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January 1993

# Arid Colorado Plateau Pilot Study - 1992

## Implementation Plan

**Environmental Monitoring and Assessment Program**

EPA/620/R-93/001
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# ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

## EMAP–Arid Colorado Plateau Pilot Study – 1992 Implementation Plan

**Susan E. Franson (Editor)**

**Desert Research Institute**
**Cooperative Agreement Number CR–816385–02**

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# ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

## Arid Ecosystems Resource Group

**William G. Kepner, Technical Director**
**Carl A. Fox, Principal Scientist**

## EMAP–Arid Colorado Plateau Pilot Study – 1992 Implementation Plan

**Susan E. Franson, Editor**

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# ACRONYMS

| | |
|---|---|
| AVHRR | Advanced Very High Resolution Radiometer |
| BLM | Bureau of Land Management |
| CEC | Cation Exchange Capacity |
| CPPS | Colorado Plateau Pilot Study |
| DQO | Data Quality Objective |
| DRI | Desert Research Institute (University and Community College System of Nevada) |
| EMAP | Environmental Monitoring and Assessment Program |
| EMAP–Arid | Arid Ecosystem Component of EMAP |
| EOSAT | Earth Observation Satellite Corporation |
| EPA | Environmental Protection Agency |
| EROS | Earth Resources Observation Satellite |
| ESP | Exchangeable Sodium Percentage (solid indicate) |
| FIA | Forest Inventory Analysis |
| FOTM | Field Operations and Training Manual |
| FS | Forest Service |
| FWS | Fish and Wildlife Service |
| GAP | FWS GAP Program (to identify gaps in protection of species and habitats) |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| HLAS | Habitat Linear Appraisal System |
| IM | Information Management |
| INEL | Idaho National Engineering Laboratory |
| K–T | Kepner–Tregoe (Decision Analysis Technique) |
| LAI | Leaf Area Index |
| LESC | Lockheed Engineering and Science Company |
| LTER | Long–term Ecological Research |
| MQO | Measurement Quality Objective |
| MSS | Multi–Spectral Scanner |
| NALC | North American Landscape Characterization |
| NCSS | National Cooperative Soil Survey |
| NDVI | Normalized Difference Vegetation Index |
| NGDC | National Geophysical Data Center (Boulder, CO) |
| NIR | Near InfraRed |
| NOAA | National Oceanic and Atmospheric Administration |
| NPP | Net Primary Productivity |
| NPS | National Park Service |

| | |
|---|---|
| NRC | National Research Council |
| NRI | National Resource Inventory |
| NSH | National Soils Handbook |
| PC | Personal Computer |
| PDR | Personal Data Recorder |
| PDSI | Palmer Drought Severity Index |
| PS–II | Personal Spectrometer II |
| QA | Quality Assurance |
| QAPjP | Quality Assurance Project Plan |
| RUSLE | Revised Universal Soil Loss Equation |
| SAR | Sodium Absorption Ratio |
| SCS | Soil Conservation Service |
| SSM | Soil Survey Manual |
| TM | Thematic Mapper |
| UCAR | University Corporation for Atmospheric Research |
| USDA | United States Department of Agriculture |
| USLE | Universal Soil Loss Equation |
| WE | Wind Erosion |
| WEPP | Wind Erosion Prediction Project |

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## ACKNOWLEDGEMENTS


The EMAP–Arid Indicator Workshop was held at Utah State Universtity October 28–30, 1991 to evaluate indicators of condition of arid ecosystems. As a result of that workshop a broad list of proposed candidate indicators was organized into a more cohesive grouping of indicator categories. The discussions during that workshop have been extremely valuable in the selection of indicator categories for the pilot study and to the development of this Implementation Plan and are greatly appreciated. Participants in that workshop included: Timothy Ball, Desert Research Institute, University and Community College System of Nevada (DRI); Terrence P. Boyle, National Park Service, Colorado State University; Robert P. Breckenridge, Idaho National Engineering Laboratory (INEL); Carl A. Fox, DRI; Douglas G. Fox, U.S. Forest Service Rocky Mountain Range Experiment Station; Susan E. Franson, Environmental Monitoring Systems Laboratory–Las Vegas (EMSL–LV), U.S. Environmental Protection Agency (EPA); Harold C. Fritts, Laboratory of Tree–Ring Research, University of Arizona; Nancy L. Hampton, INEL; Carolyn T. Hunsaker, Oak Ridge National Laboratory; Wes Jarrell, Department of Environmental Science and Engineering, Oregon Graduate Institute; Dale Johnson, DRI; K. Bruce Jones, EMSL–LV, EPA; William G. Kepner, EMSL–LV, EPA; Robert O. Kuehl, College of Agriculture, University of Arizona; Stephen G. Leonard, Department of Range, Wildlife, and Forestry, Bureau of Land Management; James A. McMahon, Department of Biology, Utah State University; Vern Meentemeyer, Department of Geography, University of Georgia; David A. Mouat, DRI; Keith Mussallem, DRI; Martin R. Rose, DRI; Carol Simmons, Colorado State University; Stan Smith, Biology Department, University of Nevada – Las Vegas; George J. Staidl, Soil Scientist, National Soil Range Team, Soil Conservation Service; Don Stevens, Ecological Research Organization, Mantech Environmental Technology, Inc.; Robin J. Tausch, USDA Forest Service Intermountain Research Station; Richard D. van Remortel, Lockheed Engineering and Sciences Corporation; Fred Wagner, Department of Range Science and Ecology Center, Utah State University; Neil E. West, Department of Range Science and Ecology Center, Utah State University; Walt G. Whitford, Department of Biology, New Mexico State University; James D. Wickham, Bionetics Corporation; Peter E. Wigand, DRI.

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# 1.0 INTRODUCTION TO THE EMAP–ARID COLORADO PLATEAU PILOT STUDY

(William G. Kepner)

## 1.1 INTRODUCTION

In response to the growing awareness of regional and global–scale environmental degradation brought about by the combined actions of all peoples on Earth, nations throughout the world are acknowledging the need to obtain critical scientific information and are establishing environmental monitoring networks to assess the condition of their important ecological resources.

The U.S. Environmental Protection Agency (EPA), in collaboration with other federal agencies, research institutes, and university systems, has initiated the Environmental Monitoring and Assessment Program (EMAP) to develop a long–term approach to assess and periodically document the condition of ecological resources at regional and national scales and to create innovative methods for anticipating emerging problems before they reach crisis proportions. The goals of EMAP are to:

1. Monitor and report on the condition of the Nation's ecological resources.
2. Evaluate the effectiveness of the sum total of current environmental policies and programs.
3. Identify emerging environmental problems before they become widespread or irreversible.

To achieve these goals, EMAP will: (1) estimate the status, extent, changes, and trends in ecological condition using an environmental indicator strategy; (2) seek associations between human–induced stresses and ecological condition; and (3) provide statistical summaries and interpretive reports on ecological status and trends to resource managers and the public. The program is focused on linking with existing environmental monitoring programs, where possible, and collecting new information as needed to achieve its objectives. EMAP is not intended as a substitute for ongoing programs, however, it may enhance their value by placing local monitoring results in the perspective of a larger geographical context.

To accomplish its goals and objectives, EMAP has established seven ecosystem monitoring and research groups (i.e., estuarine and marine; Great Lakes; surface waters; wetlands; forests; agroecosystems; and arid ecosystems) and seven cross–system program groups (i.e., design and statistics; quality assurance; information management; landscape characterization; indicators; logistics; and integration and assessment).

## 1.2 ARID ECOSYSTEMS

Arid ecosystems, as defined by EMAP, are *"Terrestrial systems characterized by a climatic regime where potential evapotranspiration exceeds precipitation, annual precipitation ranges from <5 to 60 cm, and daily and seasonal temperatures range from –40 to 50° C. The vegetation in arid ecosystems is dominated by woody perennials, graminoids, succulents, and drought–resistant trees. Physiognomy is generally low–form and canopies typically open. Arid ecosystems include associated riparian communities, however, intensively managed agriculture, such as irrigated farmland, is excluded even though it may occur in the same climatic region"* (Kepner and Fox, 1991). Arid ecosystems in the United States occupy nearly all the land surface area (excluding high–elevation forests) west of 95°W longitude (Figure 1–1). Historically, dramatic urbanization and overexploitation of natural resources have resulted in rapid desertification, i.e., the decline or loss of biotic productivity in arid and semi–arid lands due to certain natural phenomena and man–induced stresses (Bender, 1982). Once arid ecosystems are degraded significantly, they are generally unlikely to return to their prior state and hence are often termed *"fragile"* because they exhibit little resistance or resilience in the face of anthropogenic insult (UCAR, 1991). Desertification, livestock grazing, biodiversity, water resource management, air quality, and global climatic change have been identified as regionally important issues in arid ecosystems (Kepner and Fox, 1991).

