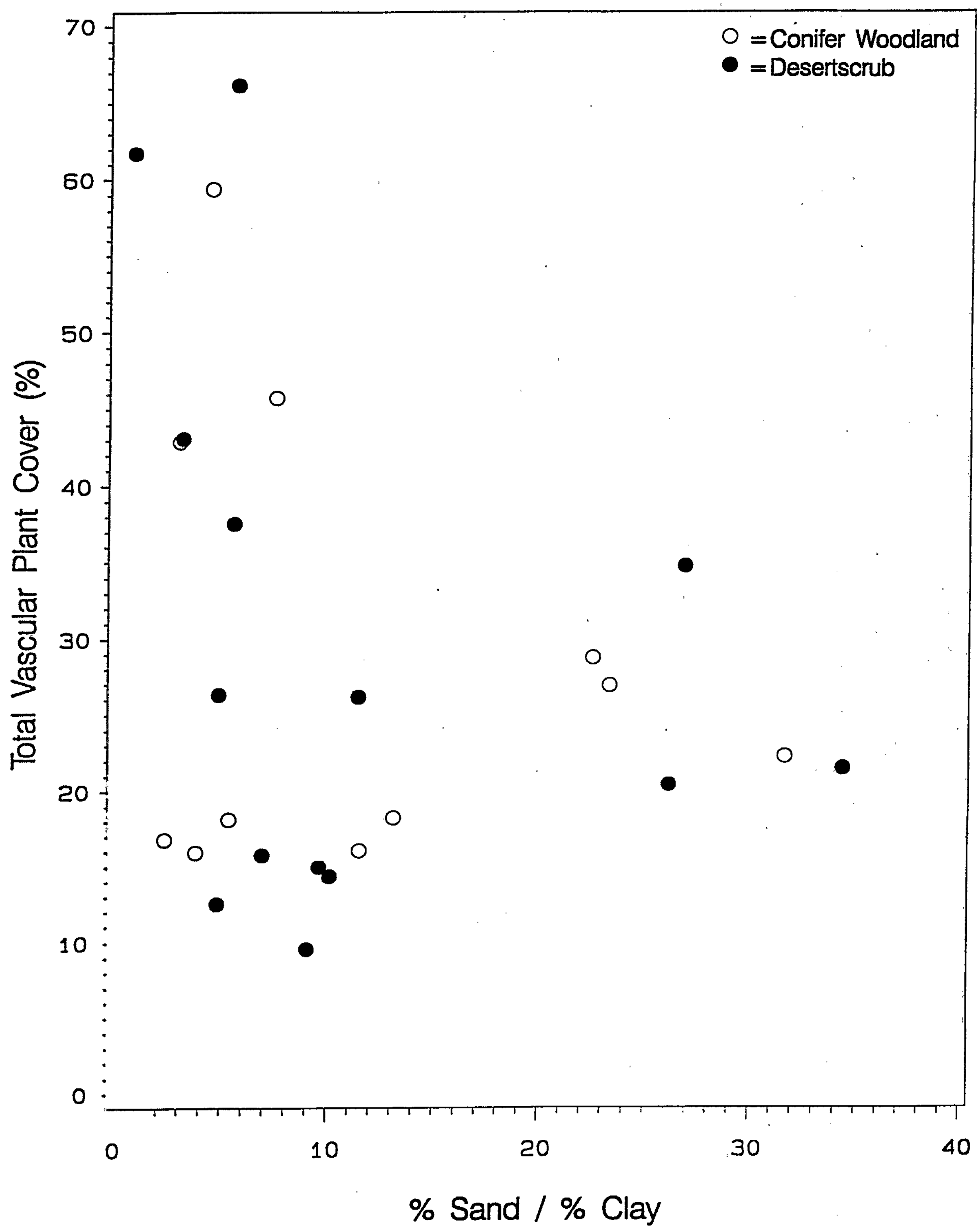

Figure 5-5. Total vascular plant cover versus the ratio of percent sand and percent clay.

semiarid environments could be compared to measured properties of those same objects to determine if remote sensing can be used to derive significant and meaningful information about environmental factors. Data obtained through remote means have the potential to allow evaluations to be conducted on scales that would be cost effective in the vast areas of the western United States.

5.2.1 Results

Spectral measurements were made at 13 sites; one of these sites was measured twice as a crew comparability exercise and only the second set of measurements was included in the data set for analysis. Overcast conditions resulted in low numbers of spectra being obtained from two sites, and no measurements were made at three other sites (Table 5-1) due to problems with the spectrometer necessitating the acquisition of a replacement instrument. During collection of ground-based spectral measurements the initialization procedure for the Personal Spectrometer was done in such a way that the white reference standard was saturated. To compensate for this error, the data set was recalculated using values for reflectance in red and infrared wavelengths from a soil spectrum from each transect or circular subplot. As a result of this error, the PSII data are biased low and have more variables than normal. This data quality issue is discussed in more detail in Section 7.

The Landsat scene did not include sites 20755 and COF101; therefore, the NDVI values obtained from the groundbased and TM data were compared for a total of 11 sites. Seven of the 11 sites used to compare satellite and ground-based NDVI values were desertscrub with a composition of varying species and the remaining four were conifer woodland with different shrub components. Overall site productivity was determined by correlating vegetation indicator species, physical site characteristics (e.g., elevation and slope), and soils data with potential vegetation species and potential production in normal years as documented on Soil Interpretation Records in the Soil Conservation Service National Soil Database. Sites were grouped by vegetation productivity classes of >1,000 kg/ha, 500 to 1,000 kg/ha, and <500 kg/ha and are listed in Table 5-2 with dominant plant species, productivity class, and soil characteristics. Total vascular plant cover was measured in alternate 1-by 2-m quadrats along each of the six transects per site and an average site value obtained (Table 5-3).

The NDVI was calculated for the 1992 pilot study using both Landsat TM and PSII reflectance data. In the case of the Landsat TM data, 16 pixels in a 4 by 4 matrix covered 1 hectare of the sample site. The NDVI was calculated for each pixel and averaged to give a site value (Table 5-4). For PSII measurements, seven circular subplot values of NDVI were calculated, each an average of 16 spectral measurements. Six transect NDVI values, each an average of 18 spectral measurements, were also determined from PSII measurements. These 13 NDVI values were averaged to provide a site NDVI (Table 5-5).

One of the primary intentions of this study on spectral properties was to examine the correlations between satellite and ground-based spectral measurements using NDVI, as well as

TABLE 5-1. THE NUMBER OF SPECTRAL MEASUREMENTS MADE AT EACH SITE

Site number	Number of spectra acquired
20753	220
20755	18
20758	220
20907	0*
20908	220
21911	120
20913	220
21060	172
21061	184
21210	220
21213	0*
21216	46
21217	220
21361	0*
21362	0**
21364	124
21366	0**
COF101	220

* No data due to instrument failure

** No data due to overcast conditions

between NDVI values and vegetation and soil variables. It is important to establish the correlation between satellite and ground-based measurements to determine whether ground-based measurements can be used in future studies to calibrate satellite data. The expected results would be high correlation between ground-based and satellite derived NDVI and correlation of both TM and PSII NDVI, to varying degrees, with ground-based measurements. Further, it was expected that the conifer woodland sites would have higher NDVI values than desertscrub sites, but that some overlap in values would exist as a result of different productivity levels. It was originally planned to compare NDVI with site productivity classes. However, the low sample number in each productivity class precluded performing this analysis.

The NDVI from both TM and PSII were plotted against each other, and, as expected, show a high correlation ($r^2 = 0.71$) (Figure 5-6). Although the PSII values are biased low as previously discussed, these results are encouraging and show that ground-based spectral measurements may be used to calibrate satellite data. Figure 5-7 shows the relationship between the PSII derived NDVI and total vascular plant cover. Figures 5-8 through 5-10 show the relationship between the TM derived NDVI and total vascular plant cover; gravel, cobbles, stones, and bare soil cover; and moss, lichen, and cyanobacteria cover, respectively. Only one graph showing the relationship between PSII-derived NDVI and selected parameters is shown as the relationship between PSII NDVI and selected variables is similar to that of TM NDVI and those same selected variables. Low productivity desertscrub sites have the lowest NDVI values for both TM and PSII, as expected.

TABLE 5-2. DOMINANT VEGETATION AND SOIL CONDITIONS AT SITES FROM WHICH SPECTRAL MEASUREMENTS WERE OBTAINED DURING EMAP-ARID 1992 PILOT

Site 20753, Dolores Point: medium productivity desertscrub dominated by *Artemesia spp., Stipa columbiana, Agropyron smithii, Vicia americana, Gutierrezia sarothrae, Chrysothamnus spp., Pinus edulis,* and *Juniperus osteosperma.* The soil surface is dark and light red/brown in color, and was moist at the time ground-based spectral measurements were made.

Site 20755, Island Canyon: low productivity conifer woodland dominated by *Pinus edulis, Juniperus osteosperma, Artemesia ludoviciana, and Opuntia spp.* The soil surface is light red with white sandstone cobbles and was dry when spectral measurements were made.

Site 20758, Tin Cup Mesa: medium productivity desertscrub dominated by *Gutierrezia sarothrae, Hilaria, Salix spp.,* and *Bromus tectorum.* The soil surface is light red/brown in color, and was dry when measurements were made.

Site 20908, La Sal Junction: low productivity conifer woodland dominated by *Pinus edulis, Juniperus osteosperma,* and *Artemesia spp.* The soil surface is dark red/brown in color and was very wet when spectral readings were taken.

Site 20911, Mustang Flat: medium productivity conifer woodland dominated by *Pinus edulis, Juniperus osteosperma, Artemesia spp., Gutierrezia sarothrae,* and *Vulpia octoflora.* The soil surface is medium to dark red/brown in color and was dry when measurements were made.

Site 20913, Gray Spot: medium productivity desertscrub dominated by *Ephedra spp., Oryzopsis hymenoides, Salix spp., Chrysothamnus spp.,* and *Gutierrezia sarothrae.* The soil surface is light to medium red/brown in color and was dry when spectral readings were made.

Site 21060, Kane Springs Mesa: low productivity desertscrub dominated by *Coleogyne ramosissima, Gutierrezia sarothrae, Ephedra spp.,* and *Juniperus osteosperma.* The soil surface is red and was dry at the time when spectral measurements were made.

Site 21061, Six Shooter Peak: medium productivity desertscrub dominated by *Hilaria, Gutierrezia sarothrae, Oryzopsis hymenoides, Sphaeralcea coccinea,* and *Atriplex confertifolia.* The soil surface was dry when measurements were made.

Site 21210, Valley City: medium productivity desertscrub dominated by *Sarcobatus vermiculatus, Halogeton glomeratus, Hilaria,* and *Brassica spp.* The soil surface is red/brown and light gray/brown and was dry when readings were taken.

Site 21216, Cedar Mesa: conifer woodland dominated by *Pinus edulis, Juniperus osteosperma, Chrysothamnus spp.,* and *Ephedra spp.* The soil surface is light, medium, and dark red/brown and was moist when the spectral readings were made.

Site 21217, Halchita: low productivity desertscrub dominated by *Gutierrezia sarothrae, Hilaria, Ephedra spp., Coleogyne ramosissima, and Compositae.* The soil surface is light red/brown in color and was dry when measurements were made.

Site 21364, Cataract Canyon: low productivity conifer woodland dominated by *Pinus edulis, Juniperus osteosperma, Coleogyne ramosissima, Gutierrezia sarothrae,* and *Bromus tectorum.* The soil surface is light to medium red/brown in color and was dry when spectral readings were taken.

Site COF101, Dove Creek: low productivity conifer woodland dominated by *Pinus edulis, Juniperus osteosperma, Hilaria,* and *Chrysothamnus spp.* The soil surface is yellow/brown, gray/brown, and red/brown and was dry when spectral measurements were made.

TABLE 5-3. TOTAL VASCULAR PLANT COVER AT EACH SITE

Site number	Vascular plant cover	Sample standard deviation
20753	43.11	5.98
20758	37.54	5.04
20908	18.13	8.69
20911	15.96	6.79
20913	34.75	6.72
21060	15.77	6.63
21061	26.18	7.39
21210	62.00	10.54
21216	18.25	6.85
21217	14.98	5.18
21364	21.48	7.06
COF101	35.16	15.25

TABLE 5-4. NDVI VALUES DERIVED FROM LANDSAT TM DATA FOR EMAP-ARID 1992 PILOT STUDY

Site number	Average site NDVI n = 16	Site sample standard deviation
20753	0.367	0.044
20758	0.243	0.014
20908	0.287	0.032
20911	0.105	0.016
20913	0.219	0.006
21060	0.173	0.012
21061	0.210	0.010
21210	0.199	0.014
21216	0.285	0.009
21217	0.199	0.007
21364	0.194	0.008

TABLE 5-5. NDVI VALUES DERIVED FROM PERSONAL SPECTROMETER II DATA COLLECTED DURING EMAP-ARID 1992 PILOT STUDY

Site number	Transect NDVI n = 6	Subplot NDVI n = 7	Average site NDVI n = 13	Site sample standard deviation
20753	0.141	0.153	0.148	0.033
20755	0.090	**	0.090	***
20758	0.076	0.091	0.084	0.025
20908	0.141	0.128	0.134	0.065
20911	0.076	0.125	0.097	0.060
20913	0.052	0.052	0.052	0.014
21060	0.048	0.046	0.047	0.023
21061	0.036	0.025	0.030	0.017
21210	0.071	0.094	0.084	0.059
21216	0.120	0.176	0.157	0.055*
21217	0.036	0.048	0.042	0.031
21364	0.078	0.058	0.075	0.067
COF101	0.170	0.168	0.169	0.066

* Only three averaged measurements.
** No data due to weather conditions.
*** Data from one transect only, standard deviation not calculated.

The poor correlation between PSII and TM NDVI and field measurements of soil and vegetation parameters was disappointing, and may be attributed to a number of factors. The low biomass and gray-green color associated with the vegetation of the region suggests that either a modified version of the NDVI or a different index may be more appropriate indicators. Different indices will be tested with 1993 data. Another contributing factor may have been that the field measurements may not have been collected in such a way as to be directly comparable with NDVI. For example, cyanobacteria and soils were measured as separate variables, even though in cyanobacteria, soil or sand grains may actually be present at the surface. It should be recalled that reflectance remote sensing measures only the surface and would therefore classify as bare soil what was classed as cyanobacteria during field measurements. The collection of pure spectra of soil, litter, and plants and their input into a mixing model would have helped to establish species composition and cover and acted as corroboration for other ground-based measurements.

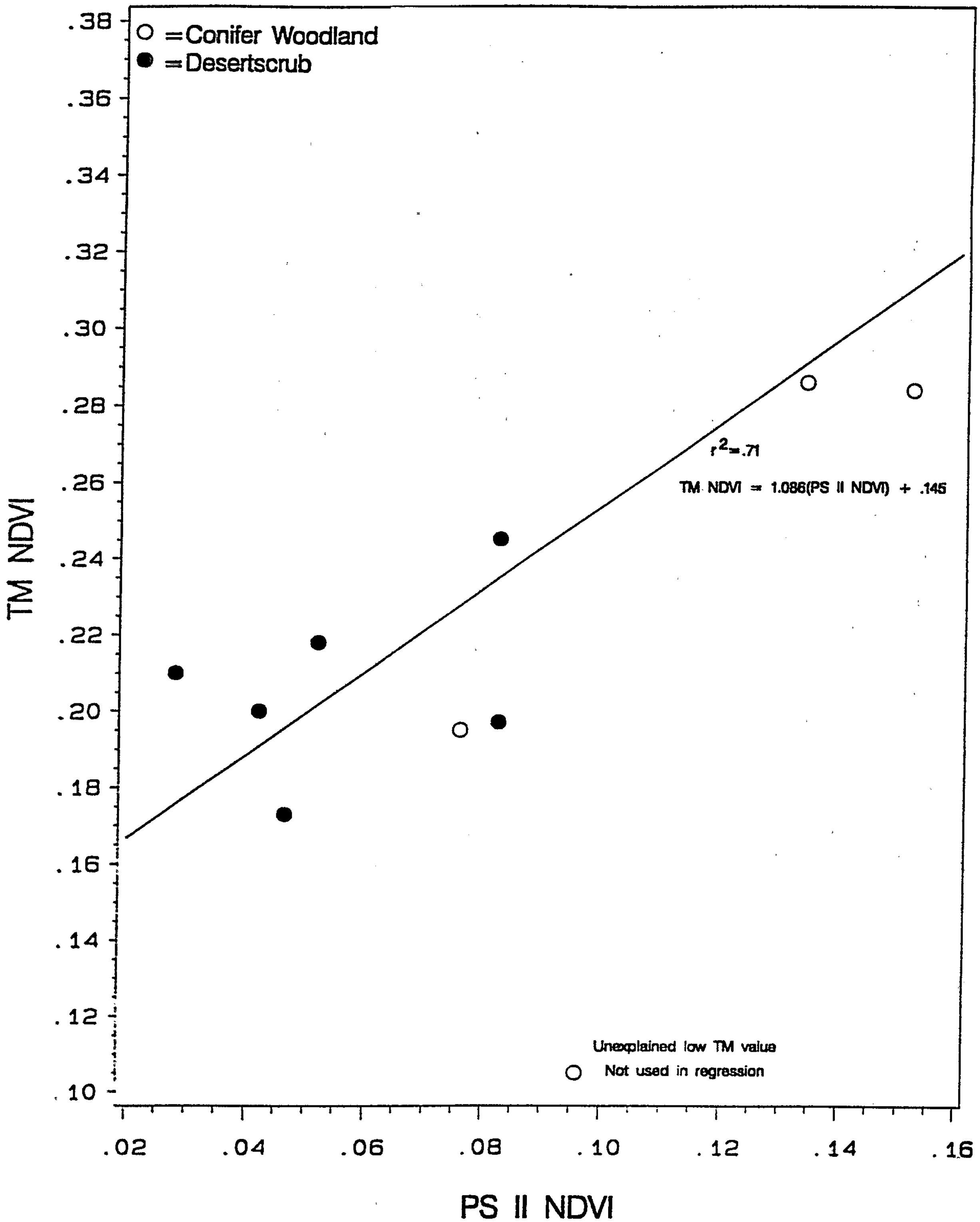

Figure 5-6. Correlation between NDVI derived from Landsat TM data and that from PSII data.

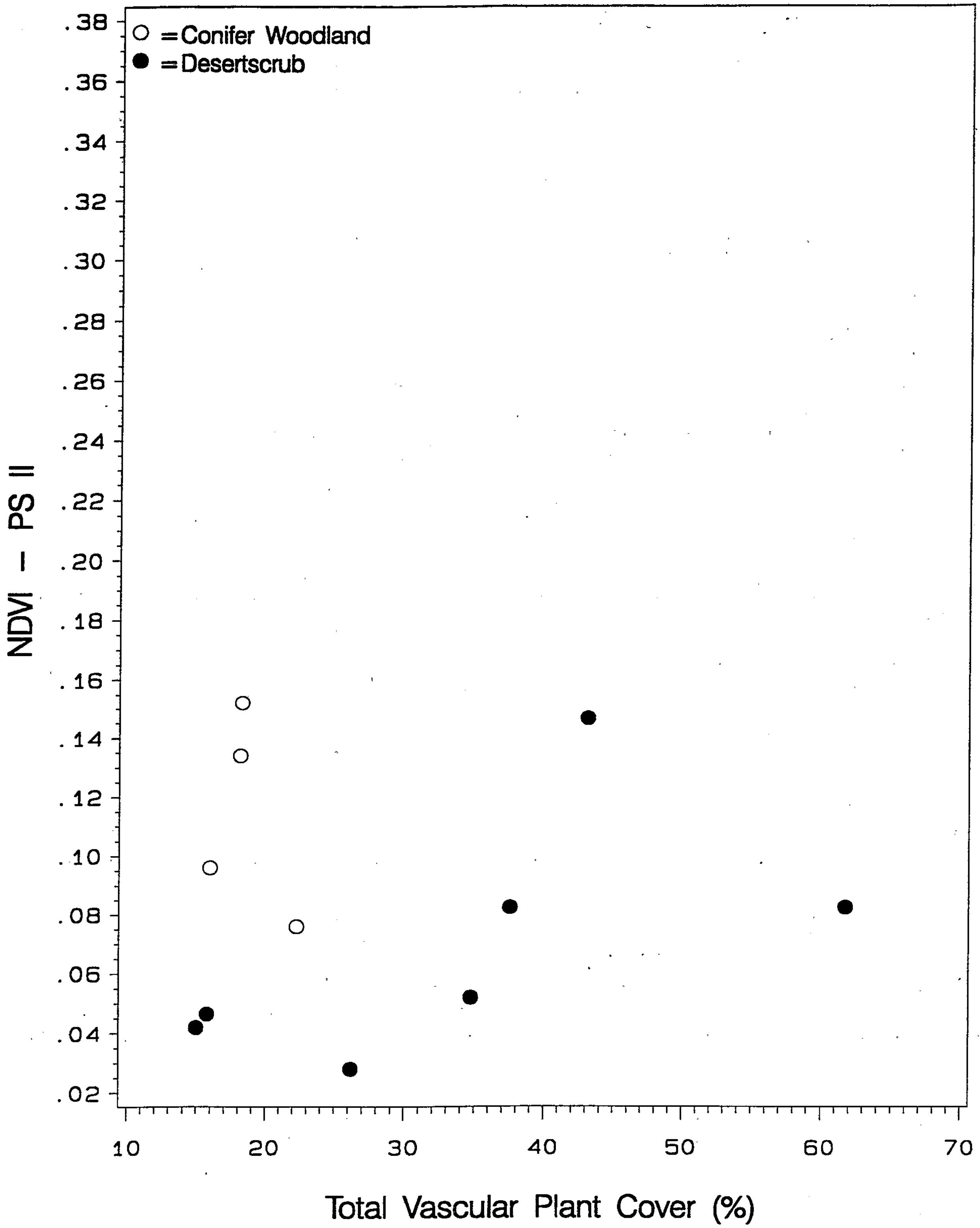

Figure 5-7. Relationship between NDVI PSII and total vascular plant cover.