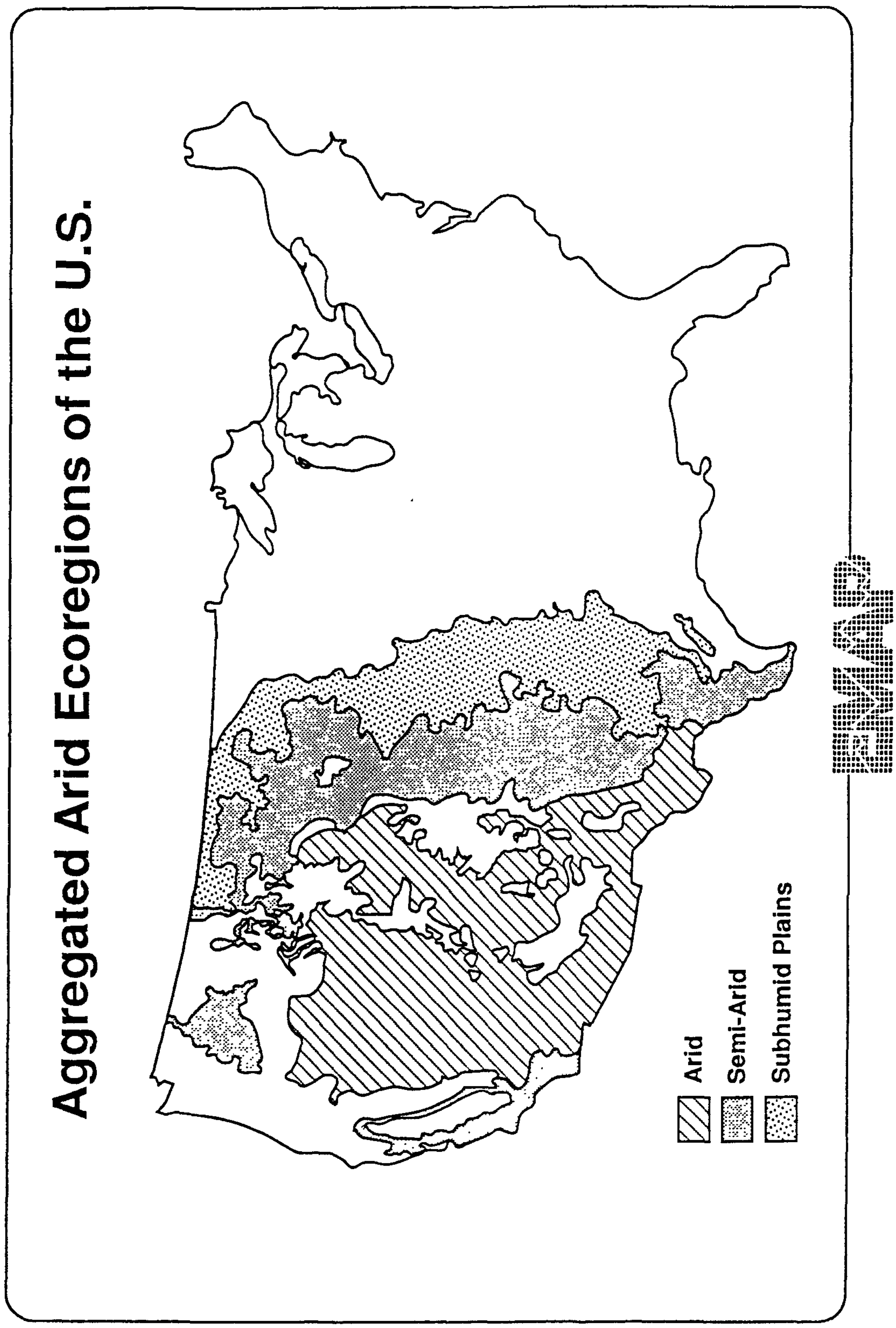


Figure 1–1. Aggregated Arid Ecoregions of the U.S.

The objectives of the EMAP Arid Ecosystems resource monitoring and research group (EMAP–Arid) parallel those established for the overall EMAP program. When fully implemented, EMAP–Arid will address the following objectives related specifically to arid systems:

1. Measure the status and trends and estimate the extent of arid ecosystems using synoptic, retrospective, and sample–based indicator measurements.
2. Determine the spatial and temporal correlation between environmental stressors and ecological condition.
3. Provide information to decision/policy makers and management, and regulatory and research agencies and institutes that can be utilized for comprehensive regional planning and management.
4. Develop a regional interagency communication and data transfer network.

It is the intent and purpose of EMAP–Arid to measure and report on the extent, condition, and trends in eight vegetation formation types (i.e., biomes) within the conterminous U.S. portion of the seven biogeographical provinces of Nearctic and Neotropical North America that reside in an arid or semi–arid climatic regime (Brown et al., 1979; Figure 1–2). These include five upland formations (desertscrub, grassland, scrubland, woodland, and tundra) and three lowland formations (riparian forest, riparian scrub, and strandland). Under full implementation, EMAP–Arid will also include the tundra of Alaska.

EMAP–Arid will utilize a set of environmental indicators that collectively can describe the condition of an ecosystem (Hunsaker et al., 1990). The operating strategy is to identify regional issues and critical questions; link them with ecological endpoints that have both social and biological relevance; and identify indicators derived from conceptual models that, when measured and integrated, can evaluate the status and trends in the condition of arid ecosystems (Figure 1–3). Three societal values are currently identified as significant to arid ecosystems and have served to focus the conceptual development of the monitoring

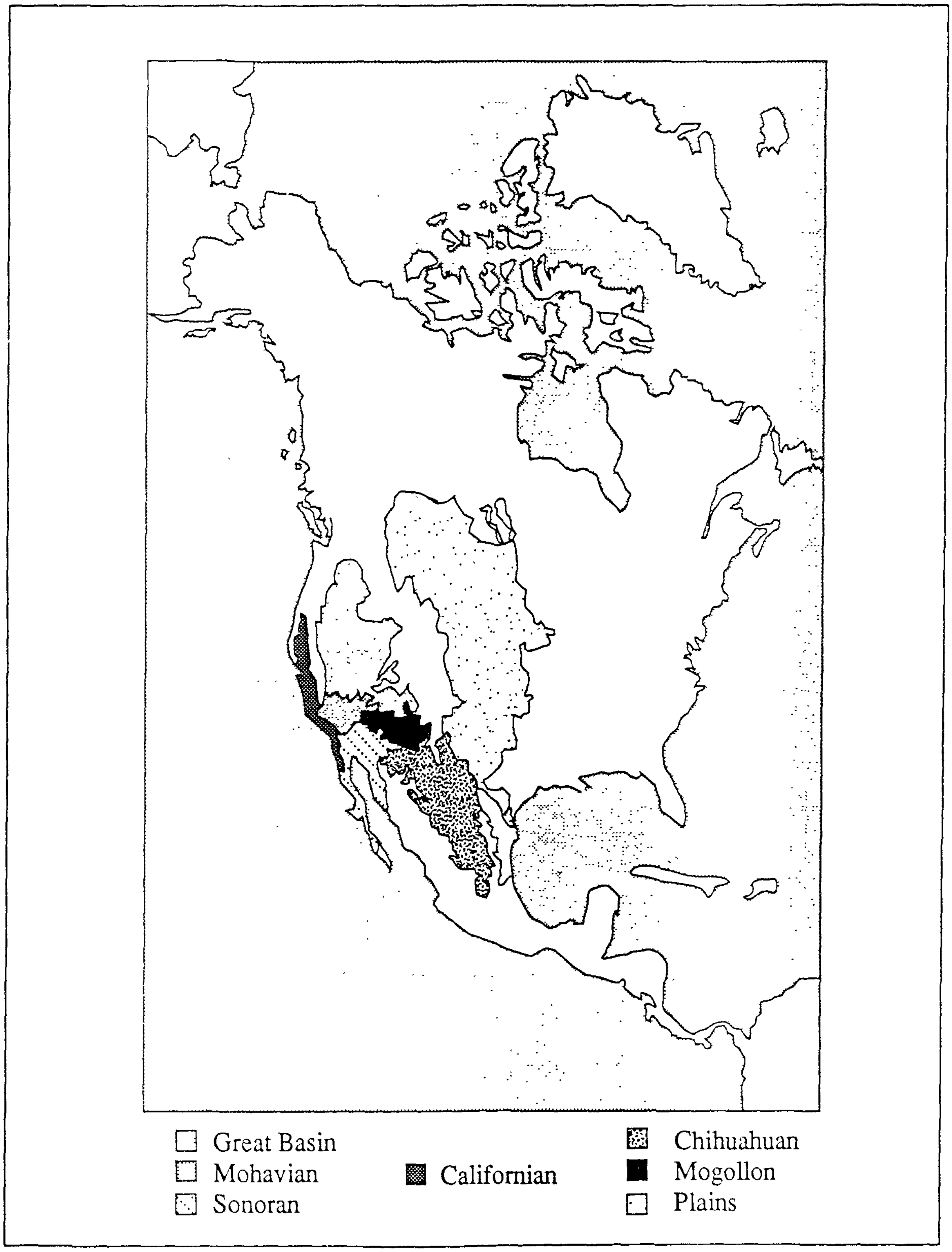


Figure 1–2. EMAP–Arid Biogeographic Provinces of North America.

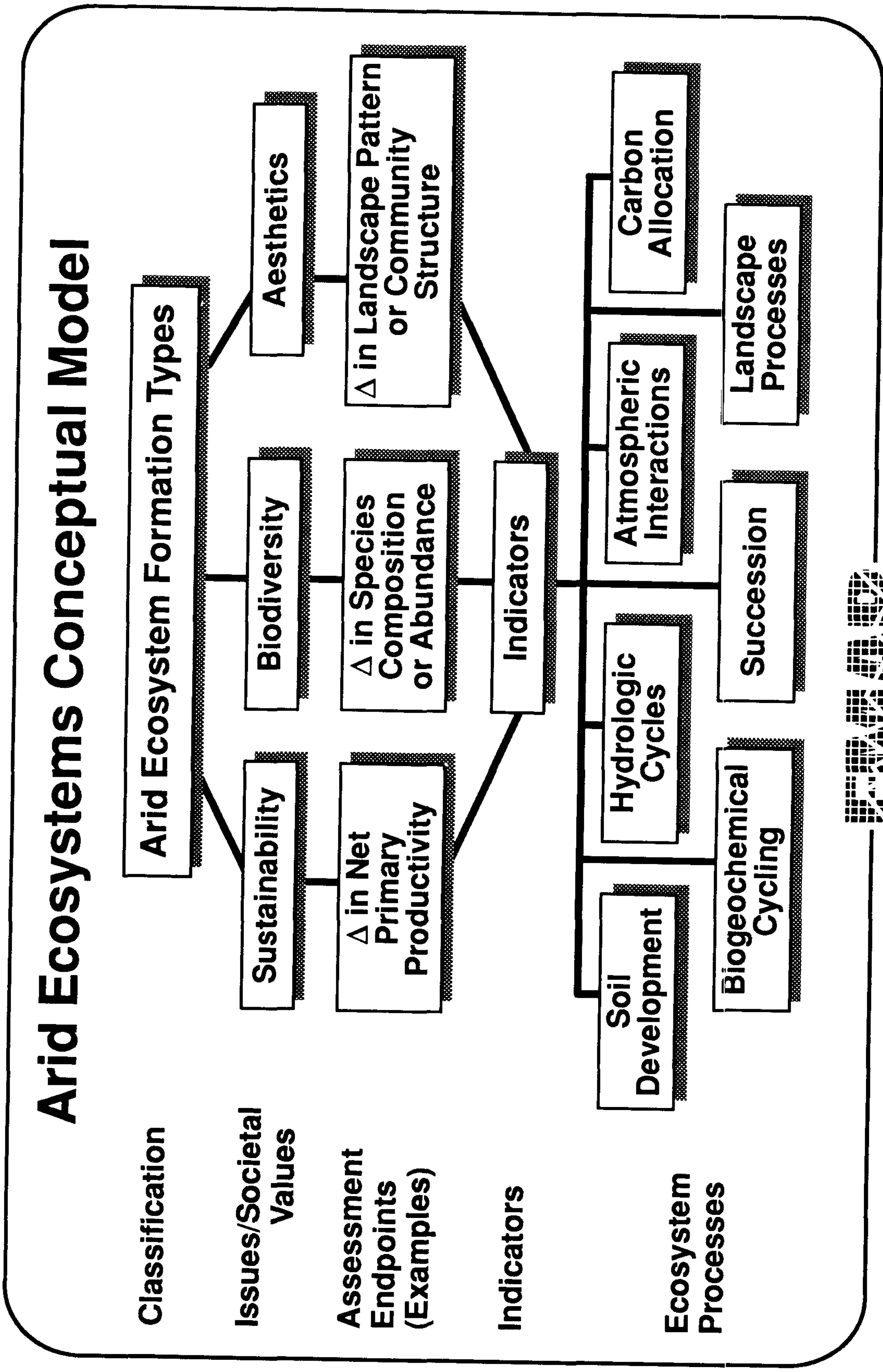


Figure 1–3. Arid Ecosystems Conceptual Model

and research strategy for EMAP–Arid, especially relative to its selection and use of indicators:

1. Sustainability
2. Biodiversity
3. Aesthetics

Sustainability is the ability of an ecosystem to sustain its potential or actual biological productivity over the long term. Within arid and semi–arid lands, loss of sustainability is usually the result of desertification. Desertification can result from an extended period of extreme drought, severe mismanagement of land, or evaporation of water leading to soil salinization. Desertification is accompanied by a change in species composition or general loss of biomass, loss of soil nutrients with remaining nutrients concentrated under shrubs, and increased removal of soil materials by wind and water erosion – all of which contribute to a loss of sustainability of the ecosystem.

Biodiversity (species richness) recently has been recognized as an important global resource. The preservation of species, communities, and ecosystems to provide natural resources (e.g., food, medicine, shelter) for daily life and ecological services (e.g., climate moderation, water and nutrient cycling, and breakdown of wastes) now and into the future has become an issue of global proportions. In essence, to ensure survival of life on Earth we must protect biodiversity.

Aesthetics as a societal value of EMAP–Arid can be broadly defined as the quality of life. It is related to the above values but focuses on the human perception of the ecosystem. Many people value arid systems not only for their ecological role but also for their beauty: the desert in bloom, mountain sheep on rocky crags, the spectacular views of the Painted Desert or Grand Canyon. Aesthetics is the societal value that ties all the others together. Without sustainability and biodiversity the beauty of the desert would be lost.

Of course the quality of life also depends on air quality, water quality and quantity, and many other things. As the EMAP–Arid develops, other such societal values will be identified, along with assessment endpoints and indicators to monitor their status and trends.

The framework for selecting and testing indicators follows a process outlined in Hunsaker and Carpenter (1990). Each EMAP Resource Group is expected to select and test a number of indicators in limited field tests or pilot exercises. These tests are intended to evaluate the ability of selected research indicators to discriminate, separately and in combination, environmental conditions and ultimately to determine which indicators are retained and moved to a higher indicator category, rejected, or held for further evaluation. If indicators are retained, they will be further tested on a regional scale via a demonstration project. A final set of core indicators will be selected for long–term implementation based on the results of regional demonstration projects and external peer review (Hunsaker and Carpenter, 1990). New or improved versions of indicators can be added to the core set following periodic reevaluation and testing of indicator performance.

This document presents a proposed plan for pilot testing three indicator categories of arid ecosystem condition (spectral properties; vegetation composition, structure, and abundance; and soil properties). These indicators were selected through a number of workshops and peer reviews, and are likely to meet all the criteria, such as being applicable and interpretable on a regional scale, suggested by Hunsaker and Carpenter (1990). Thus, they are of high priority in EMAP–Arid. Although these indicators appear to demonstrate the highest potential or capability for diagnosing ecosystem change (i.e., the ability to be merged with other data sets to make integrated assessments of ecosystem condition at the regional level), they must be considered developmental in status and subject to field testing prior to their long–term implementation.

The purpose of this study is to focus on answering important questions of indicator performance such as determining components of variance. Other important information such as requirements for methods development, logistics, data management, and quality assurance will also be gleaned from this type of study. This study is not intended to provide a regional estimate of condition.

The preparation of this plan has been a team effort of a number of scientists from various universities, research institutes, public interest groups, and federal agencies. The success of the pilot study is equally dependent on the participation of this mixture of affiliations, but particularly rests with the EPA, U.S. Bureau of Land Management (BLM), National Park Service (NPS), Forest Service (FS), Soil Conservation Service (SCS), Fish and Wildlife Service (FWS), and Navajo and Ute Nations.

In summary, the Implementation Plan for the Colorado Plateau Pilot Study is a significant first step towards regional and national implementation of EMAP–Arid. This plan provides the mechanism for coordination of indicator development and evaluation with members from participating agencies and the external scientific community via the planning and peer review process. Additionally, it provides the foundation and direction to team members who are responsible for executing the plan. We fully anticipate that a number of pilot and demonstration projects will be required in the next couple of years prior to achieving full implementation. We also are confident that the selected indicator suite and the location of the Colorado Plateau for this pilot affords us every opportunity to achieve a success upon which to further develop this program.

## 1.3 LAYOUT AND OVERVIEW OF THE IMPLEMENTATION PLAN

This Implementation Plan gives an overview of the pilot study from a technical perspective. A companion document, the Field Operations and Training Manual (FOTM) (Franson and Pollard, 1992), presents the operational aspects of the field study. These operational aspects include (1) detailed protocols for each step of the field work; (2) a Safety Plan that documents the hazards that may be encountered in the study area, safety procedures to be followed, and information about what to do in case of emergency; and (3) a Quality Assurance Project Plan that details the steps to be taken to ensure that data collected are of sufficient quality to address the objectives of the study. The indicator evaluation pilot study includes as an objective the development and evaluation of measurement protocols and quality assurance (QA) procedures. Thus, the applications of the operational details in the field data collection effort will serve as part of the review of these operational plans.

Following this Introductory Section, the Implementation Plan addresses the Conceptual Approach for the pilot study in Section 2. Questions that will be addressed in order to meet each study objective are outlined as part of this Conceptual Approach. Section 3 describes the site selection process that resulted in the choice of the Colorado Plateau for this pilot study. A description of the entire Colorado Plateau is included in Section 3, along with the exact geographic location of the pilot study. Section 4 gives an overview of the EMAP design, the overall EMAP–Arid design, and the sampling and plot design for the pilot study.

Section 5 discusses the indicators, including a rationale for their selection and use and a general description of the measurements to be made. Specific protocols for collecting the indicator data will appear in the FOTM. The intent of Section 5 is to give sufficient information to review the selected indicators from a scientific standpoint, but not to burden the reader with extensive details of the field protocols.

In a similar fashion, Section 6 on Logistics, Section 7 on Quality Assurance, and Section 8 on Information Management and GIS present overviews of these topics and are not intended to give the specific details required for the field activities that will appear in the FOTM.

Section 9 concludes the Implementation Plan with a discussion of Analysis and Reporting of the results of this pilot study. As with any exploratory research, the exact analyses that will be employed are not always known before the data are in hand. Rather, the approach to data analysis is to address the questions given in the Conceptual Approach.

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# 2.0 CONCEPTUAL APPROACH

(Carl A. Fox, William G. Kepner, and Susan E. Franson)

## 2.1 INTRODUCTION

In 1991, EMAP–Arid developed a monitoring strategy for full scale implementation of EMAP across arid ecosystems (Kepner and Fox, 1991). This strategic plan was based in part on guidelines developed by the National Research Council (NRC, 1990) for designing and implementing environmental monitoring programs (Figure 2–1). The NRC process provides a formula that leads from defining goals to disseminating information to decision makers. EMAP–Arid is closely following the NRC strategy and has completed Step 2 of this process.

The strategic plan was evaluated through a peer review process. The expectations, goals, and strategy of EMAP–Arid presented in the plan were approved by the review panel, with the recommendation that the strategy be evaluated through field evaluations and pilot studies, that is, to begin Step 3 of the NRC process.

Through the development and execution of the Colorado Plateau Pilot Study, EMAP–Arid will begin Step 3, Conduct Exploratory Studies. These exploratory studies are generally of two types: pilot studies and demonstration projects. Pilot studies are generally intended to answer specific questions about indicator performance, including sensitivity, components of variance, methods, and logistical requirements. Pilot studies are not intended to provide regional estimates of ecological condition. Demonstration projects, while addressing many of the same questions as pilot studies, are specifically designed to demonstrate EMAP's ability to estimate the condition of regional populations.

The Colorado Plateau Pilot Study will be conducted to evaluate and field test a number of issues related to design, ecological indicators, quality assurance, logistics, information management, and analysis and reporting before full scale implementation. The

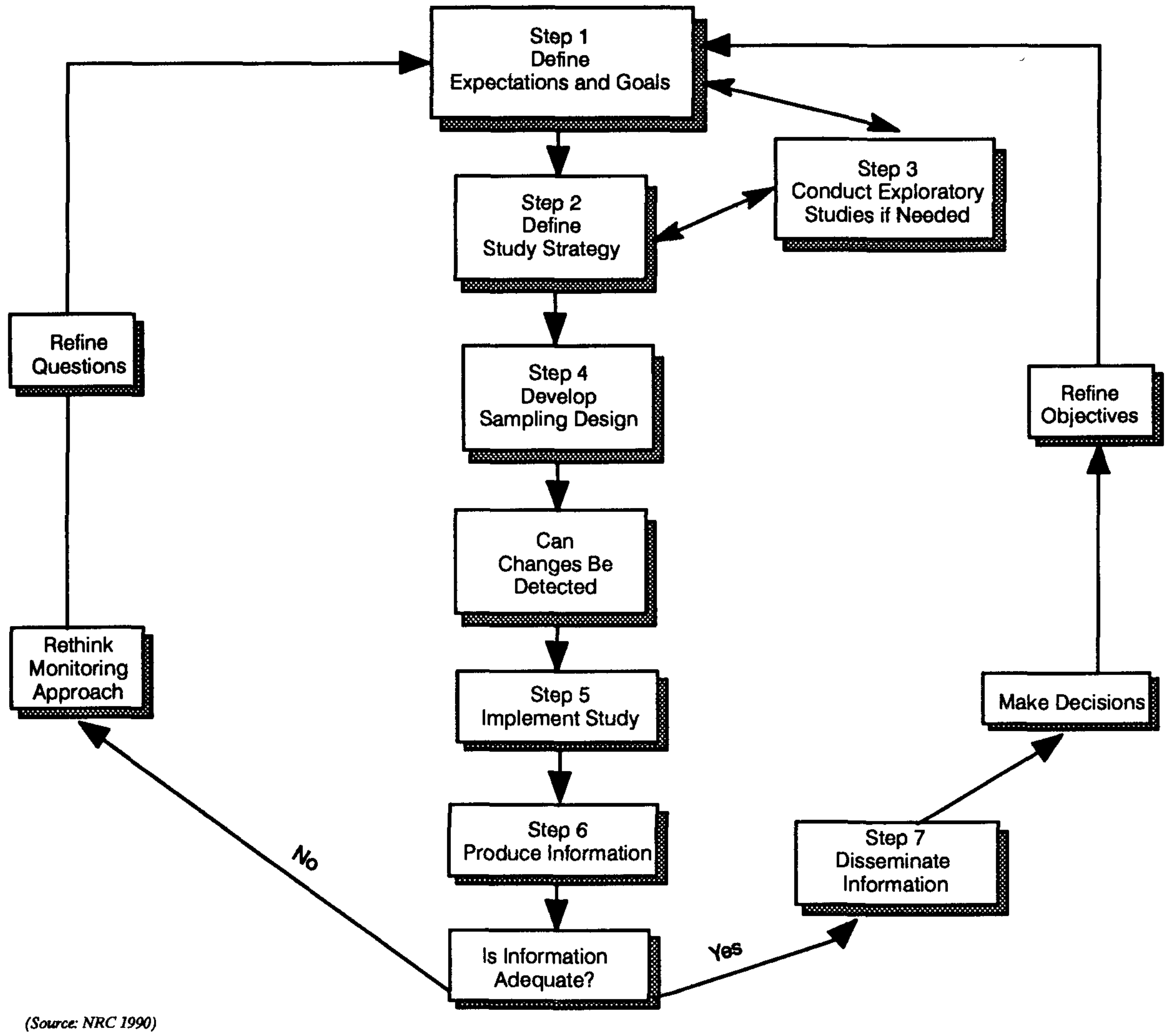


Figure 2–1. The Elements of Designing and Implementing a Monitoring Program.