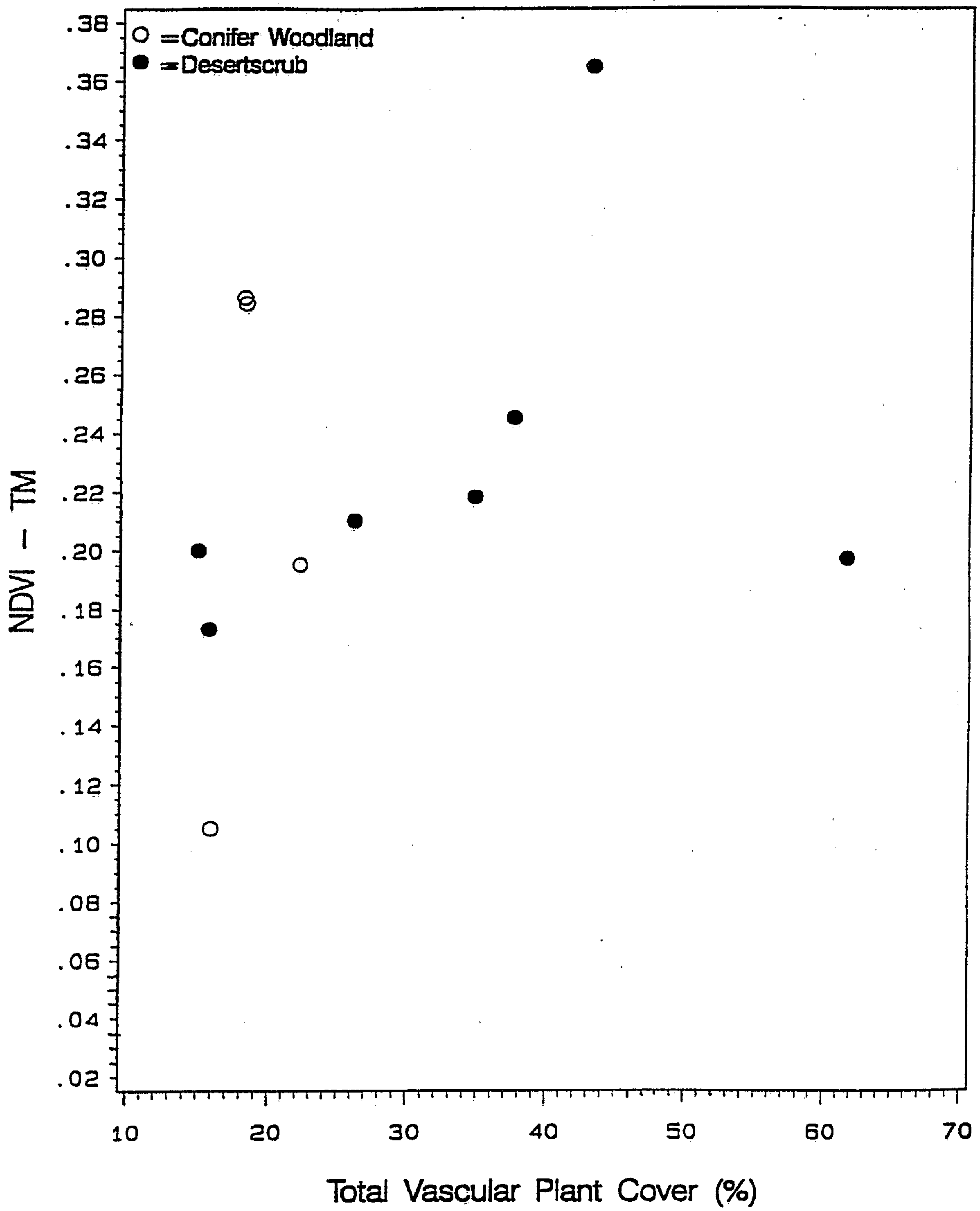

Figure 5-8. Relationship between NDVI TM and total vascular plant cover.

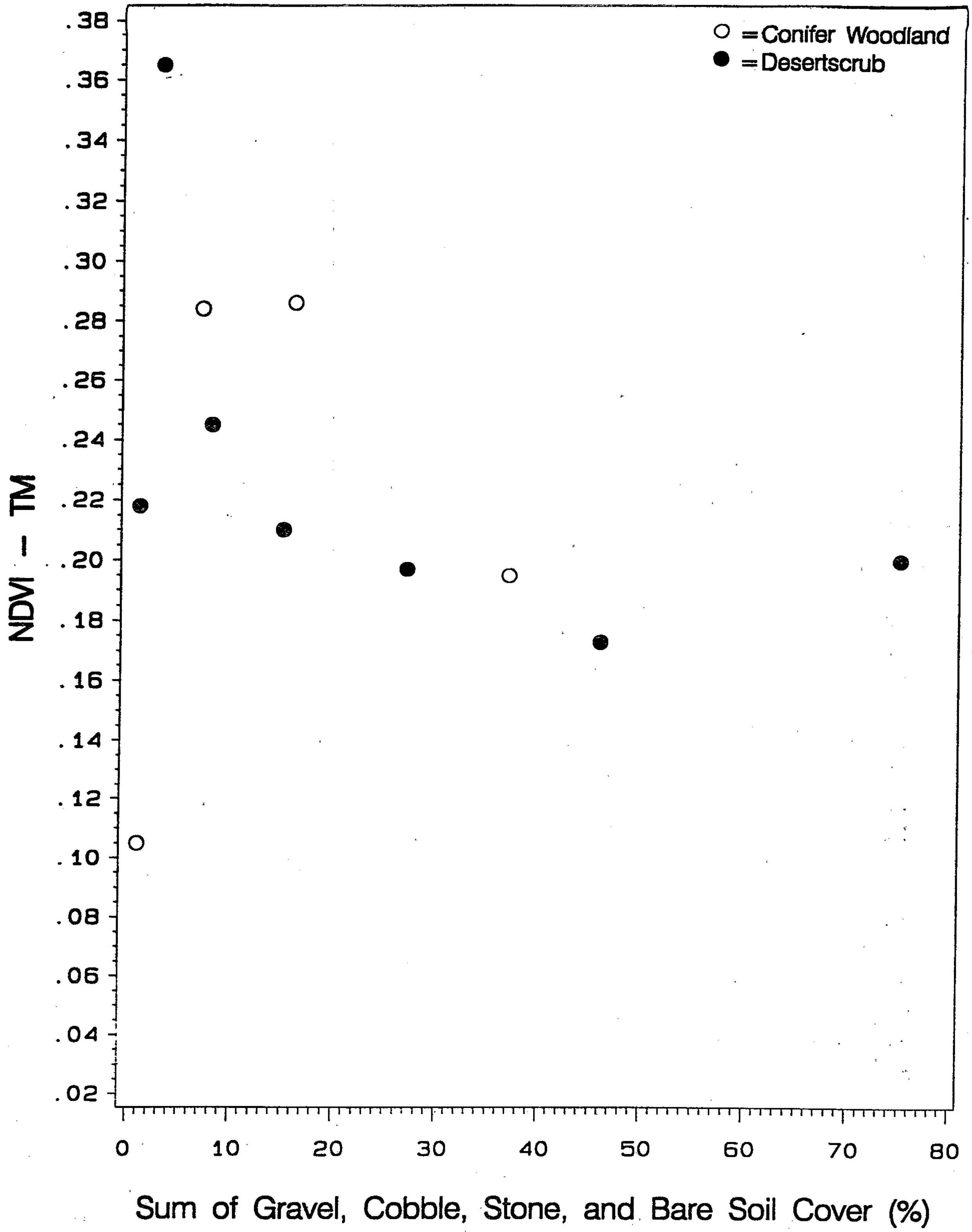

Figure 5-9. NDVI-TM versus the sum of interspace gravel, cobble, stone, and bare soil cover.

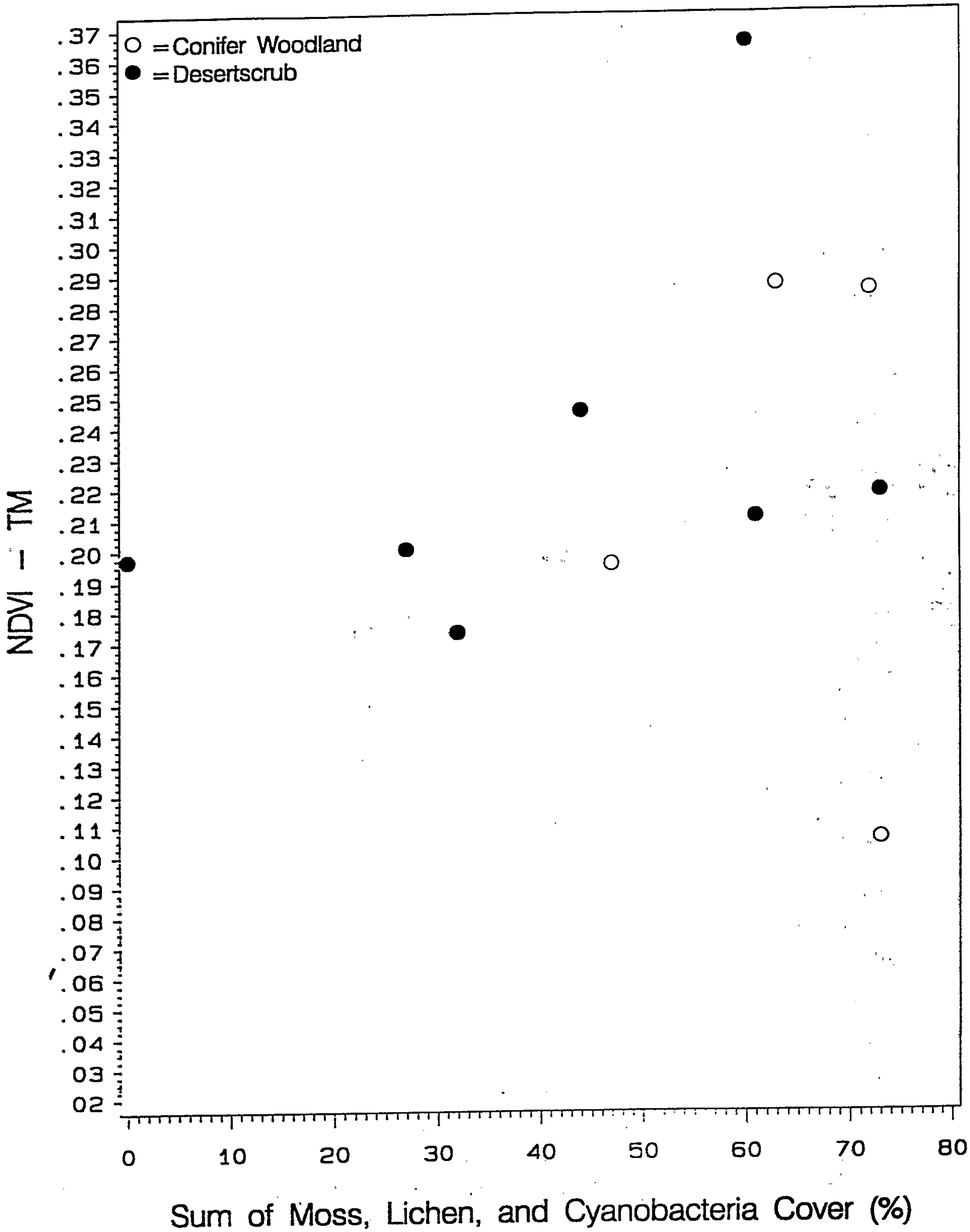

Figure 5-10. NDVI TM versus the sum of interspace moss, lichen, and cyanobacteria cover.

5.2.2 Recommendations

During planning for the 1992 pilot study field work, the EMAP-Arid researchers decided that the acquisition of spectral measurements should be confined to the transects along which vegetation assessments were made and to a series of measurements in a square grid in the circular subplots where tree data were collected. In addition, with only one spectral technician, the arid team felt that this individual should not acquire detailed descriptions of surface cover commensurate with the spectral measurements or specific measurements of land cover components. As a result of these decisions no reference spectra of soils, rocks, cyanobacteria, or representative plant species were made, and only minimal notes were taken concerning the composition of each individual spectrum. This procedure limited the correlation that could be made between spectral measurements and other variables collected in the field and therefore diminished the ecological significance that could be drawn from ground-based spectral data.

The strong correlation between the TM and PSII NDVI-derived for the 1992 study indicates that the overall concept of remote sensing as an indicator of ecosystem condition is valid, but that more research is needed into indicator selection and integration. In addition, results of the study suggest that NDVI alone may not be the most sensitive indicator for arid and semiarid regions due to sparse vegetation cover. Other vegetation indices have been derived from spectral data (Huete and Jackson, 1987, Perry and Lautenschlager, 1984), such as the soil adjusted vegetation index (SAVI). The SAVI, in addition to total surface reflectance (albedo) and other indices, will be evaluated as part of the future studies. Additional on-site information should be collected for reference spectra of soils, rocks, cyanobacteria, and representative plant species.

5.3 SOILS INDICATOR

The sensitivity of soil as an indicator of ecological condition was evaluated as part of the 1992 pilot study. A preliminary attempt was made to compare soil profile characteristics and soil physical and chemical properties collected at the study sites to the USDA Soil Conservation Service (SCS) Soil Interpretation Records (SIR). Since the SIR was determined in the field at the time of initial mapping of the soil by the SCS, it provides an historical basis and independent assessment comparison with present day measured features through time. As a result of this investigation, many issues concerning the use of soils as a means to interpret vegetation and spectral indicators and as an indicator of condition were uncovered. The following subsections describe the results of this investigation and give recommendations for further study.

5.3.1 Results--Soil Profile Description

Eighty-one soil pits at 26 sites were described and characterized as a part of the 1992 EMAP-Arid Pilot Study. These soils were categorized into four major land resource areas (MLRAs). The MLRAs are geographically associated land resource units used in agricultural planning (USDA-SCS, 1981). Most sites were in MLRA 35, Colorado and Green River Plateaus, but a few were in MLRA 34, Central Desertic Basins, Mountains, and Plateaus, MLRA 39, Arizona and New Mexico Mountains, and MLRA 48A, Southern Rocky Mountains. Forty-six pits were located on mesa and bench summits, 27 on sideslopes of alluvial fans, hillsides, and fluvial terraces, and 8 pits were located on local interfluves. Most of the soils were classified in the Aridisol soil order, and a few were classified in the Entisol, Alfisol, and Mollisol soil orders. All of the sites had a mesic temperature regime except site 20752 which had a frigid temperature regime. Many of the sites had an aridic moisture regime, seven of the 26 sites had an ustic moisture regime, and a few were transitional between aridic and ustic. The elevation of the sites ranged from 1,300 to 2,300 m. The average site slope was about 10 percent. The steepest sites were the woodland sites with slopes of 3 to 40 percent. Most of the desertscrub sites had slopes less than 7 percent.

At least one soil pit and three auger holes were excavated at each site to describe soil characteristics, draw a soil map, collect samples, and compare the described soils to the soil survey map unit and components. The main goal of this effort was to obtain baseline soil information and determine how well site-specific data compare to values in the soil interpretation record (SIR) of the USDA-Soil Conservation Service. The soil descriptions used to determine the soil series or family phase at each site are shown in Appendix B. The soil series phase was used as a key to access the SIR. The SIR contains expert estimates of soil properties and interpretive information about each soil series phase and their associated soil horizons and can be used to evaluate field measured properties. The soil map was cut with scissors along soil boundaries if more than one soil series phase was found at a site and each portion of the total map weighed to determine the percentage of soil series at each site. The estimated SIR soil properties were weighted by multiplying by the estimated soil series percentage for each site. The weighted data were summed to obtain the average property value for the site.

The field soil classification was verified by collecting field samples, performing physical, chemical and mineralogical analyses, and evaluating the resulting laboratory data. Thirty-two of the approximately 18,000 United States soil series were recognized in the field. If the same soil series was identified in the field at a given site at the second or third soil sampling area, only the first two soil horizons were sampled resulting in incomplete verification of classification of 25 percent of the pedons due to insufficient horizon data (Appendix B). However, unverified soil identifications were presumed to be correctly identified in the field and were presented in the data set as the field identified soil series. Nine series were described and sampled multiple times. These soils occurred at multiple sites and represent soils of large areal extent. For example, the Rizno soil was sampled 13 times. The Rizno series, which is shallow and has two horizons or less, is a commonly occurring soil in arid environments.

To evaluate the possibility of using published soil survey information to determine soil parameters and to develop baseline data, the soils described at the site by the field crews were compared to published soil surveys, SIRs, and series descriptions. Three sites were in areas where soil surveys were not published. Of the 23 remaining sites, 16 included at least one soil series or component of the published map unit. (A map unit is a conceptual group of delineations identified by the same name in a soil survey that represents similar landscape areas comprised of one or several soil series, plus inclusions.) Two sites were in miscellaneous rock land units with insufficient soil information. Four sites had soils which were different from those indicated in the published soil survey. More than half of the sites were in soil complexes where different soils are mapped together in a map unit. Therefore, since the soils mapped in soil surveys are not mapped in sufficient detail to be site specific, a trained soil scientist is needed in the field to correctly identify the soils at each EMAP-Arid sampling site. The value of correct identification of soil is that information about the soil which cannot be obtained by sampling may be located in the literature.

5.3.2 Results--Soil Quality

Soil quality is best defined as the capacity of a soil to promote the growth of plants; protect watersheds by regulating the infiltration and partitioning of precipitation; and prevent water and air pollution by buffering potential pollutants such as agricultural chemicals, organic wastes, and industrial chemicals. The quality of a soil is determined by a combination of physical, chemical, and biological properties such as texture, water-holding capacity, porosity, organic matter content, and depth (NRC, 1993).

Soil properties near or at the soil surface were evaluated during the 1992 pilot study as candidate indicators. Soil samples were collected from three subplots located to intersect the drip line of the canopy cover. The drip line was chosen as a sampling area to provide consistent sampling protocol and try to obtain a mixed sample of interspace and undercanopy soil. The top two mineral soil horizons were sampled and analyzed for particle-size distribution, organic carbon, cation exchange capacity, soluble salts, bulk density, and water retention (Table 5-6). For each of these parameters, a site average was computed by averaging the two mineral horizons from each pit and multiplying by the percent soil series at each site. Table 5-7 shows the maximum, minimum, median, and 75th and 25th quartiles for all horizons.