Colorado Plateau Pilot Study will test nearly all aspects of the monitoring program with a limited suite of indicators. Results will be used to plan future pilot studies and to develop regional demonstration projects leading to full scale implementation.

## 2.2 STUDY OBJECTIVES AND QUESTIONS

The overall goal of the Colorado Plateau Pilot Study (CPPS) is to evaluate a selected subset of ecological indicators to address issues of desertification and global climatic change as they relate to sustainability of arid ecosystems, a principal societal value. While this goal will not be achieved in this study, it serves to focus EMAP–Arid activities and guide the CPPS.

Specific objectives and associated questions that will be addressed in the pilot study are as follows:

Objective 1: To gather and evaluate information to move selected ecological indicators from the "research" category to the "development" stage in the indicator implementation process (Figure 2–2).

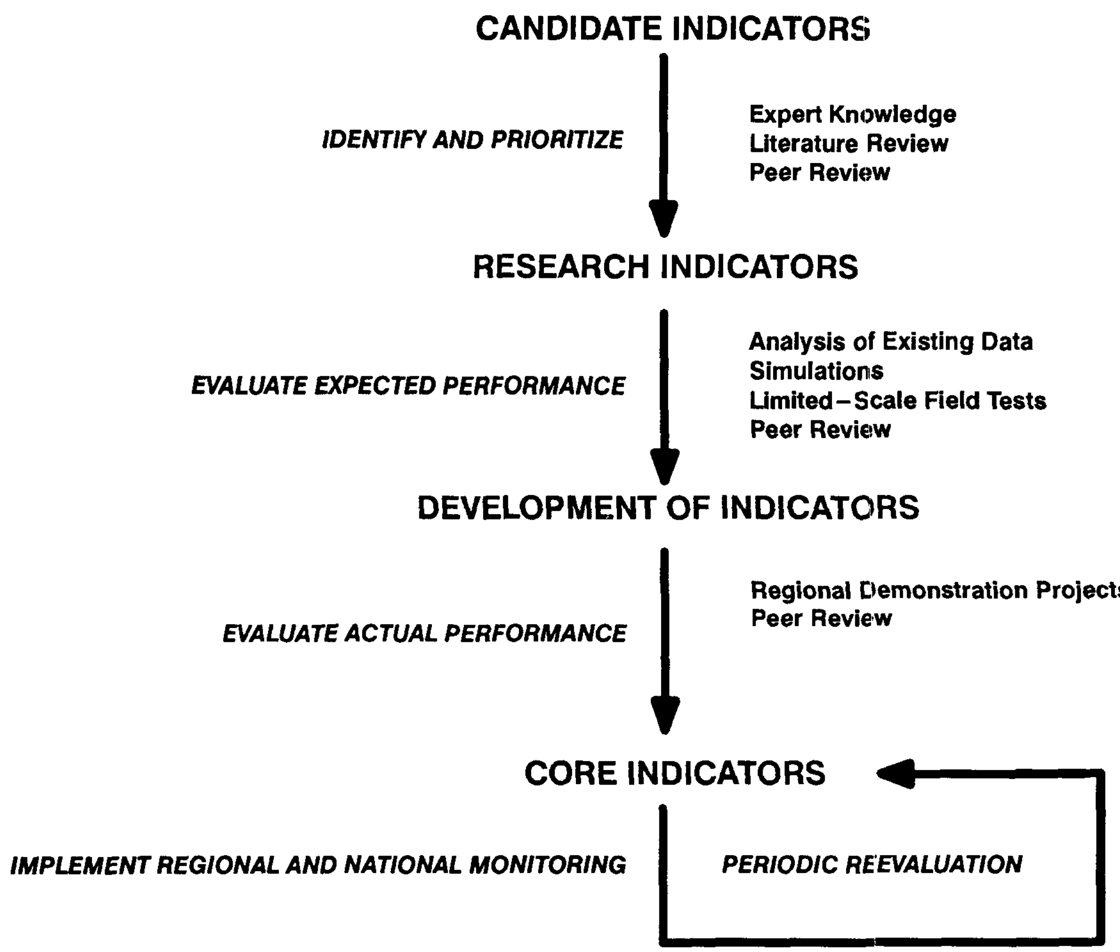


Figure 2–2. Indicator Selection, Prioritization, and Evaluation Approach for EMAP.

Questions:

1. Are the indicators for a) spectral properties, b) vegetation composition, structure, and abundance, and c) soil properties, separately or in combination, correlated with independent evaluations of site conditions? BLM, NPS, SCS, and FS all have condition assessments for some arid lands. While these assessments are based on different sets of criteria, EMAP–Arid will compare pilot study results with other condition assessments to begin to develop the assessment process.
2. What is the correlation between the remotely sensed spectral properties data from AVHRR, MSS, or TM and spectral properties data acquired through field sampling using a personal spectrometer?
3. Do remote measures of spectral properties correlate with other field measured indicators of vegetation and soils or existing assessments done by the NPS, FS, SCS, and BLM?
4. Which of the remote platforms (AVHRR, MSS, or TM, or a combination) appears to be most effective in obtaining the required spatial and temporal data necessary to link remotely sensed indicators with ground measures and existing data?

Objective 2: Evaluate the utility of using classified Thematic Mapper imagery and other data acquired from the FWS GAP Program to select frame materials for the pilot study and future studies and to provide data for extent estimation of arid ecosystems.

Questions:

5. Do the Biotic Communities Map (Reichenbacher and Brown, 1992) and the GAP data correctly identify the plant communities found at each of the pilot study sample grid points? If not, what is the level of misclassification and can this level of misclassification be compensated?
6. Do the GAP data provide adequate information to describe the extent of arid ecosystems in the pilot study area?

Objective 3: Evaluate sampling plot designs appropriate to the selected indicators.

Questions:

7. What are the sampling design between site, subplot, and sample variance components of each of the selected indicators?
8. What are the costs associated with indicator measurement? Costs to be evaluated include labor, equipment, laboratory analyses, image

analyses, cost of imagery, data analyses, etc. Costs will be evaluated relative to specific sizes of sampling units (subplots, samples, lab replicates, etc.) as well as overhead costs for a site.

9. What are the optimum numbers of subplots and samples to have a good estimate of each indicator at a site?

10. How many sites cross a vegetation/soil complex boundary? Does the addition of quadrats provide a large enough sample to allow for estimates of the vegetation indicators?

Objective 4: Evaluate the logistical, quality assurance, information management, data analysis, and reporting requirements and constraints based on the pilot study data.

Questions:

11. What specific logistical constraints restrict the implementation of each indicator? What logistic attributes favor or enhance indicator measurement (e.g., use of a helicopter)?

12. Based on the results of the pilot study, can data quality objectives be established for each indicator tested?

13. Does the information management system effectively and efficiently provide for the movement of data from the field to the analysis stage?

14. Do the methods of collecting, transferring, and analyzing data meet the reporting requirements for an EMAP pilot study?

15. What are the special logistical requirements involved with fielding multi–agency sampling crews?

The Colorado Plateau Pilot Study is not intended to be a full implementation of the EMAP–Arid monitoring program but will provide information essential to the successful development of regional demonstration projects. The pilot study will be an interagency effort to evaluate selected indicators, sampling plot designs, logistics, quality assurance, information management, and analysis and reporting. It represents EMAP–Arid's first field study after the successful development of a strategic monitoring plan. The Pilot Study is designed to fully consider those issues critical for the success and implementation of the EMAP–Arid program.

## 2.3 REFERENCES

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# 3.0 SITE SELECTION AND DESCRIPTION OF THE STUDY AREA

(Carl A. Fox, Robert P. Breckenridge, and Roger Clark)

## 3.1 THE SITE SELECTION PROCESS

### 3.1.1 Introduction

The most arid regions (i.e., deserts) on the earth are generally found within two well–defined bands 20 to 30 degrees north and south of the equator and at the poles (Bender, 1982). In North America, the major deserts (excluding the arctic) are the Chihuahuan, Great Basin, Mojave, and Sonoran, all located in the western United States. The Great Basin is considered a "cold" desert, while the others are often termed "hot" deserts.

In selecting a regional focus for the 1992 pilot study, EMAP–Arid first looked at the availability of relevant existing data and monitoring sites to assess sites located in "data rich" areas. This was done to enhance the use of existing data for interpretation of indicators and to foster interagency collaboration. Eight general areas were identified:

- Southwest New Mexico (Chihuahuan Desert)
- Great Basin National Park/Desert Experimental Range
- Northeast Utah and Southeast Idaho (Great Basin)
- Colorado Plateau (Great Basin)
- Southeast Arizona (Sonoran/Chihuahuan Deserts)
- Central California/Western Nevada (Western Great Basin)
- Central Nevada (Great Basin/Mojave Deserts)
- Northwest Arizona (Mojave/Sonoran/Great Basin)

These were identified by evaluating the sources of data relevant to the indicators identified in the EMAP–Arid Strategic Plan (Kepner and Fox, 1991) against a list of criteria that considered data quantity (number of years), data quality, site and data access, cost, and multiple agency collaboration. From this list the top four areas were selected based on their ability to meet the criteria. These four (Figure 3–1) became the final set from which a pilot location was to be selected.

### 3.1.2 K–T Analysis

To insure that the selection of the study region for the pilot was done as objectively as possible, the EMAP–Arid team employed a decision analysis procedure, the Kepner–Tregoe (K–T) Analysis (Kepner and Tregoe, 1981). K–T Analysis is a decision analysis technique that provides a quantitative methodology to insure that decisions are made in a highly systematic and logical manner, but without inhibiting creativity and innovation. The technique is focused around a decision statement that clearly defines the desired outcome. A list of "must have" and "want" objectives (criteria) is developed. The "want" objectives are weighted by giving the most important objective a score of 10 and all others a score from 10 to 1 based on their importance relative to the most important objective. The decision is then made by scoring each choice as to how well it meets the wants and compiling a weighted score.

In the case of the EMAP–Arid pilot study site selection, the four candidates were selected because they offered the opportunity of interagency collaboration and they fell within the EMAP definition of what constitutes an arid ecosystem. Thus, there were no musts in the K–T analysis. The "want" criteria and the respective weights developed by the EMAP–Arid team that included representation from the BLM, FS, EPA, DRI, SCS, and INEL are shown in Table 3–1. These criteria were then applied to the four candidate regions. The regions were rated for how well they met each criterion, with 10 assigned for a good match for the criterion and 1 assigned for a bad match for that criterion. The total weighted scores were calculated for each region (Table 3–2). Based on this analysis, the Colorado Plateau offered a study region that would best meet the selection criteria of the pilot study.

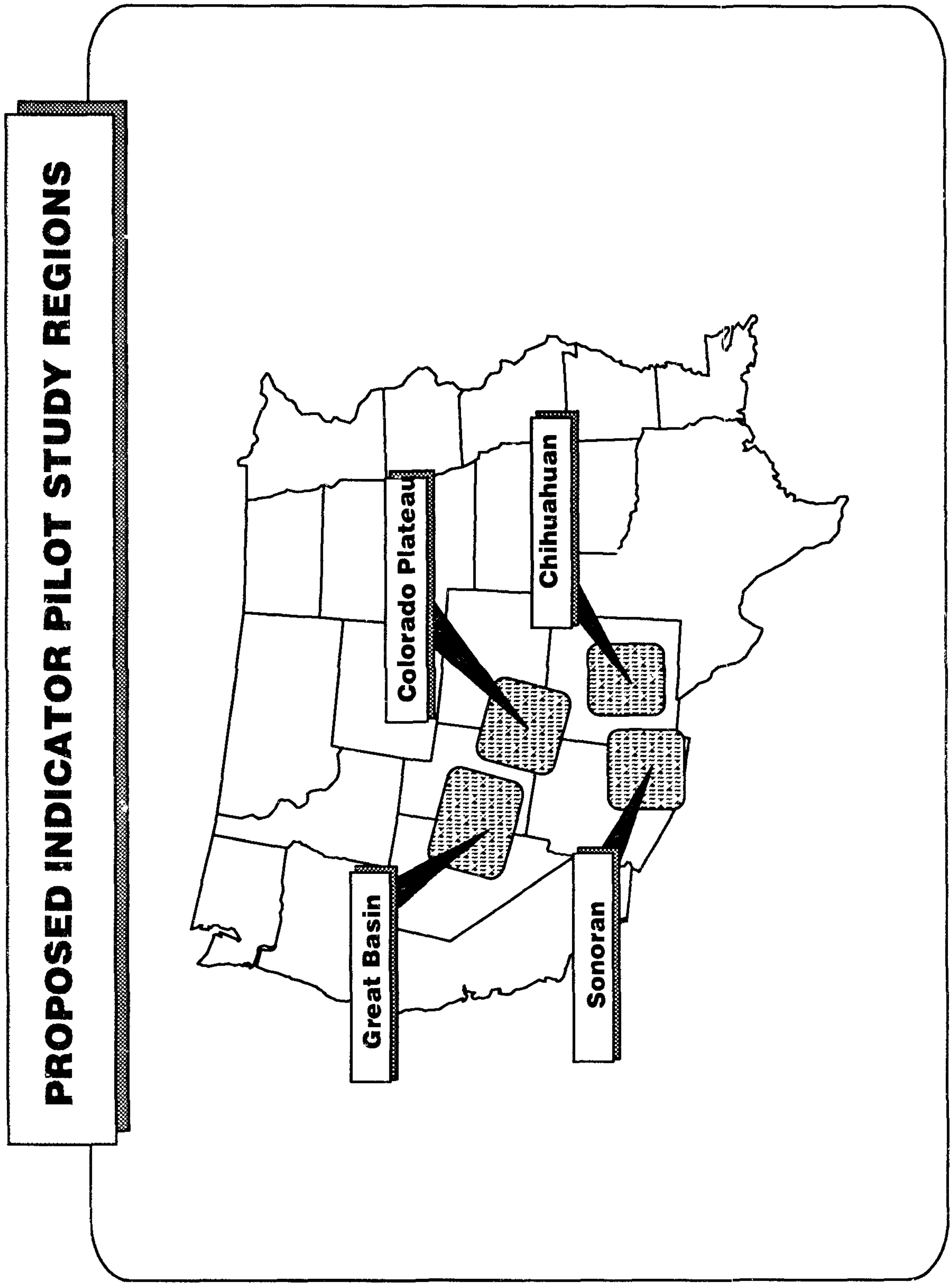


Figure 3–1. Proposed Pilot Study Regions.

TABLE 3–1. CRITERIA ("WANTS") FOR EMAP–ARID PILOT STUDY SITE SELECTION

| | "WANT" Weights |
|---|---|
| 1. Relationship of Study Area to the Issue of Desertification | 5.3 |
| 2. Relationship of Study Area to the Issue of Global Climatic Change | 4.9 |
| 3. Availability of Retrospective Data (Tree Ring Chronologies, Historical Climate Network, Fossil Pollen Records, Packrat Midden Radiocarbon Records) | 4.9 |
| 4. Quality & Quantity of Historical ($\geq$ 5 years) Data Related to Sustainability | 4.9 |
| 5. Opportunity for Collaboration with Other EMAP Groups | 3.2 |
| 6. Availability of Classified Remote Sensing Imagery | 2.8 |
| 7. Complexity of Study Area Logistics | 1.9 |

Before a final decision was reached, however, the probability and seriousness of adverse consequences (e.g., political, social, economic) in selecting the Colorado Plateau were evaluated as the last step in the K–T Analysis. These adverse consequences were rated high, medium, or low relative to the probability of occurrence and the seriousness of their effect if they did occur. This part of the K–T Analysis focused strictly on the tentatively selected site and did not allow for between site comparisons or ranking. It provided an opportunity to review all the potential consequences and greatly improved the potential for success. The end result of the final part of the K–T Analysis was that the Colorado Plateau remained the region of choice for the pilot study.

TABLE 3–2. STUDY AREA SELECTION FOR EMAP–ARID FY92 PILOT
VIA K–T DECISION ANALYSIS

| Selection Criteria "Wants" | SCORES FOR CANDIDATE SITES FOR CRITERIA* | | | |
|---|---|---|---|---|
| | Great Basin | Colorado Plateau | Sonoran Desert | Chihuahuan Desert |
| 1. Desertification | 47.7 | 45.9 | 39.7 | 45.6 |
| 2. Global Climate Change | 45.9 | 49.5 | 37.2 | 44.4 |
| 3. Retrospective Data | 42.6 | 43.1 | 35.8 | 33.3 |
| 4. Historical Data (Sustainability) | 32.3 | 29.4 | 36.3 | 44.6 |
| 5. Collaboration within EMAP | 13.4 | 32.0 | 1.3 | 16.3 |
| 6. Classified Remote Imagery | 22.4 | 28.0 | 18.8 | 18.2 |
| 7. Logistics Complexity | 11.2 | 13.1 | 15.0 | 13.3 |
| *Total Weighted Score* | 215.5 | 241.0 | 184.1 | 215.7 |

* Scores reflect how the EMAP–Arid team rated the ability of the various sites to satisfy the selection criteria from 10 (good match) to 1 (poor match). For example, the Great Basin received a value of 9 for meeting desertification criterion (that was highest rated criterion with weight of 5.3); thus weighted score for Great Basin was 9 x 5.3 = 47.7.

## 3.2 DESCRIPTION OF THE COLORADO PLATEAU

The Colorado Plateau is an arid and semi–arid tableland in the American Southwest. It is a place where climatic and geologic forces collide into monuments, mesas, canyons, badlands, spires, arches, and landscapes unlike any other on our planet. It is a terrain of sublime and stark beauty.

Life is harsh on the cold deserts of the Colorado Plateau. And yet it sustains alpine tundra, hanging gardens, xeric woodlands, blackbrush and sage shrublands, and cryptogamic communities of mosses, lichens, fungi, and cyanobacteria comprising most of the living biomass on much of its otherwise sterile soil. It is also home to scores of unique invertebrates, fish, reptiles, and amphibians.

The Colorado Plateau was first delineated by Major John Wesley Powell shortly after the American Civil War. Powell described the Plateau as a 170,000 square mile region encompassing what is today western Colorado, northern Arizona, northwestern New Mexico, the eastern two–thirds of Utah, and southwestern Wyoming. More recently, geologists have reduced Powell's definition of the physiographic province to a 130,000 square mile area slightly larger than New England (Figure 3–2).

Major Powell was attracted to the Colorado Plateau for several reasons. It was the last unmapped region of what was to become the lower 48 states; it was home to native people who had inhabited the region for at least three centuries before European contact; it revealed a unique panorama of the earth's geological history; and it held an enormous potential of natural resources for furthering the progress of a young nation. And it was as good a place as any to launch the career of a one–armed veteran, explorer, anthropologist, geologist, topographer, botanist, paleontologist, hydrologist, and entrepreneur of his own curiosity.

Today, the Colorado Plateau remains a remote region of undiscovered and forgotten places. Slightly more than a million people live in dozens of small communities which are concentrated along the Colorado River and its tributaries. Overall, its population density is about seven persons per square mile, about one–tenth that of the rest of the nation.

The Plateau's traditional economic base has been ranching and mining and to a lesser extent farming and logging. But by 1980, fewer than one in ten jobs was in agriculture (including ranching), forestry, and mining. One–quarter of the region's residents are employed in services related to tourism, recreation, and retirement. The second leading employment sector is government, where one in five residents was working in 1987. About 15 percent of land on the Colorado Plateau is privately owned. Although the proportion of private land is relatively small, the Plateau's sparse population makes the amount of privately owned acres per resident considerably higher than in much more populous