In order to provide a preliminary assessment of the soil quality at each site, the measured properties were compared to pre-existing soil property values for the soil series encountered. The published soil property values were obtained from the soil interpretation record (SIR) of the USDA-Soil Conservation Service. For each soil taxon that is recognized by the SCS through correlation in a soil survey area, important physical and chemical properties and indices of each major soil horizon or combination of similar horizons have been estimated (USDA-SCS, 1983). The SIR contains expert estimates of soil properties and interpretive information about each soil series and the associated soil horizons. A soil series may have multiple SIRs; therefore, the soil series at each site must be matched to the appropriate SIR. Unfortunately during this pilot, the appropriate SIR number was not recorded at the time of sampling. Therefore, a match was made during sample analyses according to the best judgment of the soil survey staff at the National Soil Survey Center Laboratory in Lincoln, Nebraska. During future EMAP-Arid field surveys, the SIR will be recorded at the time of sampling.

Estimated soil properties in the SIRs were compared to the measured soil parameter. Averages for the estimated soil properties were computed for each site by matching the soil series phase to its appropriate SIR, extracting the parameter of interest, and adjusting for the percentage of that series phase present at the site. The SIR properties are reported as a range of values. The midpoint of that range for a given property was determined and used in the comparisons.

The difference between the average SIR and measured property values was evaluated using the t-test (Snedecor and Cochran, 1967) to evaluate the potential use of SIR values to indicate status and trends in soil quality. The results are discussed for particle size distribution, organic carbon, cation exchange capacity, soluble salts, bulk density, and water retention difference in the following paragraphs. Analytical methods are given in Table 3-3.

TABLE 5-6. SOIL SURFACES ANALYSES[a]

Site	Form	Bulk Density g/cm^3	CEC/ Clay	CEC cmol/kg	Clay %	EC dS/m	SAR	OC kg/m^2-dm	WRD cm/dm
20752	C	1.14	0.62	18.83	13.42	0.92	0.12	1.88	0.81
20755	C	1.30	0.29	7.75	7.24	1.20	0.14	2.44	0.51
20907	C	nd	0.04	3.53	4.15	0.98	0.13	1.49	nd
20908	C	1.35	0.51	11.47	12.24	0.81	0.11	1.67	1.04
20911	C	1.38	0.63	13.13	16.45	1.52	0.11	1.35	1.53
21064	C	1.33	0.57	4.16	3.88	1.14	0.12	0.80	1.10
21211	C	1.40	0.51	5.55	6.41	2.77	1.04	1.32	0.70
21214	C	1.18	0.66	10.08	9.52	0.90	0.07	1.69	1.07
21215	C	1.16	0.52	19.46	18.90	1.12	0.05	2.75	1.19
21363	C	1.36	0.62	2.95	2.85	0.90	0.18	0.45	0.96
21365	C	1.37	0.23	8.29	20.16	0.82	0.26	1.29	0.75
COF101	C	1.22	0.38	15.82	15.37	1.69	0.21	2.65	1.17
20753	D	1.32	0.60	13.65	15.96	1.25	0.07	1.80	1.93
20758	D	1.40	0.73	11.10	12.81	0.69	0.22	0.72	1.20
20913	D	1.52	1.00	3.94	3.45	0.59	0.15	0.33	2.51
21060	D	1.44	0.26	5.46	11.69	0.98	0.07	0.79	0.81
21061	D	1.48	0.65	4.74	6.97	0.98	0.17	0.46	0.89
21062	D	1.36	0.42	7.33	8.60	1.44	2.11	1.55	1.93
21210	D	1.36	0.39	13.08	24.68	4.32	25.42	1.97	1.14
21212	D	1.43	0.35	4.80	14.32	1.49	5.91	0.26	1.00
21213	D	nd	0.61	2.22	3.32	0.00	0.00	0.41	nd
21217	D	1.33	0.67	4.23	6.52	1.04	0.06	0.34	1.32
21361	D	1.44	0.48	3.21	8.02	0.81	1.06	0.14	0.60
21362	D	1.36	0.36	5.16	13.27	0.52	0.17	0.17	0.74
21364	D	1.47	0.74	2.51	2.65	0.00	0.00	0.53	0.86
21366	D	1.34	0.69	4.26	5.86	1.27	1.35	0.20	0.37

[a] Form: Vegetative forms are C-conifer woodland and D-desertscrub; CEC = cation exchange capacity; CEC/clay = corrected for CEC of organic carbon; EC = electrical conductivity; SAR = sodium adsorption ratio; OC = organic carbon; WRD = water retention difference; nd = not determined.

TABLE 5-7. QUARTILES FOR SOIL SURFACE ANALYSES[a]

Quantity	g/cm^3	CEC/ Clay	CEC cmol/kg	Clay %	EC dS/m	SAR	OC kg/m^2-dm	WRD cm/dm
Maximum	1.71	1.86	40.1	36.9	19.80	132.1	6.09	3.79
75 quartile	1.46	0.67	10.0	14.1	1.24	0.3	1.47	1.33
Median	1.37	0.52	5.7	8.9	0.97	0.1	0.59	1.02
25 quartile	1.29	0.33	3.9	4.4	0.71	0.1	0.21	0.62
Minimum	0.72	0.01	0.7	0.4	0.45	0.0	0.00	0.19

[a]CEC = cation exchange capacity; EC = electrical conductivity; SAR = sodium adsorption ratio; OC = organic carbon; WRD = water retention difference.

5.3.2.1 Particle Size Distribution (Soil Texture)--

Particle size distribution is the fraction of sand, silt, and clay in the soil. The clay fraction is defined as the particle-size class less than 0.002 mm. Physical and chemical activities of a soil are related to the kind and amount of clay (USDA-SCS, 1983). If clay is lost preferentially (due to wind and water erosion) from a soil leaving behind higher contents of sand and silt, then the nutrient and water-holding capacity of a soil would decrease. Soil texture influences plant growth, via water holding capacity and nutrient supply capacity, and is often used as a clue to how soils have formed. Further, the content of the particle size separates is often used as model parameters and is an essential part of site characterization. The proportions of particle sizes indicate sediment history and differential erosion rates.

In the 1992 pilot study there was a significant difference (alpha = 0.01) between the SIR and measured clay content values. The SIR overestimated the amount of clay measured at nearly every site regardless of whether the vegetation class was woodland or desertscrub (Figure 5-11). In four cases, where clay content differences were greater than 10 percent, a degradation of the system is indicated above and beyond the error commonly associated with estimating particle distribution or texture by feel. In contrast, sites 21215 and 21210 appear to be accumulating clay and may be located in a depositional topographic setting. One possible explanation is that preferential removal of clay by wind and water erosion has occurred at the sites since the original properties were estimated for the SIR. Another possibility may be that the soil series phase was mismatched with the SIR or that inaccurate estimates are reported in the SIR. Because of these discrepancies, it appears that, for future EMAP-Arid field surveys, soil samples should be collected so that measurements of site-specific particle size distribution can be made.

5.3.2.2 Organic Carbon--

Organic carbon (OC) in soil samples is measured to estimate the organic matter composed of plant and animal matter in various stages of decomposition in the soil. Organic matter is estimated by multiplying the OC by the constant 1.72. The OC generally is the most chemically reactive fraction of the soil and is capable of holding moisture within the soil. High OC indicates a large nutrient pool, sustainable fertility, and C-sequestration. The OC generally correlates with

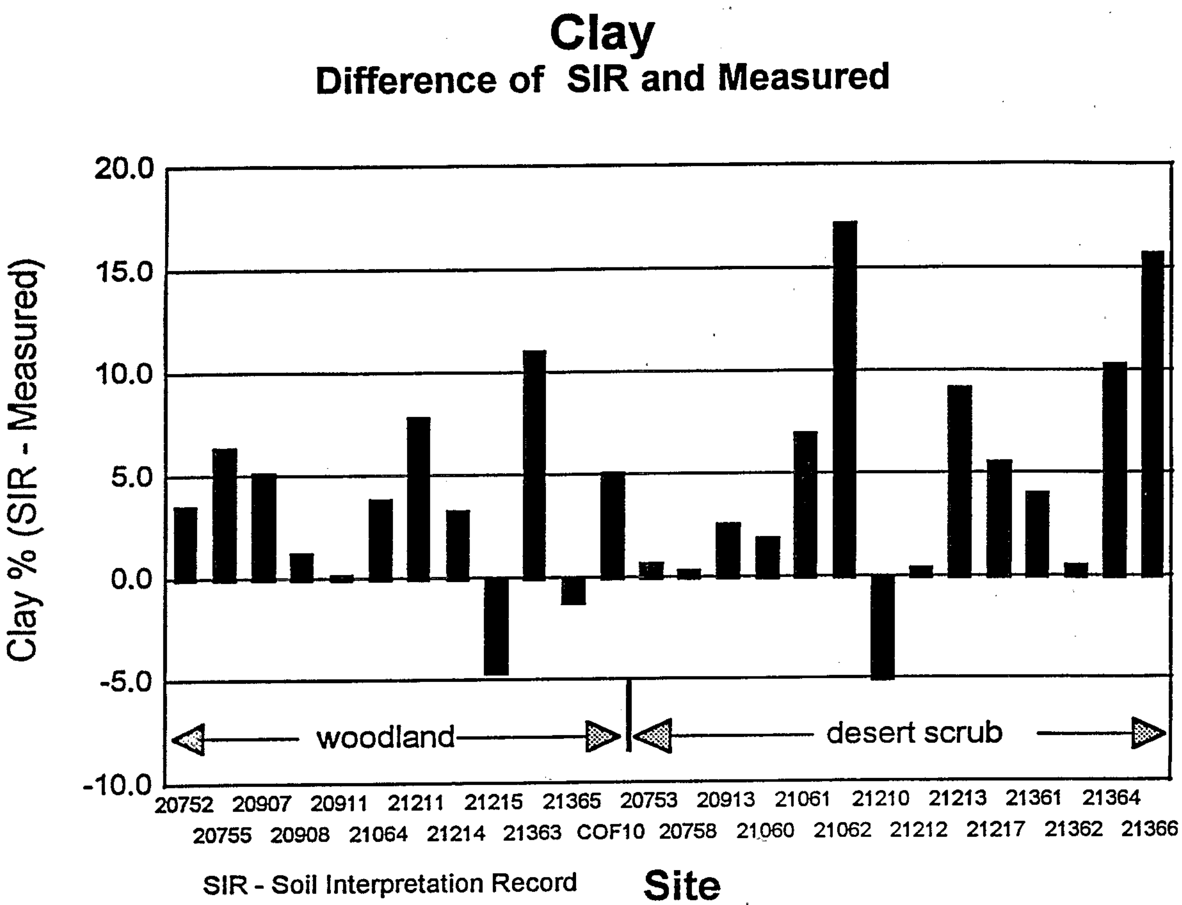

Figure 5-11. Clay-difference between SIR estimate and amount measured at site.

vegetation types and amounts and integrates long-term trends in vegetation. Data collected for each horizon were converted to a volume basis for the first 10 cm (1 dm) or to the depth of the soil, if shallower, using the following formula:

$$OC\ (kg/m^2\text{-}dm) = OC \times \text{bulk density} \times \% < 2\ mm \times 0.1 \times \text{horizon thickness.}$$

The range of values was from 0 to 6.09 kg/m^2-dm. Conifer woodlands were higher than desertscrub due to higher biomass at the woodland sites. When compared to the measured OC, the SIR OC contents significantly underestimated the OC content at the sites indicating the possible accumulation of organic matter since the SIR was originally determined (Figure 5-12). This difference is noticeable for the woodland sites because of the accumulation of pine needles even though the organic horizons were excluded from the calculation. In contrast, the OC content is higher on desertscrub sites where vegetative cover is higher than average. The measured OC value as compared to the SIR indicates a slight degradation (i.e., loss of OC) of the desertscrub sites, except at sampling locations 21062 and 21210 (perhaps due to several drought years in the Colorado Plateau). The SIR estimated average value for OC is not a good indicator of trend or status. Thus, for future EMAP-Arid surveys, the soil surface horizon should be sampled and OC measured to determine status and trend.

5.3.2.3 Cation Exchange Capacity (CEC)--

The CEC can be defined as the sum of the exchangeable cations that a soil or soil constituent can absorb at a specific pH. Decreases in CEC indicate a loss of nutrient storage. Additionally, the CEC-to-clay ratio can be used to estimate clay mineralogy and clay activity. Changes in the CEC-to-clay ratio indicate weathering and soil development. There was no significant difference between the SIR and measured values for all sites regardless of vegetative cover type (Figure 5-13). However, for most desertscrub sites, the measured CEC was lower than reported in the SIR. In two cases, where conifer woodlands were identified, the SIR markedly underestimated the CEC. At both of these sites, the SIR also underestimated the organic carbon content and clay content (figures 5-11 and 5-12) indicating the strong direct relationship between these three parameters. Thus, for first visits to a site, the CEC should be measured as baseline data. Any changes in CEC would be detected by changes in clay and organic carbon contents because they can be correlated with CEC identified on subsequent visits.

5.3.2.4 Soluble Salts--

Electrical conductivity (EC) and the sodium adsorption ratio (SAR) are indicators of salinity (soluble salts) or sodium (Na) accumulation. The lower limits of EC and SAR that affect salt sensitive plants are 0.4 siemens per meter and 13, respectively. Soils with a high SAR and low EC have poor soil structure that adversely affects plant growth. Only the Ravola soil series at site 21210 had high EC and SAR levels. The high EC values were reported on the SIR but not the high SAR values (Figure 5-14 and Figure 5-15). In general, the EC was underestimated in woodland sites and overestimated for desertscrub sites indicating that either (1) salts are accumulating in the woodlands and being lost in the desertscrub environments or that (2) the original estimates were inaccurate. When comparing the EC and SAR measured values to the SIR values, the degradation

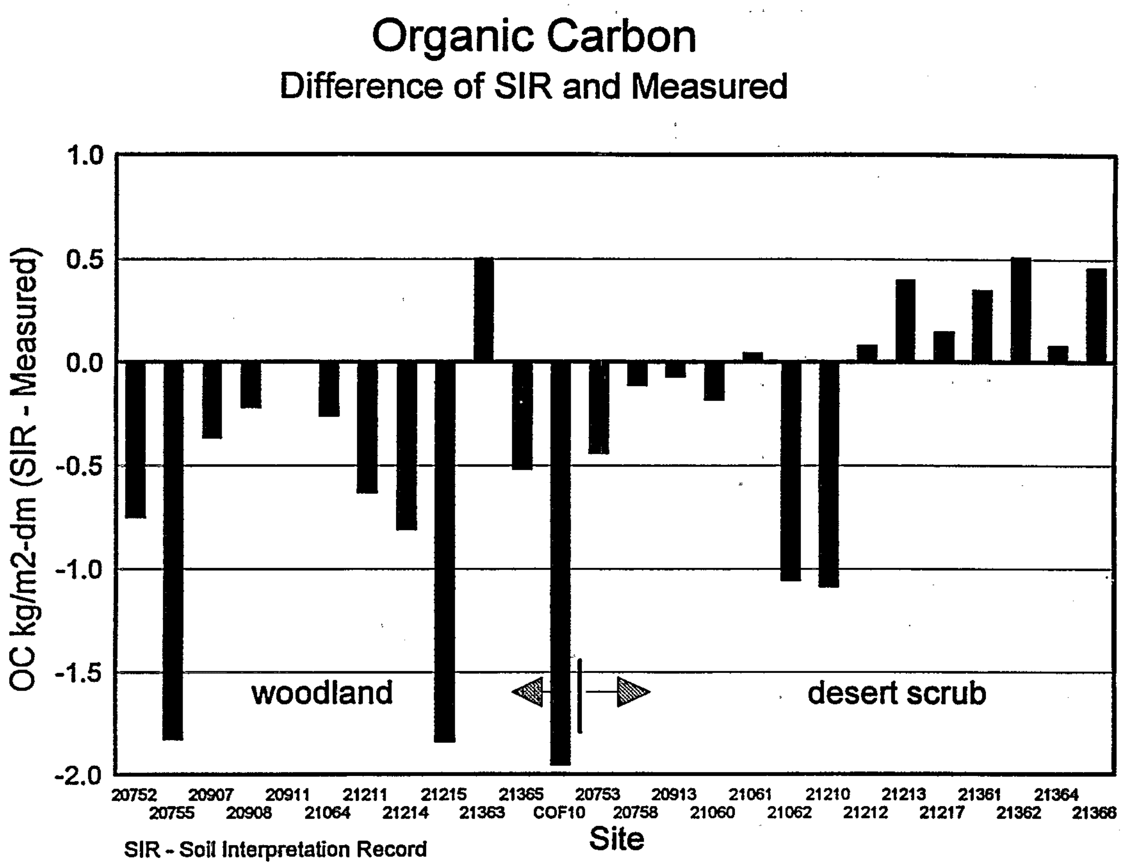

Figure 5-12. SIR organic carbon versus measured OC at site.

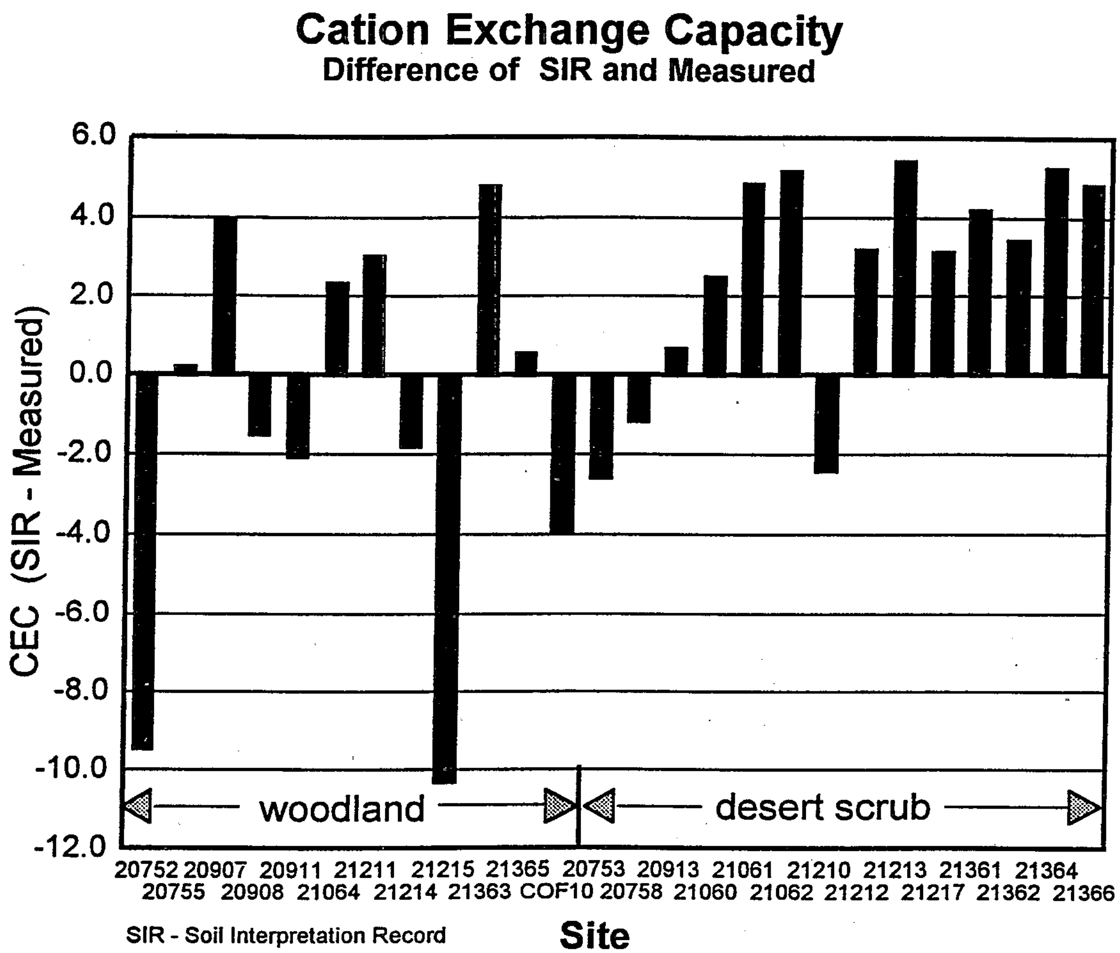

Figure 5-13. No significant difference between SIR and measured values for cation exchange capacity.