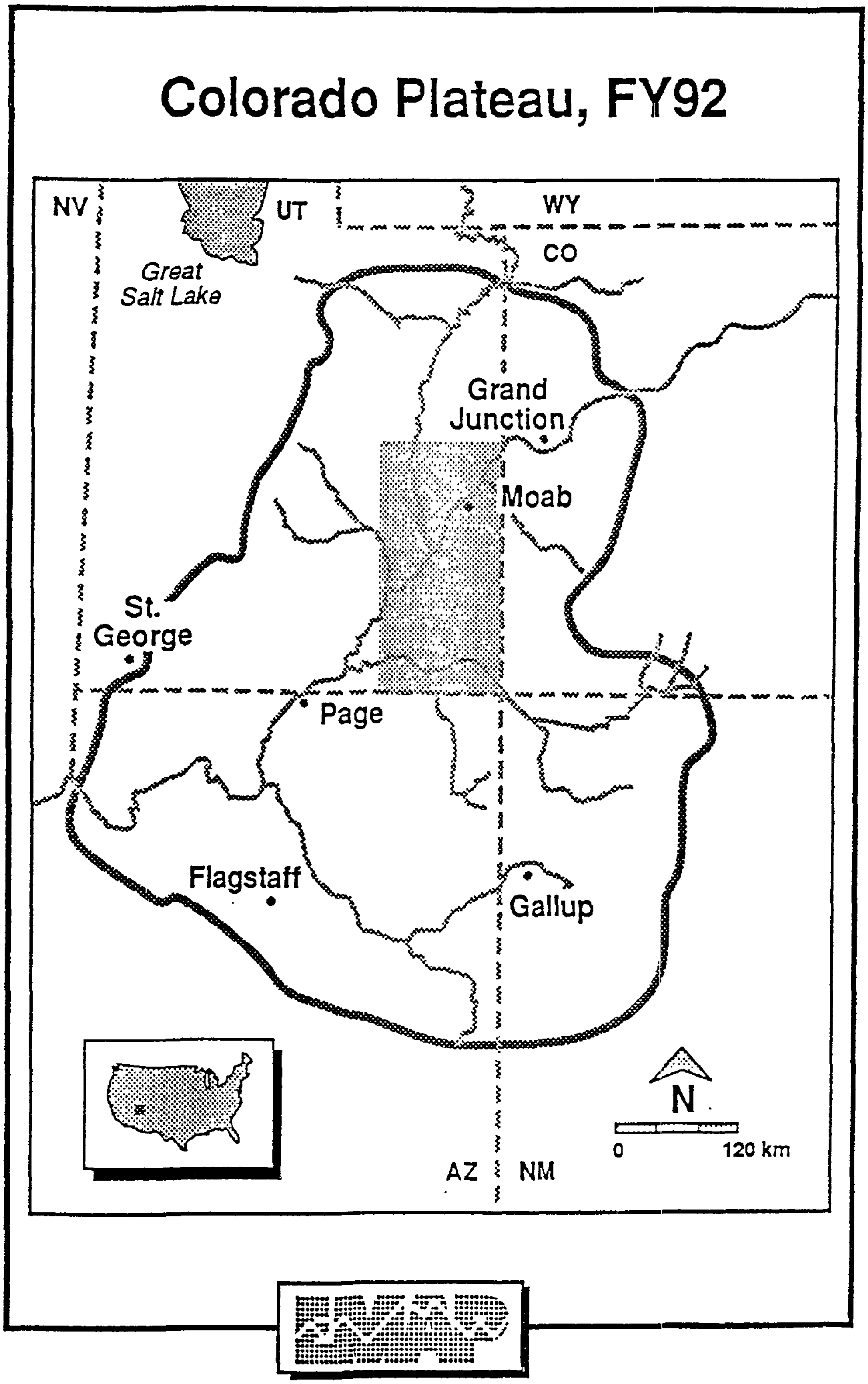


Figure 3–2. Map of the Colorado Plateau.

regions. For example, California's amount of private land per person averages 2.1 acres, while the Plateau's average is 16.9 acres.

Approximately 85 percent of the Colorado Plateau is under some form of government jurisdiction. State lands comprise six percent of the land. The Bureau of Land Management has jurisdiction over 29 percent of the Colorado Plateau; Indian tribal lands encompass 23 percent; and the U.S. Forest Service is responsible for 22 percent.

The National Park Service manages a mere four percent of the Colorado Plateau and yet its 26 units attract over 30 million visitors each year. As is generally the case in these rugged landscapes, park visitors are concentrated onto less than five percent of the land. Consequently, most of the lands of the Colorado Plateau remain relatively unchanged by direct human contact.

Nonetheless, direct and indirect impacts of human activities are widespread and increasing. The National Park Service has concluded that in all Plateau parks, haze from distant cities and nearby coal–fired generating stations reduces visibility during part of the year. NPS has also measured biological impacts from air pollution in some of its remote sampling sites. One indicator of the pervasive nature of domestic livestock on the Colorado Plateau was provided when The Nature Conservancy could only find a few relic areas in all of Utah that had not been grazed by cattle or sheep. Similarly, archaeological surveys of remote sites in Glen Canyon National Recreation Area have documented extensive livestock use and damage to prehistoric dwellings and artifacts.

Signs of human–induced change are most evident along the rivers of the Colorado Plateau. Dams, reservoirs, and diversions have eliminated most of its native aquatic and riparian habitat. Salinity in the Colorado River has increased as the result of upstream mining and farming, and riparian habitat along the Colorado River in the Grand Canyon has been completely altered by Glen Canyon Dam. Its reservoir, Lake Powell, has become a trap for selenium, mercury, and other trace elements which have been found in bioassays of introduced striped bass. Tamarisk, camelthorn, Russian olive and thistle, and many other introduced species now dominate the Plateau's riparian corridors. While the list of alarming stories goes on, it is important to recognize that for all of the insults, the Plateau has endured. And for all of its timeless and seemingly changeless beauty, evidence of change is everywhere.

Despite its aridity, water is the primary force of change on the Colorado Plateau. One reason is that most of the annual precipitation can occur during a single event. During the late summer when moisture from the south accumulates into massive afternoon thunderheads, periods of intense rainfall are scattered across the Plateau. In areas characterized by thin soils and barren rocks, runoff from these high intensity storms is quickly channeled into raging floods. Rockfalls, erosion, fresh sediments, and other signs of major and frequent flooding are ubiquitous.

The geology of the Colorado Plateau reveals that erosion and deposition have been shaping its landscape for hundreds of millions of years. The Plateau contains the most voluminous, areally extensive, and continuous series of continental sediments in the world. These sandstones, mudstones, and shales are the remnants of glaciers, streams, lakes, marshes, mud flats, and dunes. Interspersed among the deeper continental sediments are thick layers of marine limestones which date back over a billion years.

The Plateau's geology also reveals a dramatic history of climatic and ecological change. Even in recent times where evidence has not had time to become fully fossilized, researchers have documented that a cooler and much wetter climate supported quite a different array of flora and fauna than is found there today. Prior to 11,000 years ago, mammoths, musk oxen, ground sloths, and tapirs lived on the lush plant life of the Colorado Plateau. Sixty–five million years before that, the region hosted the demise of the great dinosaurs and the disappearance of now petrified forests.

The Plateau has a varying climate based upon elevation. In general, rainfall is low (<50 cm/yr), with averages around 25 cm/yr. Most precipitation falls between October and April as snow or rain. Due to high summer temperatures, evaporation usually exceeds precipitation on an annual average. Temperatures range from below 0°C in the winter to over 50°C (122°F) in the summer. The warmest month is July with maximum temperatures in excess of 50°C (USDA Soil Surveys, 1980a).

Soil is the most widely used natural resource on the Plateau. Soils on the Plateau vary widely in their characteristics. Soils on strath terraces, alluvial fans, glacial outwash fans, moraines, and talus slopes have a high content of rock fragments. The soils that formed in aeolian (wind) deposits, alluvium (water) derived from sedimentary rock, and shale landslide material have few rock fragments. The soils formed in recent aeolian deposits commonly are sandy loam, loamy sand, or sand, while soils formed from shale material are clay loam or clay. Deep soils are on mountainsides, alluvial fans, valley fills, and gently sloping mesas, benches, and cuesta dip slopes. Shallow soils and exposed sandstone are on escarpments, rims, desert benches, and sloping to moderately steep dip slopes of anticlines and synclines (USDA Soil Survey, 1970, 1980a, 1980b).

The Colorado Plateau is a landscape of topographic and climatic extremes where ecological and geological change are constant. While geologists have discovered many of its secrets during more than a century of investigation, we know relatively little about the ecology of the region. In contrast to the Plateau's hot desert neighbors to the south, not much is known about what lives there or how it lives. And despite abundant evidence of change, we have no long–term programs to monitor or to understand processes of ecological change on the Colorado Plateau.

The dynamic tapestry of life on the Plateau remains an enigma. Partly due to its isolation and protective topography, one of America's most desolate and remarkable places may hold a rich repository of ecological information about living under extreme conditions. This project launches a new expedition into what Major Powell called "the great unknown."

## 3.3 LOCATION OF THE 1992 COLORADO PLATEAU PILOT STUDY

The Colorado Plateau as described above will be the site of a demonstration study in 1993. However, the entire region of 130,000 square miles is much more extensive than needed to fulfill the requirements of the intended indicator evaluation pilot. Thus, a small portion of the Plateau was chosen.

The study area for the 1992 indicator evaluation pilot activity lies between 37° and 39° North latitude and between 109° and 111° West longitude. Figure 3–3 shows the location of the EMAP–Arid grid points on this area, superimposed on a map of rivers and major roads. The land ownership status of each sampling point is also indicated. (Data on the land status/ownership of Utah was provided by the Utah State University Fish and Wildlife Cooperative Research Unit of the US Fish and Wildlife Service GAP program.)

In this region are federal lands (i.e., BLM, NPS, and FS), part of the Navajo Nation, state lands, and private lands. This diversity of ownership and jurisdiction will allow the pilot to be interagency in its implementation. The area is bisected by the Colorado River and includes many canyon lands that will allow for evaluation of logistical requirements in some of the most difficult terrain that EMAP–Arid will face. The area includes both Great Basin Desertscrub and Great Basin Conifer Woodlands, the two formation types chosen for indicator evaluation.

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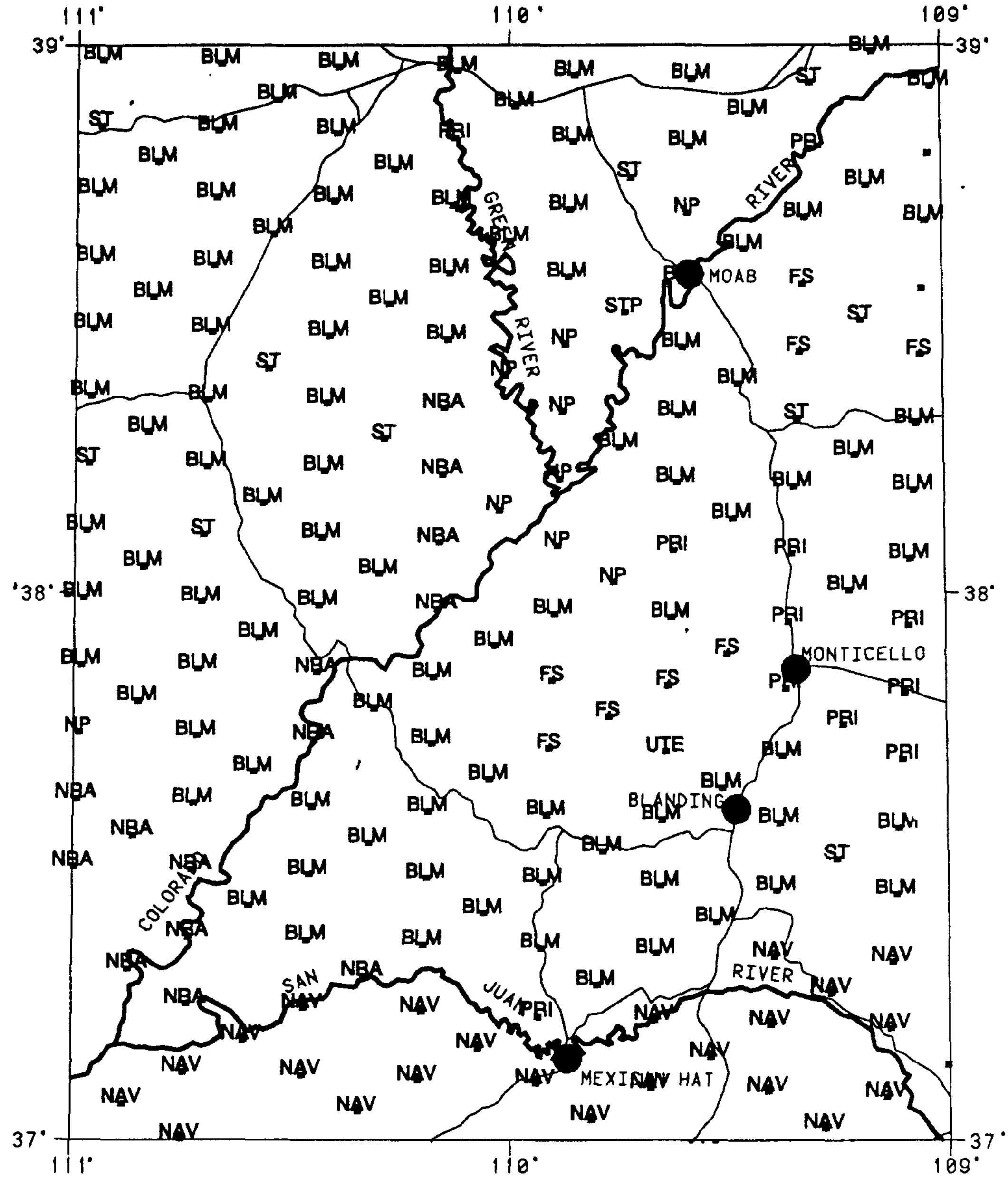