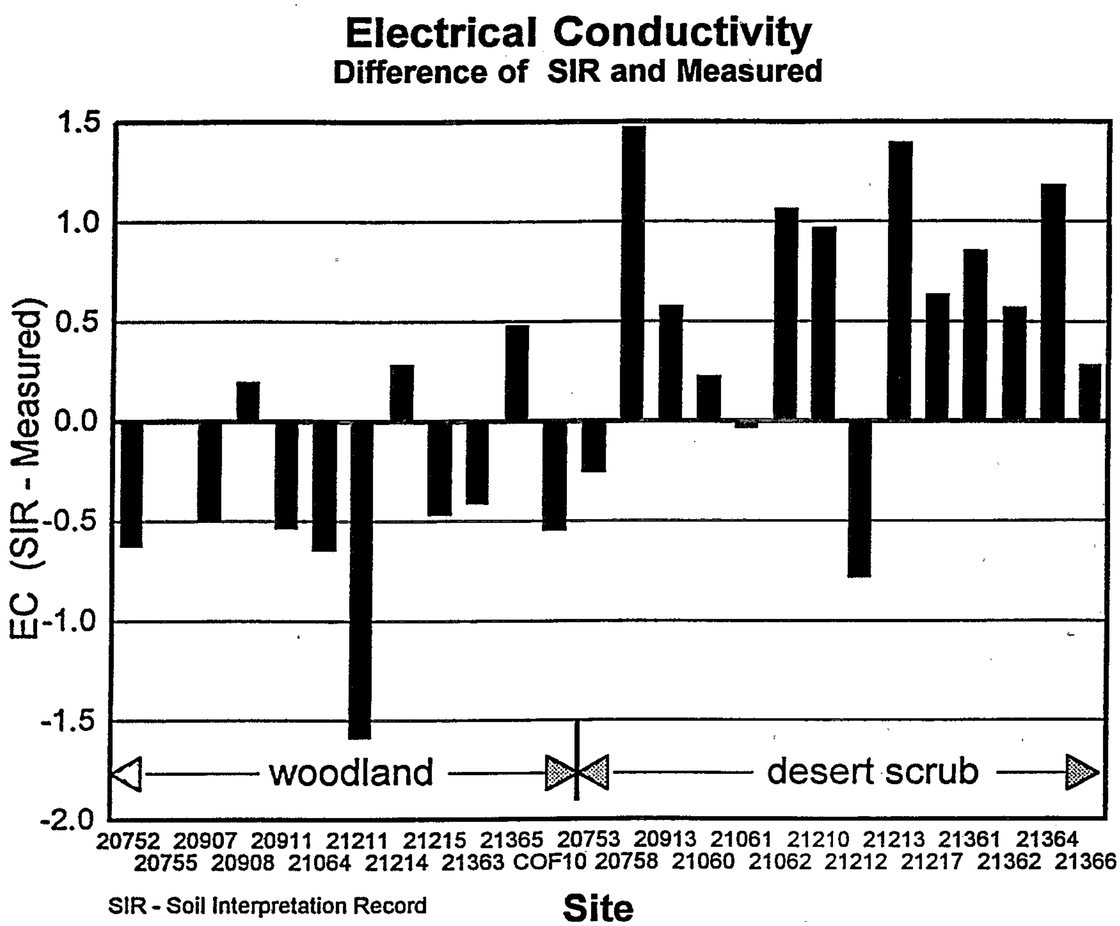

Figure 5-14. Difference between SIR and measured values for electrical conductivity at 1992 pilot study sites.

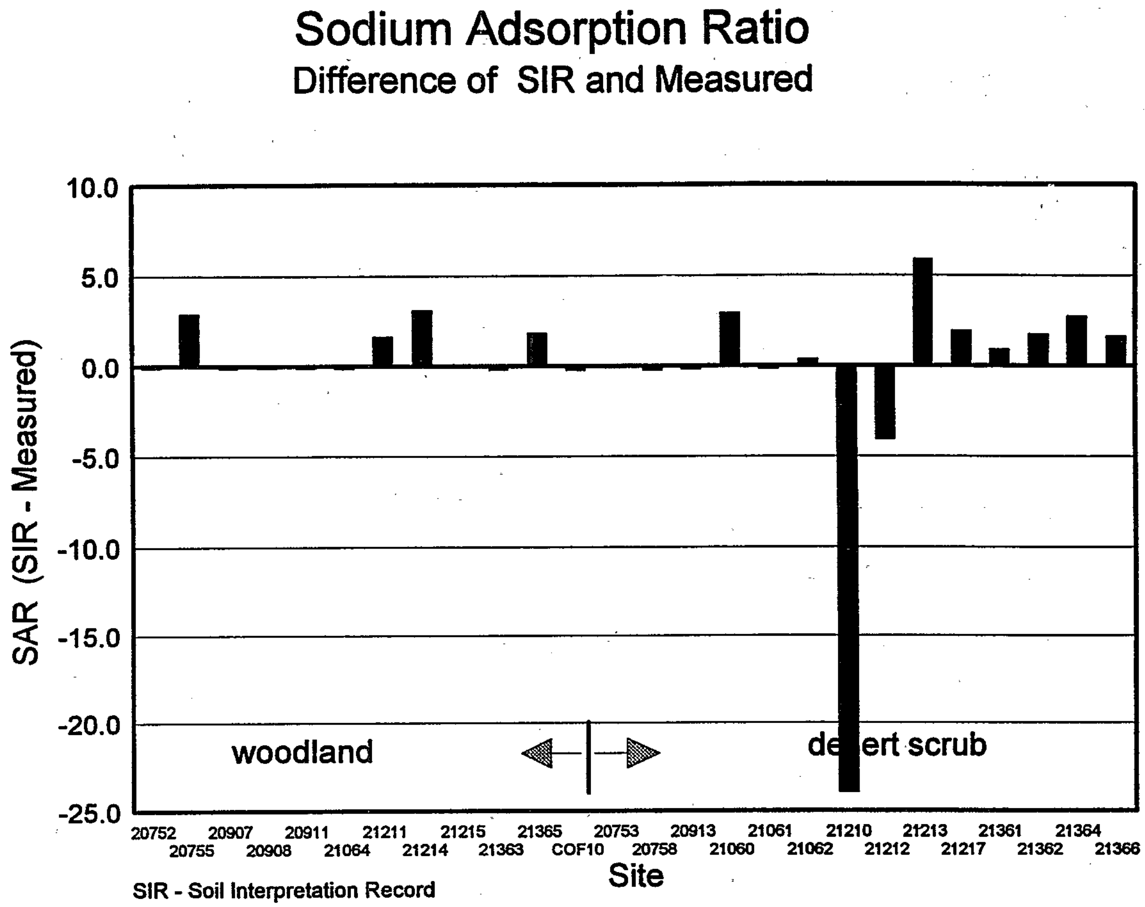

Figure 5-15. Difference between SIR and measured values for sodium adsorption ratio at 1992 pilot study sites.

of site 21210 is clearly visible as salts are accumulating at this site. Additionally, increased salt content was identified at site 21211, but not of the sodium-based salts, indicating a potential for degradation (assuming continued salt increase and accurate SIR estimates) at that site. In the future, field methods should be used to measure EC at each site since increasing EC contents indicate a threat to plant communities.

5.3.2.5 Bulk Density--

Bulk density is the mass of oven-dry soil per unit bulk volume. Volume is determined based on a sample equilibrated at a moisture tension of -33 kPa. Bulk density is used to convert weight-based data to volume-based data. Bulk density is related to soil texture. Bulk density values for mineral soils typically range from 1.3 g/cm^3 for clayey soils to 1.7 g/cm^3 for sandy soils. Bulk density values higher than those in the typical range indicate soil compaction which alters water transmission rates and impedes root penetration. For example, 90 percent of roots are impeded if the sand content is greater than 75 percent and bulk density is greater than 1.8 g/cm^3 or if the clay content is greater than 35 percent and bulk density is greater than 1.50 g/cm^3 (Jones, 1983). No horizons had a bulk density high enough to impede root growth.

In the pilot study, bulk density was not measured at all sites for all samples due to failure to obtain a natural clod or loss of sample integrity during shipping or analysis. Where bulk density was missing (two sites as indicated by nd in Table 5-6), values were estimated using DRAINMOD algorithms (Baumer, 1989) for comparison purposes with the SIR values.

A comparison of the bulk density between SIR and measured data indicates that 77 percent of the sites were within 0.1 g/cm^3 (Figure 5-16). The SIR values overestimate the measured bulk density for conifer woodland sites while they underestimate the bulk density for desertscrub sites. One possible explanation for this finding is that the increased organic carbon contents (relative to the SIR estimates) at the woodland vegetation sites is leading to an improvement in the soil at these sites (a "loosening" of the soil). In contrast, the relative loss of OC at the desertscrub sites has led to an overall increase in the bulk density in this ecosystem. More research is needed to determine significant threshold differences between SIR and measured values. However, the characterization data are adequate to determine baseline status. To determine trends and status, bulk density measurements need to be made at or near the soil surface.

5.3.2.6 Water Retention Difference--

The portion of water in soil that can be absorbed by plant roots is defined as the available water. This portion is estimated by determining the difference of water contents at 33 kPa and 1,500 kPa (WRD). The WRD affects plant growth and species composition and is affected by anthropogenically and naturally induced stresses such as erosion and compaction. A reduction in WRD would indicate that the ability of the soil to provide water to plants is being adversely impacted. The actual amount of water stored is a function of soil storage capacity and climate. The water retention difference computations were converted to a volume basis to a depth of 10 cm (1 dm) or to the depth of the soil, if shallower, using the following formula (where Db is bulk density):

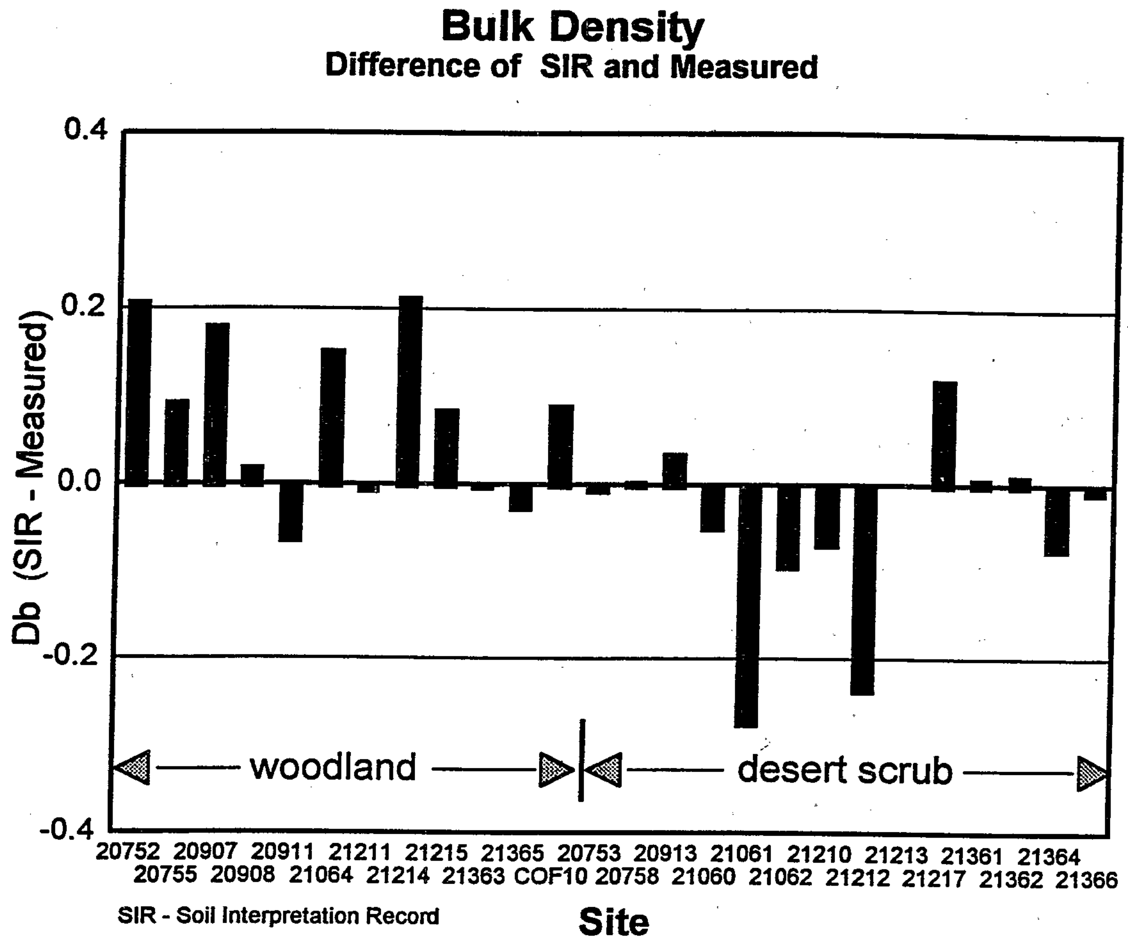

Figure 5-16. Difference between SIR and bulk measured values for bulk density at 1992 Pilot Study sites.

WRD = (33 kPa - 1,500 kPa) x Db x horizon thickness x %<2 mm

The range of WRD capacity for the top 10 cm at 1992 pilot study sites was from 0.19 cm/dm to 3.79 cm/dm. There is no significant difference between the SIR WRD and measured WRD values. However, at site 20913 a marked increase in the difference between the SIR and measured WRD value was noted indicating an improved water holding capacity at this site. Use of the SIR to evaluate the status of the WRD of soil quality is an acceptable approach. While no significant difference was determined, the range of SIR WRD values may be too wide to detect any trends. In order to determine if the WRD is increasing or decreasing, repeated measurements should be made. The WRD should be correlated with the vegetation data to evaluate the plant community with respect to the potential water resource.

5.3.2.7 Summary of Soil Quality Results--

In general, use of the SIR to evaluate status of individual properties of soil quality is an acceptable approach to obtain a reference value of the soil characteristics at EMAP-Arid sites. More research is needed to combine individual properties into a single indicator of soil quality. However, to establish trends in soil quality changes, repeated sampling of the same sites at specified intervals of time will be required.

5.3.3 Results--Erosion Index Measurements

The erosion rates calculated for the 1992 pilot study sites are given in Table 5-8. The cyanobacteria (cyano) was not considered in the computation of C, the cover and management factor. The average C factor calculated by including half of the cyanobacteria amount is reduced by about 40 percent. All the calculated erosion rates are substantially less than the soil T values in the SIR indicating that acceptable erosion levels were occurring at the site and that little degradation due to erosion was occurring. The T factor is an estimate and is traditionally used to estimate acceptable soil loss for cropland. It may be inappropriate to use the value as a benchmark in rangeland. Ten of the 26 sites were judged to be moderately eroded by soil scientists using evidence of erosion such as rills, gullies, and desert pavement. The soil loss estimated by RUSLE failed to identify these sites. The C factor was lower than expected and was the most important factor in yielding low erosion rates. Further investigation is warranted to assess the validity of the C factor model. The SCS uses the RUSLE as the best current estimate of erosion rates; however it is a lumped-model designed to meet long-term soil conservation planning needs on cropland and may not be sensitive to single condition measurements as proposed by EMAP. For example, the C factor varies temporally and calculated erosion rates will be higher when canopy cover is less. Further testing of the C factor is recommended. The use of process-oriented models, such as the Water Erosion Prediction Project (WEPP) (Lane and Nearing, 1989), should be tested to determine if they are more suitable to determine trends and status.

TABLE 5-8. SIR[a] AND RUSLE[a] FACTORS AND ANNUAL AVERAGE EROSION RATES

Site	Form[b]	K[c] (SIR)	T[c] (SIR)	A[d] (KSIR) (t/a/yr)	K[c] Eros	LS[d]	C[d] w/o cyano	C[d] = w/0.5 cyano	R[d]	P[d]	A[d] (t/a/yr)	Soil erosion class[e]
20752	C	0.24	2.50	0.02	0.28	2.33	0.00	0.00	10.00	1.00	0.03	1
20755	C	0.25	1.00	0.01	0.13	0.57	0.01	0.01	10.00	1.00	0.01	1.5
20907	C	0.17	1.00	0.02	0.08	1.35	0.01	0.01	13.40	1.34	0.01	2
20908	C	0.29	1.50	0.03	0.30	0.67	0.02	0.01	10.00	1.00	0.03	1
20911	C	0.31	5.00	0.04	0.55	0.30	0.07	0.01	16.60	1.66	0.07	2
21064	C	0.23	1.50	0.05	0.19	0.61	0.05	0.01	11.20	1.12	0.04	1
21211	C	0.27	1.49	0.02	0.20	0.43	0.03	0.01	16.50	1.65	0.01	1
21214	C	0.29	2.15	0.01	0.31	0.63	0.01	0.00	10.00	1.00	0.01	1
21215	C	0.21	2.78	0.01	0.36	0.64	0.01	0.00	9.20	0.92	0.02	1.5
21363	C	0.16	1.10	0.03	0.24	1.23	0.02	0.01	13.20	1.32	0.05	2
21364	C	0.24	1.36	0.04	0.19	0.37	0.04	0.01	10.00	1.00	0.03	2
21365	C	0.17	1.04	0.01	0.36	0.76	0.01	0.01	10.00	1.00	0.03	2
21366	C	0.14	1.00	0.03	0.69	0.71	0.04	0.03	10.80	1.08	0.15	1.7
COF101	C	0.24	1.25	0.02	0.29	0.73	0.01	0.01	10.00	1.00	0.02	1
20753	D	0.31	5.00	0.02	0.51	0.34	0.02	0.00	10.00	1.00	0.03	1.5
20758	D	0.18	3.32	0.01	0.50	0.31	0.02	0.01	10.00	1.00	0.04	1
20913	D	0.29	5.00	0.14	0.26	0.58	0.09	0.02	10.00	1.00	0.13	2
21060	D	0.25	1.00	0.03	0.11	0.33	0.04	0.02	10.00	1.00	0.01	2
21061	D	0.19	4.80	0.04	0.31	0.35	0.06	0.01	9.60	0.96	0.07	2
21062	D	0.33	5.00	0.01	0.50	0.22	0.01	0.01	10.00	1.00	0.01	1
21210	D	0.45	4.57	0.03	0.42	0.12	0.06	0.06	10.00	1.00	0.03	1
21212	D	0.15	3.09	0.01	0.24	0.42	0.01	0.00	8.50	0.85	0.01	1
21213	D	0.34	3.56	0.11	0.28	1.30	0.04	0.02	10.00	1.00	0.07	2
21217	D	0.29	1.00	0.01	0.55	0.50	0.01	0.01	10.00	1.00	0.02	1.3
21361	D	0.29	1.00	0.04	0.37	0.28	0.05	0.02	10.00	1.00	0.05	2
21362	D	0.25	1.27	0.07	0.47	1.10	0.02	0.01	9.60	0.96	0.13	2

[a] SIR is the USDA Soil Conservation Service Soil Interpretation Records. RULSE is the Revised Universal Soil Loss Equation.
[b] C = conifer woodland; D = desertscrub.
[c] K = soil erodibility factors; T = soil loss tolerance; K(SIR) and T(SIR) are from the published SIR.
[d] A = average annual soil erosion; A(KSIR) is the soil loss calculated with K(SIR) and LS, C, R, and P; cyano = cyanobacteria; t/a/yr = tons per acre per year; LS = slope-length and slope-steepness factor; C = cover and management factor; w/o = without; w = with; R = rainfall and runoff factor; P = support practice factor.
[e] Soil Erosion Classes: 1 = slight, 2 = moderate, 3 = severe (estimated by soil scientists).

5.3.4 Recommendations

Excavating as many as three pits per site to depths greater than 1 meter proved time consuming. Fortunately, the soil identification and sampling at depth will not need to be repeated if the same site is remeasured. It is anticipated that only surface horizons will need to be sampled to show changes in the arid ecosystem at a given site. We recommend identifying the soils at each site by auger observations, description, and construction of a soil map of the site. The dominant soil should be excavated, sampled, and analyzed to provide baseline data. This process allows verification of the soil series classification, establishment of baseline condition, and development of soil-vegetation relationships. Furthermore, the data provide inputs for models such as the Water Erosion Prediction Project. The auxiliary areas should be excavated only by auger to confirm and verify the soil series classification at the site. The SIR was a good estimator of several surface soil properties (e.g., CEC, available water, bulk density, and salinity) and thus can be used as a benchmark to assess condition and evaluate trends or as a source of input data for models. To improve these interpretations, the critical phase criteria should be recorded on the field data sheet and the appropriate SIR and phase identified for a more accurate assessment of the measured properties as compared to the estimated properties. The surface soil property data indicated that there were no significant differences between SIR and measured properties for cation exchange capacity, water retention difference, bulk density, or salinity. Significant differences were, however, measured between organic carbon and clay content indicating that these parameters in soil samples need to be evaluated and analyzed to provide useful data.