# FIGURE 3-3
## POTENTIAL LOCATIONS OF EMAP-ARID SAMPLING POINTS
### FOR 1992 PILOT STUDY
## DRAFT

RIVERS
MAJOR ROADS
TOWNS
SAMPLE POINT LOCATIONS

BLM - BUREAU OF LAND MANAGEMENT
FS - FOREST SERVICE
NAV - NAVAHO INDIAN RESERVATION
NP - NATIONAL PARK
NRA - NATIONAL RECREATION AREA
PRI - PRIVATE
ST - STATE
UTE - UTE INDIAN RESERVATION

DATA SOURCES: USGS
EPA - CORVALLIS
UTAH STATE UNIVERSITY

N

0 18 36
SCALE IN KILOMETERS

EMAP

PRODUCED FOR EMAP - ARID BY THE LABORATORY FOR SPATIAL ANALYSIS, DESERT RESEARCH INSTITUTE, RENO, NEVADA.

DATE: July, 1992

# 4.0 DESIGN

**(Susan E. Franson)**

## 4.1 EMAP DESIGN OVERVIEW

The EMAP design has been described in detail elsewhere (Overton et al., 1990; Kepner and Fox, 1991; White et al., 1992), but a brief summary follows.

The objectives of EMAP require a design with the following criteria:

- Consistent representation of environmental reality by use of probability samples.
- Representation of all ecological resources and environmental entities.
- Sufficient flexibility to accommodate post–aggregation for many alternative subpopulations.
- Provision for the capacity to respond quickly to a new question or issue.
- Spatial distribution of the sample of any resource according to population distribution of the resource.
- Periodic revisiting of all sampling sites.

In order to meet these criteria, EMAP has adopted a sampling design based on a random systematic triangular grid. The base density of this grid has about 12,200 points, with neighboring points separated by 27.1 km, over the conterminous United States. Each grid point is the center of a hexagon that is 40 sq km in area. The 12,200 hexagons represent a one–sixteenth sample of the area of the conterminous United States.

The 40 sq km hexagons provide the first stage in a double sampling approach. Information about the land cover within these hexagons is used to structure the field sampling, or second stage, conducted by each Resource Group. Thus, every sample is from an equal support base.

The geometry of the triangular grid allows changing of the density of sampling points to meet particular needs. For example, for rare or locally abundant resources, the grid density may need to be enhanced to provide for an adequate sample size for estimation. The triangular grid density can be enhanced by factors of 3, 4, 7, or multiples of these numbers. Similarly, the density of the grid may need to be reduced for some purposes. In particular, the dual objectives of estimation of both current status and long–term trends lead to the sampling of one–fourth of the base grid points each year. This sampling can still occur on a triangular grid, so that status estimates for the entire United States can be made each year, and each site is revisited after four years, so that trends can be determined.

## 4.2 EMAP–ARID DESIGN OVERVIEW

### 4.2.1 EMAP–Arid Population and Subpopulations

The first step in developing a sampling design is to identify the population of interest. The EMAP–Arid population was defined in Section 1.2 as follows:

*Definition of Arid Ecosystems*

Terrestrial systems characterized by:

1. Potential evapotranspiration exceeds precipitation.
2. Annual precipitation ranges from <5 to 60 cm.
3. Air temperatures range from –40 to 50° C.
4. Vegetation
    - Dominated by woody perennials, graminoids, succulents, and drought–resistant trees
    - Low–form physiognomy, open canopies
    - Includes riparian communities
    - Excludes intensively managed agriculture

Within the population of arid systems, several subpopulations are of interest. These subpopulations are defined to be the following formation types:

*EMAP–Arid Formation Types (adapted from Brown et al., 1979)*

| | |
|---|---|
| Desertscrub | Riparian Forest |
| Grassland | Riparian Scrub |
| Scrubland | Strandland |
| Woodland | |
| Tundra | |

While each of these formation types represents a subpopulation of interest to EMAP–Arid, other subpopulations can be defined, such as pinyon–juniper woodlands of the Mojave. These other subpopulations will be defined as the EMAP–Arid program evolves.

The upland formation types on the left (except for tundra) are extensive resources. Simulation studies for the Southwest have determined that adequate sample sizes for estimation of these subpopulations will result from the base density of the grid applied to arid ecosystems, without further delimitation of these at the frame development stage.

The lowland formation types, the riparian and strandland systems and tundra (at least in the alpine tundra of the conterminous U.S.) and riparian communities represent subpopulations that should be included as primary resources. Primary resources need to be explicitly defined for frame development and may require an enhancement of the grid to ensure that adequate sample sizes are obtained for estimation. It is possible that the lowland formation types could be combined into one primary resource with the three formation types representing subpopulations of that lowland primary resource.

This separation of subpopulations versus primary resources has been confirmed on a preliminary basis by overlaying the EMAP base grid on the Brown and Lowe Biotic Communities map of the Southwest. Whether the primary resource of lowland formations and tundra will yield sufficient samples for those subpopulations is yet to be determined.

Riparian systems and strandland represent elongate resources, while alpine tundra is a discrete resource. Frame materials, sampling design, and plot design for these special resources represent continuing challenges yet to be solved by the EMAP–Arid team. Other Resource Groups, primarily the Surface Water group, share some of these challenges with elongate and discrete resources. EMAP– Arid continues to interact with the other Resource Groups and the Design and Statistics team to find solutions to these challenges.

### 4.2.2 EMAP–Arid Frame and Extent Estimation

For its extensive resources, EMAP–Arid will rely on the EMAP grid, locating sampling points with respect to the grid center points by a pre–determined rule. For implementation, it is doubtful that the exact center will be used. Using the exact center point would result in generally known locations for all sample points. For reasons that are beyond the scope of this Implementation Plan, it may be beneficial to randomly offset sampling points from the grid center. This could be done by using the Forest Inventory Analysis (FIA) photo point closest to the center of the hexagon, or using some other rule. These options are being examined.

EMAP–Arid expects to use the vegetation mapping data available through collaboration with the GAP program of the Fish and Wildlife Service for extent estimation. The feasibility and methods for so doing will be a part of this pilot investigation.

## 4.3 EMAP–ARID PILOT STUDY SUBPOPULATION AND DESIGN

### 4.3.1 Pilot Study Subpopulations

The goal of the pilot is to obtain information about indicators. EMAP–Arid has chosen to test its indicators in two of its subpopulations, desertscrub and woodland. Limiting the pilot to these two formation types will allow evaluation of indicator performance in two diverse systems while maintaining an adequate sample size in each. These subpopulations are represented on the Colorado Plateau by Great Basin Desertscrub and Great Basin Conifer Woodland.

### 4.3.2 Great Basin Desertscrub (adapted from Brown et al., 1979)

Great Basin Desertscrub is characterized by low, widely spaced hemispherical shrubs. The major plant dominants are sagebrushes (*Artemisia*), saltbushes (*Atriplex*), and winterfat (*Ceratoides lanata*). These are joined in varying degrees by Rabbitbrush

(*Chrysothamnus*), Blackbrush (*Coleogyne*), Hopsage (*Grayia*), and Horsebrush (*Tetradymia*). The major series within the Great Basin Desertscrub biome are those dominated by various species of Sagebrush (*Artemisia*), Shadscale (*Atriplex confertifolia*), Blackbrush (*Coleogyne ramosissima*), Winterfat (*Ceratoides lanata*), Greasewood (*Sarcobatus vermeiculatus*), or Rabbitbrush (*Chrysothamnus*).

These principal scrub species are much–branched, non–sprouting, aromatic semishrubs with soft wood and evergreen leaves. These shrubs are mostly without spines. There are few cacti — either in numbers of individuals or species. Those present tend to be of short stature or prostrate and include a few chollas (*Opuntia whipplei, O. pulchella*), prickly pears (*Opuntia polyacantha, O. gracilis, O. erinacea*), and hedgehog cacti (*Echinocereus triglochidiatus* var. *melanacanthus, E. fendleri* var. *fendleri*). Small cacti (*Pediocactus, Sclerocactus*) and *Echinocactus polycephalus* var. *xeranthemoides* occur in more southern locales.

Species diversity is characteristically low in all major communities of this biome, with a dominant shrub occurring to the virtual exclusion of other woody species. Another feature setting this desert apart from others of the region is the absence of characteristic desert plants in minor waterways; nor is there a fringe of more closely spaced upland plants along these habitats of slightly more favorable moisture conditions. There are, however, both cosmopolitan and characteristic plants along flood plains of the larger waterways: included here are Greasewood (*Sarcobatus vermiculatus*), Four–wing Saltbush (*Atriplex canescens*), and New Mexican Forestiera (*Forestiera neomexicana*). The introduced Russian Olive (*Elaeagnus angustifolia*), and in the warmer regions Saltcedar (*Tamarix chinensis*), may be present along wetland stream channels.

Sagebrush Series – usually have Big Sagebrush (*Artemisia tridentata* var. *tridentata*), Bigelow Sagebrush (*A. bigelovii*), or Black Sagebrush (*A. arbuscula* ssp. *nova*) as dominants, although any of 18 other closely related taxa of *Artemisia* may be dominant.

Sagebrush communities are regarded by many as steppe or shrub steppe because of the usual importance of grasses.