The use of published soil maps to identify the kind and percentage of soils at a given site is an essential tool to provide overall assessments of the sampled sites. A knowledge of soil and landscape relationships is necessary and thus requires the use of SCS (or other professional) soil scientists. Future surveys need to determine the number of soil samples required to make reliable estimates; develop a method of evaluating surface soil compaction; and make a stronger effort to relate soil properties and vegetation communities.

Other recommendations include:

- Infiltration measurements are important indicator measurements for water balance and should be incorporated into the 1993 pilot study (Kepner et al., 1993).

- Sites should be located on single landscape positions to reduce the soil variability. This would eliminate the estimation of average property values for a site and enhance the interpretation of vegetation and soil relationships.

SECTION 6
FRAME MATERIALS

The Biotic Communities Map of North America, developed by Reichenbacher and Brown (1992), was evaluated to determine how well this data base identified resource classes at the 39 selected sites (29 of these sites were sampled; see Section 2). Similarly, a preliminary evaluation of the U.S. Fish and Wildlife Service (FWS) Gap Analysis Program (GAP) information was conducted to determine how well the satellite-derived data base identified plant communities found at the pilot study sample points.

The 1:8,000,000 scale Biotic Communities Map data base was digitized and imported into GIS software for correlation with the EMAP-Arid sample grid points. Although the community-level descriptions provided some utility in characterizing resource classes, the relatively coarse scale and inaccuracy (as much as six degrees off longitudinally) of the map prevented any accurate resource class identification in the pilot study area.

The GAP data set, developed by the Utah State University Fish and Wildlife Cooperative Research Unit, consists of a map of classified plant communities derived from georeferenced, Landsat TM imagery combined in a mosaic of the entire state of Utah. The construction of the GAP data was a first attempt by the FWS to classify the vegetation of Utah using Landsat TM data. The accuracy of the data set was largely unknown. An accuracy assessment of rangeland formations (resource classes) had not been conducted at that time.

6.1 RESULTS

To provide the preliminary evaluation of the accuracy of the GAP data, vegetation cover assessments were made at each of the 39 EMAP-Arid sites. It is well documented in the literature (Hay, 1979; Congalton, 1991) that at least 50 samples for each landcover category in a classification are required to perform a valid accuracy assessment. A limited number of vegetation assessments were taken at the 39 EMAP-Arid sites in hopes of providing some early evaluation results to the GAP program. The 28 landcover categories used in the GAP data set were broken down into six classes--desertscrub, grassland, pinyon/juniper woodland, water, agricultural crops, and slickrock/barren. Based on the assessments performed at each sample site, the error matrix shown in Table 6-1 was constructed. The error matrix is an array which expresses the number of sample units assigned to a particular category, in this case the landcover classes derived from the Landsat-based GAP data, relative to the actual category found on the ground (Congalton, 1991). The columns in Table 6-1 represent the ground-based data while the rows indicate the classification generated from the GAP data. The accuracy of the data set is computed by dividing the sum of the major diagonal by the total number of sample units. Accuracies for individual categories are computed by dividing the total number of correct sample units by the total number of sample units in either the corresponding row or corresponding column. An evaluation of the "producer's

TABLE 6-1. CLASSIFICATION ERROR MATRIX OF THE PRELIMINARY GAP DATA

		Vegetation Assessment on the Ground						TOTALS	USER ACCURACY
		Desertscrub	Grassland	PJ	Water	Crop	Barren		
Data Gap Results	Desertscrub	11	3	4			1	19	58%
	Grassland	1	0				1	2	0
	Pinyon/juniper	5		9				14	64%
	Water				1			1	100%
	Crop					1		1	100%
	Barren	2					0	2	0
	TOTALS	19	3	13	1	1	2	39	x
	PRODUCER ACCURACY	58%	0	69%	100%	100%	0	x	x

OVERALL ACCURACY = 56%

accuracy," or measure of omission error, indicated that 69 percent and 58 percent of the pinyon/juniper and desertscrub landcover types, respectively, were correctly classified by the GAP data. None of the grassland, however, was correctly classified. An evaluation of the "user's accuracy," or measure of commission error, yielded similar statistical results for the primary landcover types of interest. The effect of an insufficient sample size becomes obvious when evaluating the grassland classification results; with only three sample sites, the results of the grassland assessment were not meaningful.

The preliminary vegetation assessments conducted during the pilot study were performed at sites less than 1 hectare in area. To address the issue of plant community inclusions within sampled vegetation, larger area measurements need to be made to more precisely determine the referenced sample units relative to the Landsat-derived vegetation categories. To perform a valid accuracy assessment of the remote sensing GAP data set, it will be important to increase the number of samples per category evaluated in the field. Just as critical to the accuracy assessment, however, is the development of a sampling design that addresses inclusions and ensures a meaningful estimation of the extent of vegetation community types.

Preliminary results appear to indicate that plant communities distributed widely over the landscape, with thin individual canopies, are difficult to accurately classify with Landsat TM data alone. As the Landsat satellite instrument detects reflected energy from the Earth's surface, a significant portion of the spectral signal reflected from arid lands is background soil. Utah State University integrated elevation and slope data into the data set used in this evaluation, but the construction did not include a soil layer. Incorporating a soils data base into a classification model of the pilot study area would greatly aid in the discrimination of the desertscrub, grassland, and woodland resource classes. Utah State University is presently integrating a soils data base from the Soil Conservation Service (SCS) into its second generation Landsat TM-derived vegetation map of Utah. This addition should greatly improve the accuracy of the data base in the arid vegetation resource classes, and thus enhance the utility of the data for selecting frame materials for future pilots and demonstrations.

To determine whether the GAP program and EMAP-Arid definitions of specific resource classes concur, it is imperative that the EMAP-Arid group has well-developed conceptual and operational definitions of not only resource classes but biogeographic provinces as well. The EMAP-Arid researchers identified the following biogeographic provinces for reporting purposes within Arid Ecosystems. Figure 1-1 shows the distribution of the Biogeographic Provinces of North America for the EMAP-Arid resource group. These provinces are Great Basin, Plains, Mohave, Sonoran, Chihuahuan, Colorado Plateau, Californian, and Arctic. The EMAP-Arid team has also identified the following resource classes for reporting purposes. These resource classes are desertscrub, grassland, scrubland, woodland, tundra, riparian forest, riparian scrub, and strandland.

The FWS GAP definitions of plant communities and thus resource classes in the EMAP-Arid pilot study area concur, for the most part, with EMAP-Arid program definitions. The riparian resource classes, however, are not adequately defined by the GAP data. A more critical issue involving the use of the preliminary data base is its accuracy, which to date has not been adequate to characterize arid ecosystems, specifically rangeland resource classes.

Although definitions of provinces and resource classes have been identified by EMAP-Arid, the 1992 pilot study was not designed to address questions of arid resource extent. For example, definitions need to be developed to state what constitutes a pinyon juniper woodland and how inclusions found within a woodland community are to be characterized.

The 1992 pilot study did not specifically define how area extent estimates of resources can be carried out, although efforts have been made to determine the most appropriate method of sampling extent. Three basic methods of extent estimation--point samples, area samples, and "cookie cutter" samples--have been evaluated and some suggestions made as to the best choice for EMAP-Arid. The "cookie cutter" area sample appears to be the best method from both the ecological standpoint of landscape characterization and the statistical standpoint of providing a smaller variance estimate.

6.2 RECOMMENDATIONS

The EMAP-Arid group definitions of vegetation resource classes, as well as biogeographic provinces have been established. A method, or set of methods, to estimate extent of arid resources needs to be developed, with the idea that an area sampling technique will provide a better estimate of extent.

The preliminary evaluation of the GAP data was inconclusive. If the EMAP-Arid group wants to consider using GAP data in the future to select frame materials and to provide data for extent estimation of arid ecosystems, then a scientifically valid assessment of the accuracy of the GAP data must be performed. This assessment should be done on the second generation (or the most recent version) of the GAP data and must include a sufficient sample number for each land cover type.

SECTION 7
QUALITY ASSURANCE, INFORMATION MANAGEMENT AND LOGISTICS

Quality assurance (QA), information management, and logistics are integral components of EMAP field activities. In a program the magnitude of EMAP, overlooking or ignoring even apparently minor issues or details may eventually jeopardize the success of the program. Planning and documenting QA, information management, and logistics activities are essential. This section documents these activities for the 1992 pilot study.

7.1 QUALITY ASSURANCE

Quality assurance plays a critical role in EMAP-Arid research efforts. As part of the EPA Office of Research and Development, EMAP participates in the Agency's mandatory QA program (Stanley and Verner 1985). Quality assurance activities are integrally connected with study objectives, statistical design, logistics, field and laboratory measurements, information management, data analysis, and product and report generation.

7.1.1 QA Program Overview

The general objective of the EMAP-Arid QA program is to maximize the probability that data and statistical products collected by the EMAP-Arid Resource Group are of known, documented, and adequate quality to meet and satisfy the needs of the data users. The philosophy of the QA program for EMAP-Arid is one of guidance and assistance rather than enforcement. The responsibility for the quality of the data rests with all project personnel, not just the QA personnel. A specific pilot study objective related to QA was to determine whether data quality objectives could be established for each indicator tested.

Data quality objectives (DQOs) are 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. Data quality objectives are definitive, qualitative or quantitative statements developed jointly by data users (e.g., scientists, policy makers, interest groups) in conjunction with the QA staff. Data quality objectives will eventually be developed on several levels so that acceptable levels of data quality will be specifically established for individual measurements (measurement level), for indicators of ecosystem condition (indicator level), and for the EMAP monitoring program (program level, i.e., status and trends). These levels differ in that the higher levels contain more error sources and set constraints for the lower levels.

Data quality objectives at the program level include all sources of error (e.g., design, sampling, measurement, indicator) that can accumulate and affect the interpretation of EMAP data for determining status and trends. Program-level data quality is defined in terms of the ability to meet the EMAP program objectives with desired certainty. These DQOs will be used as performance criteria to assess data quality for its adequacy in determining status and trends for full implementation (Kirkland, in preparation). The following EMAP program-level target DQO for trend detection has been drafted by EMAP management:

> Over a decade each indicator of condition of a resource class on a regional scale should on average detect a linear trend of 2 percent (absolute per year); that is, a 20 percent change for a decade in the percentage of the resource class in a degraded condition. The test for a trend will have a maximum significance level of 0.2 and a minimum power of 0.7.

Indicator-level DQOs are derived from aggregated parameter data for ecological indicators. These DQOs may focus on the uncertainty associated with the data aggregation procedures used to assimilate measurement-level data that provide assessment information, e.g., an index. Data quality objectives should be developed to assure that data collected in pilot projects are of adequate quality to support the research question (e.g., does an indicator require further development or should it be included in the core group or be discarded). These DQOs must eventually be established at a level such that the program-level DQOs will be satisfied.

Measurement-level DQOs (MQOs) are established for specific field and laboratory measurement parameters. They are usually based on data user requirements and are often estimated using existing or initial baseline data. These MQOs may define acceptance criteria for detectability, precision, accuracy, representativeness, completeness, and comparability in field and laboratory measurement data. The importance of MQOs at the early phase of resource group activities stems from the fact that MQOs describe the most basic data level that will be used to validate methods. The measurement quality objectives, listed in Tables 7-1 and 7-2 were established for the 1992 pilot. MQOs were not established for spectral measurements.

One of the goals of the EMAP-Arid field QA Program was to ensure the comparability or between-crew precision of data produced by different field crews. Between-crew precision is particularly crucial for some types of data collected, such as vegetation measurements and spectral reflectance, because the data quality of these measurements cannot be assessed with QA samples.

The two field crews collecting data throughout the summer participated in several between-crew remeasurements as part of the QA Program. These were of two different types--site remeasurements and plot remeasurements. No within-crew remeasurements were performed and therefore no assessment was made of within-crew precision.

Site remeasurements were performed when one crew located, established, and measured a site that had already been measured by the other crew. In these cases, the crew was instructed to locate the permanent marker placed by the other crew and re-establish the transects. These exercises did not provide a true estimation of crew variability because the crews were not sampling exactly the same transects, subplots, and soil pits. They could, however, provide some information about the amount of measurement plus spatial variability to be expected when sites are revisited. They also provide information on the crew ability to relocate a site previously sampled by another crew. Site remeasurements were performed by the botanists and the soil scientists at four locations.

TABLE 7-1. MEASUREMENT QUALITY OBJECTIVES FOR VEGETATION

Variable	Units	Quality objective
Cover class (5 elements)	7 classes	90% agreement
Herbaceous plants		
Species	---	90% agreement
Cover class	7 classes	90% agreement
Small shrub		
Species	---	95% agreement
Cover class	7 classes	90% agreement
Large shrubs and trees		
Species	---	98% agreement
Widest crown diameter	50 cm	90% within 1 m.
Perpendicular diameter	50 cm	90% within 1 m
Height	50 cm	90% within 1 m
Basal trunk diameter	25 cm	90% within 50 cm

Plots were remeasured when both field crews visited the same previously established plot on the same day. Two plot remeasurement sites (one pinyon-juniper and one desertscrub) were performed at the end of the field season on August 11, 1992. For this exercise, two transects and two tree subplots were laid out and left in place until both botanists were finished with the measurements. The botanist from each crew measured the vegetation on each transect and on each subplot independently. Although the variance between the two botanists includes the variance associated with placement of the sampling frames on the transect, these data can be used to estimate variability between the two botanists.

The soil crews also participated in the plot remeasurement exercise with each crew excavating and describing a soil pit. After each pit was excavated and described, the crews switched places and described the other soil pit.

7.1.2 Results

The following sections provide an assessment of data quality and MQOs for vegetative, spectral, and soil measurements collected during the 1992 pilot study.

7.1.2.1 Vegetation Measurements--

Two crew comparability tests (one in pinyon-juniper woodland and one in desertscrub) were conducted using exactly the same transect lines and subplot centers. Twenty herbaceous/shrub quadrats at each plot and two tree subplots at the pinyon-juniper site were used to compare measurements between crews. No within-in crew precision or crew accuracy assessments were performed.

TABLE 7-2. MEASUREMENT QUALITY OBJECTIVES FOR SOIL ANALYSES

Parameter	Reporting units	Detection limits	Precision limits: Standard deviation	Precision limits: Coefficient of variation
Particle size				
Sand	% wt	2	1.2	3
Silt	% wt	2	1.2	3
Clay	% wt	2	1.2	3
Organic carbon	% wt	0.03	0.02	1
Total carbon	% wt	0.2	0.12	1
Cation exchange capacity	meq/100g	0.09	1.20	4
Soluble salts	mmho/cm	0.05	0.09	2
Total nitrogen	% wt	0.06	0.004	3
Clod bulk density*	g/cm^3	0.30	0.31	15
pH	pH units	0.05	0.15	
Sodium absorption ratio	meq/L	0.09	1.70	4
Water retention	% wt	1.0	0.52	4

* Was not established prior to 1992 field activities.

Table 7-3 summarizes vegetation measurement data and calculated cover values for selected attributes at each of the remeasurement plots. Each cover class value recorded by the botanist was converted to a midpoint value. An average midpoint value was then calculated for each attribute for each crew. Attributes were selected for a precision assessment based on their relative importance to indicator development. Ground cover attributes (total vascular plant cover, interspace rock fragments, and interspace litter) will be used in the calculation of an erosion index. Surface type and cryptogamic crust (cyanobacteria) are proposed indicators of temporal soil surface characteristics. The dominant shrub cover in the pinyon-juniper transect and dominant herbaceous cover and dominant shrub cover in the desertscrub transect were selected because of their importance in determining community composition.

TABLE 7-3. COVER CLASS COMPARABILITY

Attribute	Site	Crew	Average Transect Cover Value* (%)
Total vascular plant cover	Pinyon	1	18.5
	Juniper	2	18
Gravel (interspace value) (2-75 mm)	Pinyon	1	19.2
	Juniper	2	24
Cobble (interspace value) (75-250 mm)	Pinyon	1	3.9
	Juniper	2	2.7
Stones (interspace value) (> 250 mm)	Pinyon	1	3.8
	Juniper	2	2.6
Litter (interspace value)	Pinyon	1	12.2
	Juniper	2	16.4
Surface Type I (total)	Pinyon	1	3.8
	Juniper	2	8.5
Surface Type II (total)	Pinyon	1	60.3
	Juniper	2	25.6
Surface Type III (total)	Pinyon	1	32.1
	Juniper	2	40
Cyanobacteria	Pinyon	1	63
	Juniper	2	68
Blackbrush	Pinyon	1	15.7
	Juniper	2	14.5
Total Surface Cover	Pinyon	1	61.4
	Juniper	2	66.3
Total vascular plant cover	Desertscrub	1	46.5
		2	57.1
Gravel (interspace value) (2-75 mm)	Desertscrub	1	4.2
		2	7.8
Cobble (interspace value) (75-250 mm)	Desertscrub	1	0.9
		2	0
Litter (interspace value)	Desertscrub	1	27.4
		2	16.1
Surface Type I (total)	Desertscrub	1	0
		2	21.8
Surface Type II (total)	Desertscrub	1	89.1
		2	12.1
Surface Type III (total)	Desertscrub	1	7.3
		2	45.8
Cyanobacteria	Desertscrub	1	47.5
		2	46.3
Green Mormon Tea	Desertscrub	1	19.3
		2	15.3
Russian Thistle	Desertscrub	1	12.5
		2	14.6
Total Surface Cover	Desertscrub	1	79
		2	81

* Cover class values were converted to midpoint of class (i.e., cover class 1 midpoint = 0.5; cover class 2 midpoint = 3; cover class 3 midpoint = 15; cover class 4 midpoint = 37.5; cover class 5 midpoint = 62.5; cover class 6 midpoint = 85; cover class 7 midpoint = 97.5) and then averaged for 20 quadrats.

Original MQOs required a 90 percent agreement between crews for individual cover classes (i.e., agreement at the quadrat level). Only two attributes, total vascular plant cover and blackbrush in the pinyon-juniper transects achieved this MQO. Agreement at the quadrat level is probably an unrealistic objective because there may be slight variations in quadrat placement even along the same transect and in decisions where actual cover is borderline between two cover classes (i.e., one botanist could report a cover class of 3 and the other a cover class of 4 and both botanists could be technically correct). Transect theory assumes that, if an adequate sample is taken, the difference between measurements of the same population will not be significant. A recommendation for a more realistic MQO would be to require that the average of the transect cover values recorded by the botanists be within ±5 percent of each other (i.e., if one botanist reported an average cover value of 80 percent, then the value reported by the other botanist should be within the range of 75 to 85 percent).

With the exception of surface types, average ground cover attributes for the pinyon-juniper transect were within ±5 percent of each other for the 20-quadrat comparison. Ground cover attributes for the desertscrub transect were within ±5 percent of each other with the exception of total vascular plant cover, litter, and surface types. The values for total vascular plant cover and litter (both showed an 11 percent difference) were reciprocal between the crews, possibly indicating a difference determining live versus dead portions of plants. The sum of ground cover values that would be used in calculating an erosion index were within ±5 percent of each other for both the pinyon-juniper and the desertscrub transects. Between-crew precision for dominant species cover was entirely acceptable.

There was very poor comparability between crews for measurements of surface types. As much as a 77 percent difference was observed between the average values for the two crews. Crews had trouble early in training distinguishing between surface types because of qualitative and subjective class breaks. Quantifying class breaks for many different soil types would probably be a formidable task requiring extensive data collection and analysis. Surface types are also associated to a great extent with cryptogamic development on and within the soil surface. The cryptogamic components appear to be more readily identified and quantified. Therefore, it is recommended that surface types be dropped from further consideration as an indicator measurement.

Measurements for each tree and large woody species in a subplot included number (count) of seedlings and saplings less than 1 meter high, longest crown diameter and largest diameter perpendicular to the longest axis, height, and stem diameter. All MQOs listed in Table 7-1 were met; however, analyses of the data indicated that the MQOs were much too broad and probably inappropriate. A 90 percent comparability within a meter on crown diameters and height may be appropriate for very large trees but extremely broad for most pinyon pine and juniper trees. Agreement within 5 cm would have been more realistic than the 50-cm MQO listed in the QA plan. Stem diameters above 50 cm are infrequent on many of the woodland species. In all cases, a relative (%) comparability would be more appropriate because allowable variation would be proportional to size. Table 7-4 gives the tree measurements recorded by each crew.

Two species were encountered on the two subplots with 100 percent agreement between crews on species identification. Total counts for saplings were the same between crews. However, one crew recorded five junipers and one pinyon while the other recorded four junipers and two pinyon trees. Species identification error is highly unlikely between these two species

TABLE 7-4. EMAP-ARID CREW COMPARABILITY FOR TREE MEASUREMENTS[a]

		CREW 1					CREW 2				
Sub-plot	Spp	Sap1 #	CD1 m	CD2 m	HT m	SD cm	Sapl #	CD1 m	CD2 m	HT m	SD cm
A1	JUOS	2	3.5	3.9	2.5	20	2	3.7	3.0	2.4	20
						11					12
B1	JUOS	3	4.7	3.6	3.1	15	2	4.5	3.9	3.4	16
						42					43
						13					15
			3.0	2.9	1.7	21					25
			3.3	3.6	2.8	46		2.6	2.6	2.7	47
	PIED	1	1.4	1.5	1.6	6	2	1.6	1.6	1.8	7

[a] Spp: JUOS = Utah juniper, PIED = pinyon pine
Sapl: saplings <1 m high
CD1, CD2: crown diameter in meters; longest axis and longest diameter perpendicular to longest axis.
HT = height in meters.
SD = stem diameter in centimeters (cm); SD preceded by blank cells indicates multiple stems of the same tree.

even for very young plants. Therefore, the error is probably either a recording error or each crew missed counting a sapling of each species. In either case, these types of errors can be minimized with better procedural guidance and emphasis during training.

Crown diameters, CD1 and CD2, were converted to a single value, the geometric mean, for comparison. The geometric mean was calculated as the square root of the product of CD1 and CD2. Two junipers and the one pinyon pine were within ±5 percent for the between-crew mean value. One juniper was only within ±15 percent. An error of this magnitude probably indicates a recording error; however, it could also have been due to a hurried measurement. A significant error occurred in Subplot B1 by one crew recording one tree with four stems while the other crew recorded the same stems as two trees, one with three stems and one with a single stem. Basal area calculations would not be affected but total crown area is greatly increased by the addition of separate crown dimensions for another tree. Overall, the crown measurements are unacceptable and indicate a need for increased emphasis during training or a reevaluation of procedures. Only one of the four common height measurements exceeded ±5 percent of the between-crew mean and that was by ±6 percent.

Three of the eight stem diameters exceeded ±5 percent of the between-crew mean and all were within ±10 percent; ±5 percent is desirable but difficult with woodland species. Branched stems near measurement points and the loose (compressible) bark of Utah juniper can impede consistent measurement. Additional discussion with woodland experts is advised to determine appropriate measurement quality standards as well as additional emphasis during training.

A total of 25 plant species were identified between both crews on the desertscrub transects. Crew 1 had a 96 percent agreement to the total plant list established by both crews, while crew 2 had a 92 percent agreement. All plants missed by one or the other crew were "rare" in abundance, having a transect cover value of one fourth of one percent or less.

There were 11 species identified on the pinyon-juniper transects; each crew identifying only 9 of them. Again the species missed were rare accounting for cover values of three quarters of one percent or less. The limited number of quadrats available for comparison may be a limiting factor for establishing a true comparison, especially considering the few species identified and the rarity of the species missed. Minor differences in quadrat placement could easily account for "hit or miss" differences on rare plants. Comparability relative to missing one or two rare plants is exaggerated by the low number of species present.

7.1.2.2 Spectral Reflectance Measurements--

Spectral data were collected along the vegetation transects and in vegetation subplots. Each of these measurement units has a unique file, identified by site number and subplot or transect designation. Transect measurements were made in six groups each comprising three spectral measurements within a 2-m quadrat. These were taken at 3.5, 4.0, and 4.5 meters along the tape, then repeated at 9.5, 10.0, and 10.5 meters; 15.5, 16.0, and 16.5 meters; 21.5, 22.0, and 22.5 meters; 27.5, 28.0, and 28.5 meters; and finally at 33.5, 34.0, and 34.5 meters. A meter stick was used to ensure that all measurements were taken 50 cm from the tape and at 1 m above the ground. In the case of circular subplots, a square grid was laid out around the center of the subplot and spectral measurements were taken in a 4 by 4 matrix with each point separated by 3.0 m. A protocol was established to ensure that the pin flags used to mark sampling locations were removed prior to acquisition of spectra and that no shadows from the technicians or instrument fell in the field of view of the spectrometer.

A number of variables affect spectral reflectance and the precision and accuracy of measurements. Atmospheric haze increases reflectance in short wavebands, particularly 400 to 500 nm, and clouds affect the whole range of the visible spectra from 400 to 700 nm (Lillesand and Kiefer, 1987). Spectral measurements were not taken at all if cloud cover was estimated to be greater than 50 percent. If cloud cover was up to 50 percent but no clouds obscured the sun then measurements were taken as normal. Atmospheric clarity and the amount of cloud cover and wind speed and direction were recorded in the comments section of the header for each transect and subplot data file on the computer. In addition, weather conditions, soil moisture, and the vegetation and soils comprising each spectra were recorded on field forms on a spectrum by spectrum basis. Sun angle and shadowing also affect spectral measurements and, in an effort to maintain consistency in the data, spectra were taken between 10:00 am and 3:00 pm when the sun angle was highest and shadows minimal. Atmospheric and illumination conditions may cause a change in the reference spectra at a site during the day. As this occurs, the changes can be captured within the calibration.

A stringent methodology for the calibration of the spectrometer must be followed prior to beginning each group of spectral measurements. The instrument was calibrated at least thirteen times at each site. Although the instrument was calibrated according to procedures established for the study, a misunderstanding of the calibration procedures led to data quality problems with all of the spectral reflectance data collected during the study. Although the operators performed the calibration to the white reference standard as instructed, they did not toggle the necessary switch and as a result the white reference standard information was not saved. When the instrument executed the automatic internal calibration it was doing so to a non-existent reference standard. As a result there is no way to calibrate the spectral data for atmospheric conditions. The indicator lead believes that the spectral data are biased low but this bias is neither quantifiable nor consistent across the data. It is also believed that the variability introduced by incorrect calibration procedures is low.

Only one spectrometer was available for use and one technician operated the instrument from June 29 through July 26 and again from August 18 through 20, 1992. A second technician worked from July 27 through August 17, 1993. On July 27 both technicians worked together with the second technician taking the measurements under the direction of the first to ensure consistency in methodology because measurements for between-crew variability for other indicators were made on a day when only one spectral technician was present. No assessment of the between-crew precision of spectral measurements can be made.

Both the spectrometer and the computer ceased functioning during fieldwork and had to be replaced with equipment of the same specification. Both spectrometers measure reflectance and are calibrated against the same standards. Tests and corrections can be made for any electronic variability between instruments. No spectral measurements were recorded on three days while an alternate spectrometer was acquired. These problems could be avoided in the future if two spectrometers and computers were available for use. In the case of inexperienced crew members, a training period of 1 week before the official field training session begins would be necessary. Familiarity with computers is a prerequisite for operation of the spectrometer.

Spectral data were acquired from 13 sites. At 6 of the 13 sites all 220 measurements were taken. For the other 6 sites, 2 had measurements from 10 plots, 2 from 7 plots, 1 from 3 plots and 1 from only 1 plot. Weather conditions were largely responsible for the partially completed sites. Three sites targeted for spectral measurement were not measured due to instrument failure and cloudy conditions were responsible for lack of data from two other target sites. This record could be improved by conducting field work earlier in the year before the thunderstorm season. Overall, cloudy conditions and instrument failure were each responsible for a 20 percent loss of potential spectral data.

7.1.2.3 Soil Measurements--

As described earlier, site remeasurements and plot remeasurements were performed several times during the study. No MQOs for field measurements were established prior to the study. The field soil descriptions for two sites were evaluated for consistency. The results of the comparison between the two field crews are given in Table 7-5 for some of the more important parameters. Similar map units, soil series, permeability, slope, soil column depth, moist A horizon, color and texture were reported by both crews. One inconsistency noted was the recording by one soil

TABLE 7-5. BETWEEN-CREW COMPARISONS FOR FIELD MEASUREMENTS

Parameter	Crew 1	Crew 2
Site 1--Soil series classification	Fine-loamy mixed mesic ustic calciorthid	Fine-loamy mixed mesic ustollic calciorthid
Horizon A	0-6 cm depth	0-2 cm depth
Color dry	5yr 6/4	5yr 6/6
Color moist	5yr 4/6	5yr 5/6
Texture	FSL	FSL
Sand	74	65
Silt	15	25
Clay	11	10
Very fine sand	20	20
Permeability	Moderate	3
Slope length	3	3
Slope %	3	3
Aspect	SW	SW
Site 2--Soil series classification	Fine-loamy mixed mesic ustollic calciorthid	Fine-loamy mixed mesic ustollic calciorthid
Horizon A	0-10 cm depth	0-3 cm depth
Color dry	5yr 6/4	7.5yr 5/6
Color moist	5yr 4/4	7.5yr 4/6
Texture	FSL	FSL
Sand	73	56
Silt	15	30
Clay	12	14
Very fine sand	25	20
Permeability	Moderately rapid	2
Slope length	3	3
Slope %	3	3-4
Aspect	SE	SSE

scientist of permeability as a numerical value (e.g., 2 in/hr) while the other crew recorded this value as a descriptive term (e.g., moderately rapid). There were significant differences between the crews for depth of horizon A, percent sand, silt, and clay content. These are, however, coarse field measurements and are repeated in the laboratory. There were also significant differences between the two crews for depth of A horizon. Although there was no MQO established prior to the study, it is generally felt that the agreement between the two crews should have been better for this parameter.

All bulk soil samples were sent to the U.S. Soil Conservation Service Soil Survey Laboratory at the National Soil Survey Center in Lincoln, Nebraska. Analyses included particle size, organic and total carbon, cation exchange capacity, soluble salts, nitrogen, sodium absorption ratio, pH, and water retention. The results given in this section can be compared to the MQOs given in Table 7-2. The MQOs established for the pilot were probably unrealistic and were too rigid for the purposes of this study. These MQOs should be reevaluated for further pilot activities.

Reference soil was obtained from a soil pit dug during training exercises. The soil was removed from the pit, air dried, and mixed as thoroughly as possible by hand. One bag of reference soil was included in each batch of field samples sent to the laboratory. The nine reference samples provided a check of the consistency of the laboratory over the course of the study. The samples do not provide an accuracy check as there were no known values for the samples. Table 7-6 summarizes the analytical data from the nine reference samples.

It should be noted that some of the variability apparent in the results may have resulted from hand mixing the samples in the field and not from analytical variability. The results show that most of the analyses were within or close to the MQOs listed in Table 7-2. Analyses for which no MQOs were developed also were within limits generally accepted for these types of laboratory soil analyses. Although the standard deviations and the coefficients of variation (CV) were high for carbonate and rock fragment percentages, this result is probably due partly to the field homogenization process and partly to the very low rock fragment content of the samples.

To assess laboratory precision, seven samples were split at the analytical laboratory to obtain three replicates of each split sample. Table 7-7 shows the range of the means, the standard deviations, and the coefficients of variation (e.g., the lowest mean of the replicate analyses of the seven samples for percent total clay was 2.3 and the highest mean was 28.7) for seven of the most important analyses. All results were within acceptable limits with the exception of organic carbon. Three of the seven replicate analyses for organic carbon resulted in high CVs (20, 22, and 115%). The 115% CV was obtained because the concentration of organic carbon present in the sample was below the detection limit. The other two high CVs are possibly indicative of an analytical problem.

Field duplicates were collected from the deep soil pit at each Group A site that the soil scientists visited. The crew collected the sample, mixed it by hand, and split it into two sample bags. The data from these samples can be used to assess system precision (i.e., the variability associated with these results includes variability associated with the sample collection process and with laboratory analysis).

TABLE 7-6. SUMMARY STATISTICS FOR REFERENCE SAMPLES

Parameter	N[a]	Mean	Maximum	Minimum	Standard deviation	CV[b]
Total Clay (%)	9	15.73	17.20	14.50	0.95	6.02
Total Silt (%)	9	30.24	33.10	28.90	1.38	4.57
Total Sand (%)	9	54.02	55.60	51.70	1.11	2.05
Fine Silt (%)	9	10.74	11.60	10.10	0.56	5.21
Very Fine Sand (%)	9	33.41	35.30	31.40	1.41	4.22
Fine Sand (%)	9	12.97	14.30	12.00	0.95	7.30
Medium Sand (%)	9	4.87	5.30	4.70	0.20	4.11
Walkley-Black Organic Carbon	9	0.27	0.29	0.25	0.01	3.70
NH4OAC Cation Exchange Capacity	9	8.46	8.70	8.20	0.17	1.97
15 Bar Water on Air Dry Soil-Weight %	9	6.90	7.50	6.20	0.56	8.13
pH, 1:1 Soil-Water Suspension	9	8.29	8.40	8.20	0.08	
pH, 1:2 Soil-CACL2 Suspension	9	7.73	7.80	7.70	0.05	
Carbonate, < 2 mm Fraction	9	6.30	7.50	3.40	1.16	18.43
2-5 mm Weight Percentage of < 75 mm	9	1.00	2.00	0.00	0.50	50.00
5-20 mm Weight Percentage of < 75 mm	9	0.44	1.00	0.00	0.53	118.59
20-75 mm Weight Percentage of < 75 mm	9	0.78	7.00	0.00	2.33	300.00
Field Water Content of Bulk Sample	9	6.51	6.90	6.30	0.20	3.02

[a] N = number. [b] CV = coefficient of variation.

Table 7-8 shows the range of the means, the standard deviations and the CVs for each crew for seven of the most important analyses. One crew collected twelve duplicate pairs while the other crew collected seven duplicate pairs. Overall the results of the analyses of the samples collected by Crew 1 tended to show more variability than those collected by Crew 2. This may indicate that Crew 1 did not mix the samples in the field as well as Crew 2 did. This is evident most notably with the results of percent total clay and organic carbon. For total clay, five of the twelve pairs of samples collected by Crew 1 demonstrated CVs above 10 percent (10.8, 10.1, 13.2, 12.9, and 33.7 percent). Most of the results were, however, close to the detection limit of the method. Only one of the pairs collected by Crew 2 demonstrated a CV above 10 percent (17.4 percent) for total clay content. This one sample also had a very low clay content. For organic carbon, seven of the twelve pairs of samples collected by Crew 1 demonstrated CVs above 10

TABLE 7-7. SUMMARIZED RESULTS OF LABORATORY REPLICATE ANALYSES

Parameter	Range of means	Range of standard deviations	Range of coefficient of variation
Total clay (%)	2.3 - 28.7	0 - 0.61	0 - 8.9
Total silt (%)	10.1 - 42.3	0.7 - 1.25	1.8 - 8.5
Total sand (%)	33.7 - 86.5	0.51 - .05	0.9 - 2.6
Organic carbon	0.01 - 1.78	0 - 1.12	0 - 114.6
Cation exchange capacity	1.7 - 11.3	0.1 - 1.57	0.9 - 11.8
pH	7.4 - 8.8	0.06 - 0.26	
15 bar water	2.2 - 10.8	0.12 - 0.64	0.7 - 5.1

TABLE 7-8. SUMMARY OF RESULTS OF FIELD DUPLICATE ANALYSES

	Range of means		Range of standard deviation		Range of coefficient of variation	
Parameter	Crew 1	Crew 2	Crew 1	Crew 2	Crew 1	Crew 2
Total clay (%)	1.6-34.4	2.8-16.6	0.07-1.84	0.07-1.13	2.0-33.7	0.7-17.4
Total silt (%)	3.9-32.9	3.5-41.6	0.0-2.3	0.14-4.81	0.0-20.2	1.2-11.0
Total sand (%)	36.4-93.3	45.3-93.7	0.21-4.03	0.07-5.02	0.2-6.1	0.1-11.1
Organic carbon	0.13-1.3	0.06-0.97	0.01-0.47	0.0-0.08	0.0-42.8	0.0-18.1
Cation exchange capacity	1.4-22.4	3.5-10.7	0.0-0.42	0.14-0.78	0.0-7.4	1.6-8.9
pH	6.60-8.75	7.15-8.60	0-0.35	0.0-0.7		
15 bar water	1.9-12.1	2.5-6.2	0.07-0.49	0.07-0.42	1.6-17.0	2.3-9.9

percent (19.2, 16.6, 20.0, 32.6, 30.6, 10.9, and 42.8 percent). All samples collected by Crew 1 had concentrations above the detection limit. Only one of the pairs collected by Crew 2 demonstrated a CV above 10 percent (18.1 percent).

7.1.3 Recommendations

The QA Program for EMAP-Arid should be expanded. One individual should be committed to the position of Quality Assurance Manager for the EMAP-Arid Resource Group. This individual should coordinate QA issues between the indicator leads and assume responsibility for follow-up on QA issues. This individual should also serve as the QA group representative in interactions with the EMAP-wide QA Group and the EMAP QA Director located at EPA Headquarters.

The training program should be expanded and include more dry runs. Indicator leads must be in attendance throughout the dry runs to ensure that the crew is performing adequately and within the guidelines of the training. A proficiency check of the crew should be one of the last activities during training. Crew members should be tested for all duties they will be expected to perform during the field study. The data collected during proficiency exercises must be thoroughly analyzed and studied. Indicator leads should be responsible for evaluating members of the field crew and certifying that they are able to perform the necessary tasks.

An increased effort should be placed on completing forms during training. Forms must be designed to minimize confusion and not be ambiguous. Units should either be hard-coded on the form if appropriate or the unit should be a required field for completion. One area of confusion on the forms was the entry for slope/aspect. Sometimes the value was recorded by the crew as an alphabetical value (e.g., S-SW) and sometimes it was recorded in degrees. Soil permeability was another area of confusion. One crew recorded this value as a numerical value (e.g., 2 in/hr) while the other crew recorded this value as a descriptive term (e.g., moderately rapid) indicating a range of values.

An audit schedule should be developed for future field studies. This schedule should include audits of the field crews, laboratory audits, and audits of the information management system. Audits should be coordinated by the QA Manager, well-documented, and performed by persons with expertise in the indicator area being audited.

In addition to the between-crew precision remeasurements by the field crews, within-crew remeasurements should also be performed to assess a crew's ability to reproduce results. Vegetation, soil profile, and spectral measurements should be performed by experts to provide a reference or a "known" value. This would allow an accuracy assessment to be performed on the field measurements.

In the future, vegetation measurement frames should be placed and left in place until all QA remeasurements have taken place. This would eliminate the variance associated with placement of the frames and would, therefore, lead to a truer estimate of crew variability.

Accuracy and precision measurements should take place both during training and early in a study to ensure that the field crew is technically competent and fully understands the standard operating procedures. An accuracy and precision assessment of all field measurements should be performed. Increased effort must be placed on evaluating QA data as soon as possible after data collection to allow for early detection and correction of any problems which may affect data quality. Electronic data capture would enhance our ability to evaluate QA data real-time. Standardized methods should be developed for assessing precision and accuracy from remeasurement data.

Reference samples with known concentrations should be used to monitor analytical laboratory accuracy.

Increased effort should be place on development of MQOs. Realistic MQOs that address the needs of the EMAP-Arid resource group should be developed.

At this time, quantitative DQOs cannot be established for each indicator tested. Analytical paradigms for interpretation of measurements relative to societal values and goals have not been established, nor have the measurement parameter requirements for each indicator or procedures to correlate, combine, and index them into a DQO been completed. From information gathered during the 1992 pilot, data quality objectives for future measurement activities will be refined and expanded.

7.2 INFORMATION MANAGEMENT

The activities and functions performed by information management (IM) are integrally connected with the study objectives, statistical design, logistics, field and laboratory measurements, quality assurance, 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. For the 1992 pilot study the following IM functions were planned for testing and evaluation:

- use of field forms in the data collection effort,

- use of Portable Data Recorders (PDRs) in selected data collection efforts,

- transfer of data between the field and EMAP-Arid IM central office,

- specifications of initial requirements for the EMAP-Arid Information Management system,

- use of external data sets,

- hardware and software requirements for the field,

- coordinating requirements between IM and the design, quality assurance, logistics, and statistics elements, and

- availability of data to evaluate the results of the pilot study.

7.2.1 Results

A summary of information management efforts related to field forms data collection software, coding scheme development and training for the 1992 Pilot Study areas follows.

Field Forms--The development of the paper forms for data collection and the instructions for completing those forms was a combined effort of the information manager, the indicator leads, and the statistician. For each site an individual packet was prepared containing all required forms and the assigned site and soil sample numbers. A close-to-final version of the field forms was available for the training session but the forms did not go through a full-fledged field trial to determine their usability until the beginning days of the pilot study. Based on the use of the field forms in the first few days of the pilot study, changes were made to the forms concerned with site information and vegetation transects. Changes to the latter form were cosmetic to ease the appropriate placement of the data. Changes to the site information form allowed additional information to be captured. The new forms were available to the field crews by mid-July.

Data Collection Software--A software program for portable data recorders (PDRs) and PCs was developed to handle data entry in the field and data editing in post-field activities. A documentation manual described the use of the program, care of the PDR, and the transferring, printing, and editing of the data. Software for the PDR was developed using the C language and C-Scape, a collection of C routines for easy screen generation. This software was not ready for implementation prior to the field effort. Because of time limitations for software development, a complete program to collect the vegetation data was not available until the end of July. Although minor changes were made to the program based on a few days of field testing (in conjunction with completing the paper field forms), the availability of the program so late in the field season precluded adequate testing. Consequently, PDRs were not used routinely for data collection for any of the field measurements. The PDR programs were used at the central office as one of the tools for entering the data captured on the field forms.

Coding Schemes--Identification and coding schemes were developed to track film rolls and site photography; PC disks; data forms; soil samples and voucher specimens of unidentified plant species; sites, transects, pits, plots and points; and data file names. The coding scheme identified sites, vegetation transects, circular plots and quadrats, soil pits, film rolls, and data files. This scheme included an obvious reference in the code to the EMAP site number. The code for the vegetation samples also included a reference to the transect and quadrat of the sample. Codes for the soil samples reflected the format used by the Soil Conservation Service since these data would initially be entered into that data base.

Training--Training activities covered the use of the PDR for data collection and for transferring information between the PDR and a PC; requirements for filling out the field forms; the importance of QA and documentation in data collection; the coding schemes and labelling protocols; and the post-field activities for data collection. As only a partial data collection program for the PDR was available by the time of training, use of the software was not covered during training.

The information management system provided a reasonably effective, but not efficient movement of data from the field to the analysis stage. Lessons were learned about the design and use of forms to capture the necessary data and about clarifying the directions for their use. Lessons were also learned about the development of software on the PDR for use in the field.

Data from the field were moved to the analysis stage but with more effort and with lower quality than had been anticipated. The prime reasons were the lack of lead time to prepare and test the electronic data collection system for use in the field and the lack of available time in the field or at the base office to follow quality assurance procedures for the data. Thus, the computerization of the data took more effort; there were questions about the data for which assumptions had to be made; and data were not transferred to the central office in a timely manner to allow for feedback to the field crews.

The information management and data analysis systems were not reasonably adequate to enable reporting within the required time period, partly due to the loss of information management support for 6 months due to changes in EPA procurement approaches. Verifying the vegetation data took a lot more effort than was anticipated and the IM systems were not efficient enough to enable timely reporting. The efforts from this pilot study did provide a base of experience for the next pilot.

7.2.2 Recommendations

One of the most critical learning experiences gleaned from the 1992 pilot study was awareness of the complex process of moving data from the field to the central office. Greater emphasis must be placed on electronic data capture in the field and on real-time QA checks of the data. Emphasis also should be placed on coordinating the IM efforts and needs for all indicator categories (much of the IM 1992 effort was related to the vegetation indicator) to ensure that all data flow smoothly from the field to the data analysis stage and to ensure that all of the data receive an adequate and timely QA review. The use of external data sets and incorporation of these data bases into a centralized EMAP-Arid system were beyond the scope of this pilot. Future pilots and IM activities need to address this issue.

7.3 LOGISTICS

The 1992 EMAP-Arid pilot study was conducted in part to obtain important information related to areas such as logistical requirements. Logistics activities include site selection and reconnaissance, training, staffing, mobilization, and field implementation. A detailed description of these logistics planning activities is presented in Baker and Merritt (1991). Identifying logistical constraints on field implementation and assessing the requirements for assembling and deploying multiagency sampling teams were questions addressed in the 1992 pilot study.

7.3.1 Results

As a result of the pilot study a number of lessons were learned and logistical guidelines were reinforced for EMAP-Arid. These were compiled in an unpublished report entitled "EMAP-Arid Ecosystems 1992 Colorado Plateau Pilot Study Field Operations Report." This document summarized logistic activities from the initial planning process through the final debriefing of the field events. Documentation of these logistics activities in itself is a valuable exercise for the planning of future EMAP-Arid field activities.

A summary of the logistics guidelines reinforced are as follows:

- Detailed logistics planning with adequate lead time is key to a successful field program.

- Detailed protocols documented in a field operations and training manual are critical to the performance of the field events.

- The spectral, vegetation, and soil samples could be routinely collected at a site using 4-wheel-drive vehicles, backpacking, or helicopter for very remote locations with limited access.

- Multiagency sampling crews were effective and provided local expertise and working facilities.

Specific lessons learned are as follows:

- Issues related to the National Environmental Policy Act and archaeological clearance need to be identified and resolved early in the logistics planning efforts.

- A 1 to 2 week training program is required to fully train the field crews and a full "practice run" should be included in the program to evaluate the field crews so additional training or adjustments can be made before routine sampling starts.

- Global positioning systems (GPS) can be used by the field crews with limited training to find the general site location, but permanent marks may have to be used in the long term to accurately relocate a site.

7.3.2 Recommendations

The overall success of the 1992 field season sampling effort was strongly attributed to the field personnel and how well they worked together as a team. However, a number of changes to the 1992 pilot study operations could facilitate future activities. One such change is the addition of an Implementation Coordinator position to the EMAP-Arid team. This key position would provide implementation guidance, direction, and logistical support for the monitoring activities conducted by multi-agency sampling crews. Duties would include forming communication linkages among and between field crews, team indicator leaders, information management, and quality assurance personnel, managers, and participating federal agencies, contractors, and cooperators.

In addition, other general guidelines could be adopted by the EMAP-Arid team to improve future studies. These include:

- Initiating anticipatory planning in the preliminary stages to help direct all components of the projects (regardless of whether they are major or minor).

- Increasing efforts to ensure clear, accurate, and timely communications within and beyond the EMAP-Arid team. Maintaining an accurate picture of the status and condition of the project would avoid potential problems and define progress.

- Briefing and debriefing each agency accurately on the field study. Documentation describing the field study freely available from the inception of the project would also enhance the communications networks.

SECTION 8
CONCLUSIONS, RECOMMENDATIONS, AND ADDITIONAL STUDIES

The 1992 pilot study was the first EMAP-Arid field study and addressing the objectives developed for this study is essential to full implementation of the program. Questions related to these objectives will continue to be important elements in planning for future pilot studies. During the 1992 pilot study, the EMAP-Arid team was successful in partially addressing these objectives but, more importantly, the planning and implementation of this study uncovered issues that were not fully understood or perceived in initial design efforts. For example, the original assumptions that the EMAP-Forest design would be applicable to EMAP-Arid indicator measurements or that independent site condition assessments from land management agencies could readily be used to evaluate sensitivity of indicators were inaccurate. Only as the 1992 field work progressed were these difficulties pinpointed. This section summarizes the major conclusions and recommendations drawn from the 1992 pilot study, clarifies some of the issues not initially perceived, and draws implications from the study results. Activities conducted in a 1993 pilot study and activities planned for future studies relative to these conclusions, issues, and implications are described where appropriate.

Plot Design--Evaluating the EMAP-Forest sample plot design as a common design that could also be used by the EMAP-Arid group was of interest to EMAP in the effort to help facilitate and integrate assessment across resource groups. However, after initial adoption of this common plot design, questions arose during the 1992 field study as to its appropriateness for arid ecosystems. These questions were raised because of the difference in the vegetative structure and soils found in forested and arid resource classes. The issues raised were subsequently substantiated by preliminary analysis of the data in early 1993 and by the data analyses presented in this report. As reported in Section 4, the variance assessment of EMAP-Arid indicator measurements obtained using the modified EMAP-Forest plot design shows considerable discrepancy among the variables and indicates that additional plot designs should be evaluated. These considerations led to the development of a plot design study conducted in 1993.

The 1993 pilot study was designed to establish the sampling support area and optimum plot size required for the selected indicator measurements. The approach was to oversample an area to characterize the local site variability and assess an integrated plot design that best quantifies measures for vegetation, soils, and spectral properties for EMAP-Arid program requirements (Kepner et al., 1993). These oversized plots or macroplots were 180 by 180 m with 36 sampling units for soils and 120 by 120 m with 100 sampling units for vegetation and spectral properties. Five macroplot locations were selected in the Colorado Plateau within desertscrub, grassland, and conifer woodland resource classes. Costs, time efficiency, and site impact were also part of the 1993 pilot evaluation. Results from the 1993 pilot study will be reported in the fall of 1994 and used to plan and develop a pilot study in 1995 at sites with known conditions.

Indicator Sensitivity--An evaluation of indicator sensitivity against sites of "known" condition was not possible with the results from the 1992 pilot study. The primary assumption of the EMAP-Arid researchers that site conditions could be obtained from existing assessments made by the various land management agencies was unfounded. There were significant differences in agency descriptions of the condition of a site and in several cases no consistent rating of a site could be established; this finding is similar to conclusions reported more recently by the NRC (1994). Results for both vegetation and soils indicate that additional indicator sensitivity studies should be conducted. Vegetation and soil indicator development will continue as part of the 1993 pilot. Results from the spectral data show a strong correlation between Landsat TM and PSII NDVI and indicate that the overall concept of remote sensing as an indicator of ecosystem condition is valid. The NDVI may not be the most sensitive indicator and other indices such as reflectance (albedo) or SAVI need to be evaluated. These and other indices will be evaluated from data collected during the 1993 pilot study.

A gradient study, evaluating a range of different environmental conditions, is planned in 1995 to assess current indicator measurements and possible additional faunal indicator measurements evaluated in a 1994 pilot study. The study should be conducted in areas with known levels of condition, for example, sites in different successional stages such as Long-term Environmental Research sites (Friedel 1991) or degree of stress (e.g., different grazing intensity). Conducting this type of study independent of the EMAP probability sampling grid would ensure that enough data are collected to make statements on the sensitivity of indicators. By using long-term data sets and comparing EMAP indicator data with existing data (e.g., for species composition, erosion, and soil quality), it should be possible to determine how the indicators perform over time and how well they meet the EMAP program-level DQOs. Specific recommendations in Section 5 for indicator measurements should be incorporated into the 1995 Pilot Study.

Frame Material--Based on a limited assessment, preliminary data bases from the GAP and Biotic Communities Map of North America appear quite variable with respect to identifying arid land resource classes and appear marginal in their ability to calculate the amount or extent of individual arid resource group types. This variability appears to result from differences in definitions and differences in scale of point samples versus satellite-derived coverage. However, the study included only a limited number of observations in each land cover type. If the EMAP-Arid group wants to consider using GAP data in the future to select frame materials and to provide data for extent estimation of arid ecosystems, then a scientifically valid assessment of the accuracy of the GAP data must be performed. This assessment should be done on the second generation (or the most recent version) of the GAP data and must include a sufficient sample number for each land cover type. If improvements in accuracy are obtained an oversample strategy should be developed to account for unresolved error. If, for example, the GAP data are determined to be accurate 85 percent of the time, then the sampling strategy must include sampling enough alternate sites to resolve the 15 percent difference. This sample-based accuracy assessment study should be conducted prior to any future assessment of EMAP-Arid resources using these techniques.

Quality Assurance--The 1992 pilot study demonstrated that a comprehensive QA program encompassing logistics and all aspects of a data collection activity is an essential component of field studies such as those conducted by EMAP. Major conclusions drawn from the 1992 pilot study include the following items. The training program must be expanded to include more dry runs and a formal proficiency check of all crew members. Precision and accuracy assessments must be made very early during field activities and then again periodically to ensure that the field crew is technically competent and is following standard operating procedures. Audits should be performed for field and laboratory operations to ensure that standard operating procedures are being followed and to acquire feedback from field and laboratory personnel. Data recording and entry procedures must be developed in such a way as to maximize recording accuracy and to allow for real-time examination and analysis of the data.

The above findings from the 1992 pilot study were incorporated into the plot design study design conducted in 1993 (Kepner, 1993). In that study, the training program was expanded to include more dry runs and a proficiency check of the crew was performed during training. An increased effort was placed on data recording procedures with the vegetation data entered electronically on portable data recorders rather than on paper forms. Between-crew precision remeasurements and within-crew remeasurements were made during the first week of field operations and then again weekly to ensure that the field crew was technically competent and fully understood the standard operating procedures. Further refinements of the QA program based on the results from the 1993 pilot are being developed for future activities.

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APPENDIX A

SOIL CLASSIFICATION

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
20752A 7560'	A2 30%	VEATCH VAR.	LOAMY-SKELETAL,MIXED TYPIC ARGIBOROLL: PIED-JUOS/CEMO2-QUGA-AMUT/POA-WYAR	67%
	B2 40%	VALTO DRY	LOAMY-SKELETAL,MIXED,NONACID,FRIGID LITHIC USTORTHENT: JUOS-PIED/AMUT/LEMO2-POA-BRTE	43%
	C2 30%	KUNZ	FINE-LOAMY,MIXED MOLLIC EUTROBORALF: JUOS-PIED/ARTEM-CEMO2-AMUT/POA-LEMO2	64%
20753A 6920'	A1 34%	BARX VAR.	FINE-LOAMY,MIXED,MESIC USTOLLIC HAPLARGID: JUOS-PIED/ARTRV-CHVIL4/VIAM-ORHY	37%
	B1 33%	BARX VAR.	FINE-LOAMY,MIXED,MESIC USTOLLIC HAPLARGID: PIED-JUOS/ARTRV-OPPO-CHVIL4/VIAM-STCO3	43%
	C1 33%	BARX VAR.	FINE-LOAMY,MIXED,MESIC USTOLLIC HAPLARGID: ARTRV-CHVIL4/VIAM-STCO3	49%
20755A 6280'	A1 34%	RIZNO	LOAMY,MIXED(CALC.),MESIC LITHIC USTIC TORRIORTHENT: PIED-JUOS/PUTR2	16%
	B1 33%	RIZNO	LOAMY,MIXED(CALC.),MESIC LITHIC USTIC TORRIORTHENT: PIED-JUOS/CELE3-PUTR2	19%
	C1 33%	RIZNO VAR.	LOAMY-SKELETAL,MIXED(CALC.),MESIC LITHIC USTIC TORRIORTHENT: PIED-JUOS/ARARA	13%
20758A 5040'	A1 42%	AVAR FAM.	FINE-LOAMY,MIXED,MESIC USTOLLIC NATRARGID: GUSA2-ATCO/BRTE-HIJA-SAKA	42%
	B1 42%	QUAZO FAM.	LOAMY-SKELETAL,MIXED,MESIC LITHIC USTOLLIC HAPLARGID: GUSA2-ATCO/BRTE-SAKA-HIJA	37%
	C1 16%	AVAR FAM.	FINE-LOAMY,MIXED,MESIC USTOLLIC NATRARGID: GUSA2-ATCA2/BRTE-HIJA-SAKA	35%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
20907A 7000'	A1 34%*	ROCK OUTCROP	N/A: PIED-JUOS	31%
	B1 33%*	STRELL VAR.	MIXED,(NON-ACID),MESIC LITHIC USTIPSAMMENT: PIED/JUOS	31%
	C1 33%*	PODO VAR.	LOAMY,MIXED(NON-ACID),MESIC LITHIC USTORTHENT: PIED-JUOS	24%
20908A 6365'	A1 34%	SHALAKO VAR.	LOAMY-SKELETAL,MIXED,MESIC LITHIC USTOLLIC CALCIORTHID: PIED-JUOS/ARTRT-GUSA2	22%
	B1 33%	SHALAKO	LOAMY,MIXED,MESIC USTOLLIC LITHIC CALCIOTHID: JUOS-PIED/ARART-GUSA2	16%
	C1 33%	ANASAZI	COARSE-LOAMY,MIXED,MESIC USTOLLIC CALCIORTHID: PIED-JUOS/ARTRT-GUSA2	16%
	A2 34%	ANASAZI	COARSE-LOAMY,MIXED,MESIC USTOLLIC CALCIORTHID: PIED-JUOS/ARTEM	19%
	B2 33%	SHALAKO VAR.	LOAMY-SKELETAL,MIXED,MESIC LITHIC USTOLLIC CALCIORTHID: JUOS/ARTEM	31%
	C2 33%	ANASAZI	COARSE-LOAMY,MIXED,MESIC USTOLLIC CALCIORTHID: PIED/ARTEM	25%
20911A	A1 34%	BARX VAR.	FINE-LOAMY,MIXED,MESIC USTOLLIC HAPLARGID: JUOS/ARTRV	13%
	B1	(ARTIFACTS)	SOIL NOT SAMPLED: JUOS/ARTRV	11%
	C1	(ARTIFACTS)	SOIL NOT SAMPLED: JUOS/ARTRV	24%
20913A 5133'	A2 27%*	ANETH	SANDY,MIXED,MESIC TYPIC TORRIORTHENT: CHRYS9-EPVI/AGST2-HYFI-CHAEN-ORHY	31%
	B2 27%*	ANETH	SANDY,MIXED,MESIC TYPIC TORRIORTHENT: EPVI-GUSA2/SAKA-ORHY-CHAEN	36%
20913A CONT.	C2 27%*	ANETH	SANDY,MIXED,MESIC TYPIC TORRIORTHENT: EPVI-CHRYS9/AGST2-HYFI-ORHY	37%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
	D2 19%*	(OTHER)		
21060A 5480'	A1 34%	RIZNO VAR.	LOAMY-SKELETAL,MIXED(CALC.), MESIC LITHIC USTIC TORRIORTHENT: CORA-EPTO	16%
	B1 33%	RIZNO VAR.	LOAMY-SKELETAL,MIXED(CALC.), MESIC LITHIC USTIC TORRIORTHENT: JUOS/CORA-GUSA2	11%
	C1 33%	RIZNO VAR.	LOAMY-SKELETAL,MIXED(CALC.), MESIC LITHIC USTIC TORRIORTHENT: FRAN2/CORA-COME5	20%
21061A 4870'	A1 43%	STRYCH	LOAMY-SKELETAL,MIXED, MESIC USTOLLIC CALCIORTHID: ATCO-GUSA2-CORA/HIJA-SPCO4-HEVI4	29%
	B1 42%	STRYCH	LOAMY-SKELETAL,MIXED, MESIC USTOLLIC CALCIORTHID: CORA-ATCO-GUSA2/HIJA-ARPU9-HEVI4	28%
	C1 11%	STRYCH	LOAMY-SKELETAL,MIXED, MESIC USTOLLIC CALCIORTHID: CORA-ATCO-GUSA2/HIJA-HEVI4-SPCO4	21%
	D1 4%	(OTHER)		
21062A 5900'	A2 33%	SUWANEE	FINE-LOAMY, MIXED (CALC.), MESIC USTIC TORRIFLUVENT: ATCA2-OPPO/SPCR-BRTE-TRTE-ERCI6	61%
	B2 33%	SUWANEE	FINE-LOAMY, MIXED (CALC.), MESIC USTIC TORRIFLUVENT: ATCA2-ARTRT-OPPO/BRTE-SPCR-ERCI6	62%
	C2 34%	SUWANEE	FINE-LOAMY, MIXED (CALC.), MESIC USTIC TORRIFLUVENT: OPPO-ATCA2/SPCR-BRTE-ERCI6	76%
21064A 4960'	A2 44%	BATTERSON	SANDY, MIXED, MESIC LITHIC USTIC TORRIORTHENT: GUSA2-EPVI/SEMU3-LEMO2	23%
	B2 44%	TRAVESSILLA	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTENT: JUOS-PIED/GUSA2-CHRYS9/SEMU3	32%
21064A CONT.	C2 12%	ROCK OUTCROP	N/A: PIED-JUOS/EPVI-GUSA2/SEMU3-LEMO2	26%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
21065A 4400'	A2		SOIL NOT SAMPLED: CORA-EPTO/HIJA	21%
	B2		SOIL NOT SAMPLED: CORA-EPTO/HIJA-ORHY	13%
	C2		SOIL NOT SAMPLED: CORA-EPTO/HIJA-ORHY	32%
21210A 4520'	A2 33%	RAVOLA	FINE-SILTY, MIXED (CALC.), MESIC TYPIC TORRIFLUVENT: SAVE4/BRASS2-HAGL-SAKA	71%
	B2 33%	RAVOLA	FINE-SILTY, MIXED (CALC.), MESIC TYPIC TORRIFLUVENT: SAVE4/HAGL-BRASS2	57%
	C2 34%	RAVOLA	FINE-SILTY, MIXED (CALC.), MESIC TYPIC TORRIFLUVENT: HAGL-BRASS2	58%
21211A 5618'	A1 4%	AMODAC FAM.	COARSE-LOAMY, MIXED, MESIC USTOLLIC CALCIORTHID: JUOS/CORA-OPPO-EPVI/GILIA	23%
	B1 32%	ROCK OUTCROP	N/A: JUOS/OPPO-EPVI-GUSA2/GILIA	25%
	C1 32%	ROCK OUTCROP	N/A: JUOS/CORA-OPPO-EPVI/GILIA	7%
	D1 32%	RIZNO	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT:	
	A2 4%	ANASAZI	COARSE-LOAMY, MIXED, MESIC USTOLLIC CALCIORTHID: JUOS/CORA-OPPO/GILIA	15%
	B2 32%	ROCK OUTCROP	N/A: JUOS/OPPO-CORA/GILIA	25%
	C2 32%	ROCK OUTCROP	N/A: JUOS/OPPO-CORA/GILIA	9%
21211A CONT.	D2 32%	RIZNO	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT:	
21212A 5091'	A2 20%*	FIREBALL FAM.	LOAMY-SKELETAL,MIXED,MESIC TYPIC HAPLARGID: ATCO-CORA/HIJA-ORHY	28%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
	B2 30%*	BLACKSTON	LOAMY-SKELETAL, MIXED, MESIC TYPIC CALCIORTHID: ATCO-CORA/ORHY-HIJA	25%
	C2 35%*	BLACKSTON	LOAMY-SKELETAL, MIXED, MESIC TYPIC CALCIORTHID: ATCO-CORA/HIJA-ORHY	26%
	D2 5%	(OTHER)		
21213A 5360'	A1 20%	REDBANK VAR.	SANDY-SKELETAL, MIXED (CALC.), MESIC TYPIC TORRIFLUVENT: JUOS/ATCA2-ARFR4/AMBRO-ORHY	22%
	B1 21%	RIZNO VAR.	LOAMY-SKELETAL, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: ARFR4/AGSP	29%
	C1 20%	REDBANK VAR.	SANDY-SKELETAL, MIXED (CALC.), MESIC TYPIC TORRIFLUVENT: FRAN2-AMUT/AGSP-AMBRO	17%
	D1 39%	(OTHER)		
21214A 7000'	A2 27%	ANASAZI	COARSE-LOAMY, MIXED, MESIC USTOLLIC CALCIORTHID: PIED-JUOS/CEMO2	63%
	B2 46%	RIZNO	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: PIED/CEMO2-AMUT	37%
	C2 27%	MIVIDA HIGHRAIN	COARSE-LOAMY, MIXED, MESIC USTOLLIC CALCIORTHID: PIED	37%
21215A 7500'	A2 40%	BARX	FINE-LOAMY, MIXED, MESIC USTOLLIC HAPLARGID: PIED-JUOS	43%
	B2 26%	SEIS	LOAMY-SKELETAL, MIXED, MESIC USTOLLIC CALCIORTHID: PIED-JUOS	41%
21215A CONT.	C2 26%	SOUTHFORK FAM.	LOAMY, MIXED, MESIC SHALLOW USTOLLIC HAPLARGID: PIED-JUOS	44%
	D2 8%	(OTHER)		
21217A 4995'	A2 34%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: CORA-SSSS/ORHY	14%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
	B2 33%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: CORA-SSSS/CRYPT	21%
	C2 33%	MOENKOPIE VAR.	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: CORA-SSSS/SAKA	10%
21361A 4390'	A1 34%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: ATCO-EPTO/HIJA	14%
	B1 33%	MOENKOPIE VAR.	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: ARCA12-ATCO-EPTO/HIJA	5%
	C1 33%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: EPTO-ATCO/HIJA	10%
	A2 34%	MOENKOPIE VAR.	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: ATCO-EPTO/HIJA	13%
	B2 33%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: ARLUL2/HIJA	9%
	C2 33%	MOENKOPIE	LOAMY, MIXED (CALC.), MESIC LITHIC TORRIORTHENT: EPTO-ATCO/HIJA	21%
21362A 5395'	A1 32%	CANYON FAM.	LOAMY, MIXED (CALC.), MESIC SHALLOW USTIC TORRIORTHENT: CORA-EPTO/HIJA	11%
	B1 32%	RIZNO	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: CORA/HIJA	18%
	C1 32%	RIZNO	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: CORA-EPTO/HIJA	9%
21362A CONT.	D1 4%	WAYNECO VAR.	LOAMY-SKELETAL, MIXED, MESIC SHALLOW USTOLLIC CALCIORTHID:	
21363A 6620'	A2 32%	WAYNECO	LOAMY, MIXED, MESIC LITHIC USTOLLIC CALCIORTHID: PIED-JUOS/GUSA2	30%
	B2 32%	ROCK OUTCROP	N/A: JUOS-PIED	23%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
	C2 32%	MELLENTHIN	LOAMY-SKELETAL, MIXED, MESIC LITHIC USTOLLIC CALCIORTHID: PIED-JUOS/GUSA2	14%
	D2 4%	(OTHER)		
21364A 4950'	A1 9%	PIRODEL FAM.	SANDY, MIXED, MESIC USTOLLIC CALCIORTHID: JUOS/CORA	19%
	B1 82%	RIZNO VAR.	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: JUOS/CORA	16%
	C1 9%	RIZNO VAR.	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: JUOS/CORA	29%
21365A 5920'	A2 15%*	BOND	LOAMY, MIXED, MESIC LITHIC USTOLLIC HAPLARGID: JUOS/SHRO-CHRYS9-GUSA2	16%
	B2 15%*	MELLENTHIN	LOAMY-SKELETAL, MIXED, MESIC LITHIC USTOLLIC CALCIORTHID: JUOS-PIED/SYLO-EPVI	18%
	C2 40%*	SKOS	LOAMY-SKELETAL, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: JUOS/SHRO-COME5-GUSA2	17%
	D2 30%*	ROCK,RIZNO, OTHER		
21366A 5226'	A1 42%	SKOS VAR.	LOAMY, MIXED (CALC.), MESIC SHALLOW USTIC TORRIORTHENT: CORA-COME5	16%
	B1 42%	SKOS VAR.	LOAMY, MIXED (CALC.), MESIC SHALLOW USTIC TORRIORTHENT: JUOS/COME5-CORA	10%
21366A CONT.	C1 8%	SND	LOAMY, MIXED (CALC.), MESIC LITHIC USTIFLUVENT: CORA-GUMI	3%
	D1 8%	SND	SANDY-SKELETAL, MIXED (CALC.), MESIC LITHIC USTIFLUVENT:	
COS10163 60'	A2 10%	TRAVESSILLA	LOAMY, MIXED (CALC.), MESIC LITHIC USTIC TORRIORTHENT: JUOS-PIED/CEMO2-CHVIL4-ARARN/POSE-ORHY	41%

SITE #/ ELEV.	PLOT % AREA[a]	SOIL SERIES[b]	SOIL CLASSIFICATION: DOMINANT VEGETATION[c]	% VEG COVER[d]
	B2 45%	GERST	LOAMY, MIXED (CALC.), MESIC SHALLOW USTIC TORRIORTHENT: JUOS-PIED/CHVIL4-ARARN/HEMI2	29%
	C2 45%	GERST	LOAMY, MIXED (CALC.), MESIC SHALLOW USTIC TORRIORTHENT: PIED-JUOS/CEMO2-CHVIL4-ARARN/HEMI2	36%

NOTES:

[a]PLOT/ % AREA: A,B,C,ETC. Represents corresponding soil sample and combination of radial and external vegetation transect of the same prefix letter. A * following % indicates estimated area.

[b]SOIL SERIES: Variant is abbreviated var., family is fam.

[c]SOIL CLASSIFICATION: DOMINANT VEGETATION: Vegetation will not always correlate with soil or miscellaneous land type (i.e., rock outcrop) listed because of transecting across soil boundaries. Plant symbols are according to the national list of scientific plant names. A – between plant symbols indicates codominants within a layer; A / separates plant layers (i.e., trees/shrubs/herbaceous).

[d]% VEG. COVER: Indicates total vascular plant cover viewed from the vertical position.

APPENDIX B

SOIL DESCRIPTION

SITE	PEDON	PLOT	FORM	SERIES	TAXA-JUNCT	MAP UNIT	SURVEY NO.	MLRA	TEXTURE	MODIFIER	GREAT GROUP	TEMP	NOTES
20752A	9200778	A	C	VEATCH	T	RP	680	E 48A	LOAMY-SKELETAL	TYPIC	ARGIBOROLL	FRIGID	VEATCH LACKS ARGILLIC
20752A	9200779	B	C	VALTO DRY	T	RP	680	E 48A	LOAMY-SKELETAL	LITHIC	USTORTHENT	FRIGID	
20752A	9200780	C	C	KUNZ		RP	680	E 48A	FINE-LOAMY	MOLLIC	EUTROBORALF	FRIGID	
20753A	9200770	A	D	BARX	T	RO	680	E 48A	FINE-LOAMY	USTOLLIC	HAPLARGID	MESIC	CLAY HIGHER THAN 27%
20753A	9200771	B	D	BARX		RO	680	E 48A					INSUFFICIENT HORIZ. TO CLASSIFY
20753A	9200772	C	D	BARX		RO	680	E 48A					INSUFFICIENT HORIZ. TO CLASSIFY
20755A	9201008	A	C	RIZNO	T	100	633	D 35	SANDY	LITHIC USTIC	TORRIORTHENT	MESIC	
20755A	9201010	B	C	RIZNO	T	100	633	D 35	SANDY	LITHIC USTIC	TORRIORTHENT	MESIC	
20755A	9201011	C	C	RIZNO	T	100	633	D 35	LOAMY-SKELETAL	LITHIC USTIC	TORRIORTHENT	MESIC	
20758A	9200897	A	D	AVAR FAMILY		231	638	D 35	FINE-LOAMY	USTALFIC	HAPLARGID	MESIC	
20758A	9200899	B	D	QUAZO FAMILY		231	638	D 35	LOAMY-SKELETAL	LITHIC USTOLLIC	HAPLARGID	MESIC	
20758A	9200900	C	D	AVAR FAMILY		231	638	D 35					INSUFFICIENT HORIZ. TO CLASSIFY
20907A		A	C			70	633	D 35					ROCK OUTCROP
20907A	9201004	B	C	STRELL	T	70	633	D 35		LITHIC	USTIPSAMMENT	MESIC	C2 HORIZON NOT STRELL IS FRIGID
20907A	9201005	C	C	PODO	T	70	633	D 35		LITHIC	USTIPSAMMENT	MESIC	
20908A	9200755	A	C	ANASAZI		79	633	D 35	COARSE-LOAMY	USTOLLIC	CALCIORTHID	MESIC	
20908A	9200751	A	C	SHALAKO	T	79	633	D 35	LOAMY-SKELETAL	LITHIC USTOLLIC	CALCIORTHID	MESIC	CLASSIFICATION OF STRYCH
20908A	9200756	B	C	SHALAKO		79	633	D 35	LOAMY	LITHIC	CAMBORTHID	MESIC	NOT CLASSIFICATION OF SHALAKO
20908A	9200752	B	C	SHALAKO	T	79	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY
20908A	9200759	C	C	ANASAZI		79	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY
20908A	9200757	C	C	ANASAZI		79	633	D 35	COARSE-LOAMY	USTOLLIC	CALCIORTHID	MESIC	
20911A	9200782	A	C	BARX	T	58	638	D 35	FINE-SILTY	USTALFIC	HAPLARGID	MESIC	
20911A		B	C					D 35					ARTIFACTS, NOT
20911A		C	C					D 35					ARTIFACTS, NOT
21060A	9201019	A	D	RIZNO	T	71	633	D 35		LITHIC USTIC	TORRIPSAMMENT	MESIC	
21060A	9201021	B	D	RIZNO		71	633	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	IRREGULAR DECREASE OC W/ DEPTH
21060A	9201022	C	D	RIZNO	T	71	633	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	INCREASE IN OC WITH DEPTH
21061A	9200999	A	D	STRYCH	T	88	633	D 35	LOAMY-SKELETAL	USTOCHREPTIC	CALCIORTHID	MESIC	
21061A	9201001	B	D	STRYCH		88	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY
21061A	9201002	C	D	STRYCH		88	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY

21062A 9200885	A	D	SUWANEE		66	638	D 35	FINE-LOAMY	USTIC	TORRIFLUVENT	MESIC		
21062A 9200886	B	D	SUWANEE		66	638	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21062A 9200887	C	D	SUWANEE		66	638	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21064A 9200889	A	C	BATTERSON		57	638	D 35	SANDY	LITHIC USTIC	TORRIORTHENT	MESIC	92P 5493 IS DUP. SAMPLE OF 92P 5492	
21064A 9200890	B	C	BATTERSON		57	638	D 35	SANDY	LITHIC USTIC	TORRIORTHENT	MESIC		
21064A	C	C			57	638	D 35					ROCK OUTCROP	
21210A 9200774	A	D	RAVOLA		75	624	D 34	FINE-SILTY	TYPIC	TORRIFLUVENT	MESIC		
21210A 9200775	B	D	RAVOLA		75	624	D 34					INSUFFICIENT HORIZ. TO CLASSIFY	
21210A 9200776	C	D	RAVOLA		75	624	D 34					INSUFFICIENT HORIZ. TO CLASSIFY	
21211A 9200784	A	C	AMODAC FAMILY		52	624	D 35	COARSE-LOAMY	TYPIC	CALCIORTHID	MESIC		
21211A 9200978	A	C	ANASAZI	T	52	624	D 35	COARSE-LOAMY	USTOCHREPTIC	CALCIORTHID	MESIC		
21211A	B	C			52	624	D 35					ROCK OUTCROP	
21211A	B	C			52	624	D 35					ROCK OUTCROP	
21211A	C	C			52	624	D 35					ROCK OUTCROP	
21211A	C	C			52	624	D 35					ROCK OUTCROP	
21211A 9200980	D	C	RIZNO		52	624	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC		
21211A 9200785	D	C	RIZNO		52	624	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC		
21212A 9201016	A	D	FIREBALL		57	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21212A 9201017	B	D	BLACKSTON		57	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21212A 9201018	C	D	BLACKSTON		57	633	D 35						
21213A 9201012	A	D	REDBANK		42	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21213A 9201014	B	D	RIZNO	T	42	633	D 35	LOAMY-SKELETAL	LITHIC	USTORTHENT	MESIC	RIPARIAN AREA.	
21213A 9201015	C	D	REDBANK	T	42	633	D 35					INSUFFICIENT HORIZ. TO CLASSIFY	
21214A 9200907	A	C	ANASAZI				D 39	COARSE-LOAMY	USTOLLIC	CALCIORTHID	MESIC	UNMAPPED AREA MANTI LA SAL NF	
21214A 9200908	B	C	RIZNO				D 39	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	UNMAPPED AREA MANTI LA SAL NF	
21214A 9200909	C	C	MIVIDA HIGHRAIN					D 39				UNMAPPED AREA MANTI LA SAL NF	
21215A 9200912	A	C	BARX		45	638	D 39	FINE-LOAMY	USTOLLIC	HAPLARGID	MESIC		
21215A 9200913	B	C	SEIS		45	638	D 39	LOAMY-SKELETAL	USTOLLIC	CAMBORTHID	MESIC		
21215A 9200914	C	C	SOUTHFORK		45	638	D 39	LOAMY	USTOLLIC	HAPLARGID	MESIC		
21217A 9200974	A	D	MOENKOPIE		RSG	643	D 35	LOAMY	LITHIC	TORRIORTHENT	MESIC		
21217A 9200976	B	D	MOENKOPIE		RSG	643	D 35	LOAMY	LITHIC	TORRIORTHENT	MESIC		
21217A 9200977	C	D	MOENKOPIE		RSG	643	D 35	LOAMY-SKELETAL	LITHIC	TORRIORTHENT	MESIC		

21361A	9200982	A	D	MOENKOPIE				D 34					DUP. PEDON 92P 786 A HORIZON
21361A	9200786	A	D	MOENKOPIE				D 34					UNMAPPED AREA
21361A	9200983	B	D	MOENKOPIE				D 34					DUP. OF PEDON 92P 787 A HORIZON
21361A	9200787	B	D	MOENKOPIE				D 34	LOAMY	LITHIC	TORRIORTHENT	MESIC	UNMAPPED AREA
21361A	9200984	C	D	MOENKOPIE				D 34					DUP. OF PEDON 92P 788 A HORIZON
21361A	9200788	C	D	MOENKOPIE				D 34	LOAMY	LITHIC	TORRIORTHENT	MESIC	UNMAPPED AREA
21362A	9200891	A	D	CANYON FAMILY		119	631	D 35	LOAMY	USTIC	TORRIORTHENT	MESIC	
21362A	9200893	B	D	RIZNO		119	631	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	
21362A	9200894	C	D	RIZNO		119	631	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	
21362A	9200895	D	D	WAYNECO	T	119	631	D 35	LOAMY-SKELETAL	USTOCHREPTIC	CALCIORTHID	MESIC	
21363A	9200910	A	C	WAYNECO		45	631	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	
21363A		B	C			45	631	D 35					ROCK OUTCROP
21363A	9200911	C	C	MELLENTHIN		45	631	D 35	LOAMY-SKELETAL	LITHIC USTIC	TORRIORTHENT	MESIC	
21364A	9200877	A	D	PIRODEL		83	631	D 35	SANDY	USTOLLIC	CALCIORTHID	MESIC	
21364A	9200879	B	D	RIZNO	T	83	631	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	
21364A	9200880	C	D	RIZNO	T	83	631	D 35	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	
21365A	9200882	A	C	BOND		51	638	D 35	LOAMY	LITHIC USTOLLIC	HAPLARGID	MESIC	
21365A	9200883	B	C	MELLENTHIN		51	638	D 35	LOAMY-SKELETAL	LITHIC USTIC	CALCIORTHID	MESIC	
21365A	9200884	C	C	SKOS		51	638	D 35	LOAMY-SKELETAL	LITHIC USTIC	TORRIORTHENT	MESIC	
21366A	9200901	A	D	SKOS	T	13E2	638	D 35	LOAMY-SKELETAL	USTIC	TORRIORTHENT	MESIC	
21366A	9200903	B	D	SKOS	T	13E2	638	D 35	LOAMY	USTIC	TORRIORTHENT	MESIC	
21366A	9200904	C	D	SND		13E2	638	D 35					TOO THIN (1CM) TO CLASSIFY
21366A	9200905	D	D	SND		13E2	638	D 35	SANDY-SKELETAL	LITHIC	USTIFLUVENT	MESIC	
COF101	9300092	A	C	TRAVESSILLA		78	675	E 48A	LOAMY	LITHIC USTIC	TORRIORTHENT	MESIC	PINON-USTIC TORRIORTHENTS
COF101	9300093	B	C	GERST		78	675	E 48A	LOAMY	USTIC	TORRIORTHENT	MESIC	
COF101	9300094	C	C	GERST		78	675	E 48A					INSUFFICIENT HORIZ. TO CLASSIFY

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