Shadscale Series – has Shadscale (*Atriplex confertifolia*) as dominant. The general appearance of this community is one of open starkness with the dominant woody plants attaining heights of only 0.3 to 0.6 m. Although widely scattered, perennial grasses are commonly found in the Shadscale community.

Blackbrush Series – has Blackbrush (*Coleogyne ramosissima*) as dominant. Perennial grasses are commonly prevalent in unburned stands.

Other Series – several additional communities may be found within the Great Basin Desertscrub biome. These may have as dominants: Sand Sagebrush (*Artemisia filifolia*), Greasewood (*Sarcobatus vermiculatus*), Four–wing Saltbush (*Atriplex canescens*), Fivehook Bassia (*Bassia hyssopifolia*), Inland Saltgrass (*Distichlis spicata* var. *stricta*), Common Russian Thistle (*Salsola kali*), seepweeds (*Suaeda* spp.), or Winterfat (*Ceratoides lanata*).

### 4.3.3 Great Basin Conifer Woodland (adapted from Brown et al., 1979)

This cold–adapted evergreen woodland is characterized by the unequal dominance of two conifers — juniper (*Juniperus*) and pinyon (*Pinus*). These trees rarely, if ever, exceed 12 m in height and are typically openly spaced (woodland), except at higher elevations and other less xeric sites where interlocking crowns may present a closed (forest) aspect. The shorter, bushier junipers ("cedars") are generally more prevalent than pinyons, but either may occur as an essentially pure stand. Structurally, these juniper–pinyon woodlands are among the simplest communities in the Southwest.

Several species of juniper may assume or share dominance in the Southwest. These include Rocky Mountain Juniper (*Juniperus scopulorum*), Utah Juniper (*J. osteosperma*), and One–seed Juniper (*J. monosperma*). Rocky Mountain Pinyon (*Pinus edulis*) is the common pinyon almost throughout, although west of longitude 113.5 it is largely replaced by the single needled form (*P. monophylla*) or the Four–leaved Pinyon (*P. quadrifolia*). Not included as Great Basin Conifer Woodland species are Alligator–bark Juniper and Mexican Pinyon.

The understory typically is composed of grasses (e.g., *Bouteloua gracilis*) and shrubs, e.g., Threadleaf Groundsel (*Senecio longilobus*) and Snakeweed (*Gutierrezia sarothrae*). Also well represented in many of these grass understories are Galleta Grass (*Hilaria jamesii*), Indian Ricegrass (*Oryzopsis hymenoides*), and Western Wheatgrass (*Agropyron smithii*). Other grasses include several muhleys (*Muhlenbergia* spp.), dropseeds (*Sporobolus* spp.), and Junegrass (*Koeleria cristata*).

### 4.3.4 Pilot Study Design

From the above descriptions, it may seem that the decision about which formation type a site lies within is somewhat subjective. One of the questions that the pilot will address is the frequency of sites crossing a boundary between vegetation types. Thus, the pilot will, in part, test whether these descriptions are sufficient to unambiguously define the subpopulations. In addition, EMAP–Arid is exploring the development of a dichotomous key for use in on–ground identification of formation types.

The area of the pilot is restricted to approximately the area bounded by 37 to 39 degrees North latitude and 109 to 111 degrees West longitude (see Figure 3–3). To locate the points for pilot testing of the indicators in this area, the base grid was enhanced by a factor of four, then every fourth point was chosen. This has the same effect as locating the sampling points one–half the distance to the nearest point to the northeast. This strategy of point location allows the triangular grid to be maintained, but does not compromise the sampling points that will be used for implementation.

Forty points lie within this area, which was selected to achieve approximately 20 sites each of Great Basin Desertscrub and Great Basin Conifer Woodland. Each of the 40 chosen points will be visited. If the sample site falls within either Great Basin Desertscrub or Great Basin Conifer Woodland, sampling will proceed. If the sample site falls into some other subpopulation, it will not be sampled. It is expected that sampling will occur on approximately 30 sites, with about 15 in each subpopulation.

## 4.4 PLOT DESIGN FOR MEASURING INDICATORS

The sample plot consists of specific plot designs for each indicator overlaid on one another resulting in a hexagon shaped plot (Figure 4–1). This plot design resembles that being used by the Forest Health Monitoring Program (Kucera and Martin, 1991) with additional features and modifications to accommodate arid ecosystems. Greater details of the sampling procedures are found within the sections for the specific indicators and in the Protocols of the Field Operations and Training Manual. However, general information on the plot design is provided here to orient the reader for the upcoming sections and to present the sampling of all indicators as a part of an overall design.

Figure 4–1 shows a central circular subplot, MD, centered on each designated EMAP–Arid sampling point. Six satellite subplots are located with their centers 40 m from the center point and oriented at 0, 60, 120, 180, 240, and 360 degrees relative to compass North. Each of these circular subplots is 7 m in radius, with an area of 154 sq m. Radial transects, AR, BR, and CR, extend from the center point to the centers of subplots A1, A2, and A3, respectively. Exterior transects, AE, BE, and CE, extend between centers of subplots A1 and A2, B1 and B2, and C1 and C2, respectively. Soil sampling locations are at AP, BP, and CP, each 20 m from the associated subplot center point.

Shrubs and trees greater than 1.5 m in height within subplots MD, A1, B1, and C1 will be identified and measured as a part of the vegetation composition, structure, and abundance indicator.

The vegetation composition, structure, and abundance of shrubs less than 1.5 m in height will be measured in 1 m x 2 m quadrats, aligned with their long axis parallel to each of the six transects. The quadrats along each transect are separated by 1 m intervals, with 12 quadrats sampled along each of 6 transects, for a total of 72 quadrats sampled on the

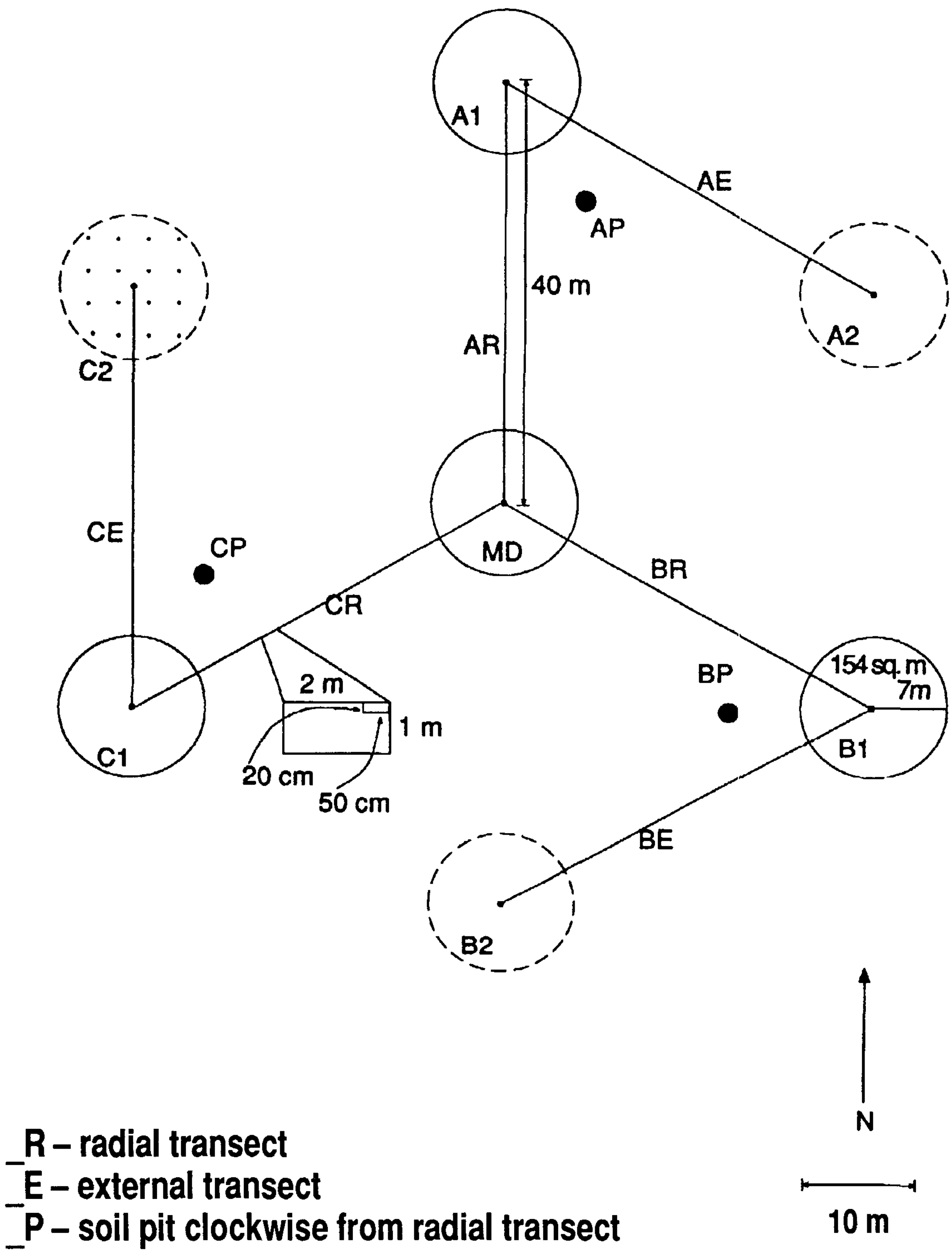


Figure 4–1. EMAP–Arid Sample Plot Design.

plot. Within each of the 1 m x 2 m quadrats is a 20 cm x 50 cm subquadrat that will be evaluated to determine the vegetation composition, structure, and abundance of forb and grass ground cover, and surface soil attributes.

Three soil sampling areas are located at AP, BP, and CP. At one of these areas, a soil pit will be dug to evaluate characteristics of the soil profile and to collect soil samples to be sent to the laboratory for analysis of physical and chemical properties. At the two remaining areas, soil will be described to 50 cm, augered and described below this depth to 1.5 m or bedrock, and samples collected from the top two horizons and sent to the laboratory for analysis. The above approach will be used at half of the study plots. At the other half, all three soil areas will have surface soils described to a depth of 50 cm, augered and described below this depth to 1.5 m or bedrock and samples collected from the top two horizons. The study plots for complete soil profile determination were randomly chosen from the 40 available sites.

Information on spectral properties will be measured on half of the 40 sites. Measurements will be made within each of the seven circular subplots on a grid centered on the subplot center. The grid illustrated for subplot C2 is a square of 4 x 4 points with vertical and horizontal spacing between sampling points of 3 m. In addition, 3 spectral measurements will be made evenly spaced in the 1 m x 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" (Figure 4–2). 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 sq m or a hexagon with 60 m from the center to each vertex, with an area of 9350 sq m. This is an important conceptualization, especially for the spectral properties indicator. TM pixels are 30 m on a side, so that a 3 x 3 cluster of pixels represents 8100 sq m and a 4 x 4 pixel cluster covers 14,400 sq m. Thus,

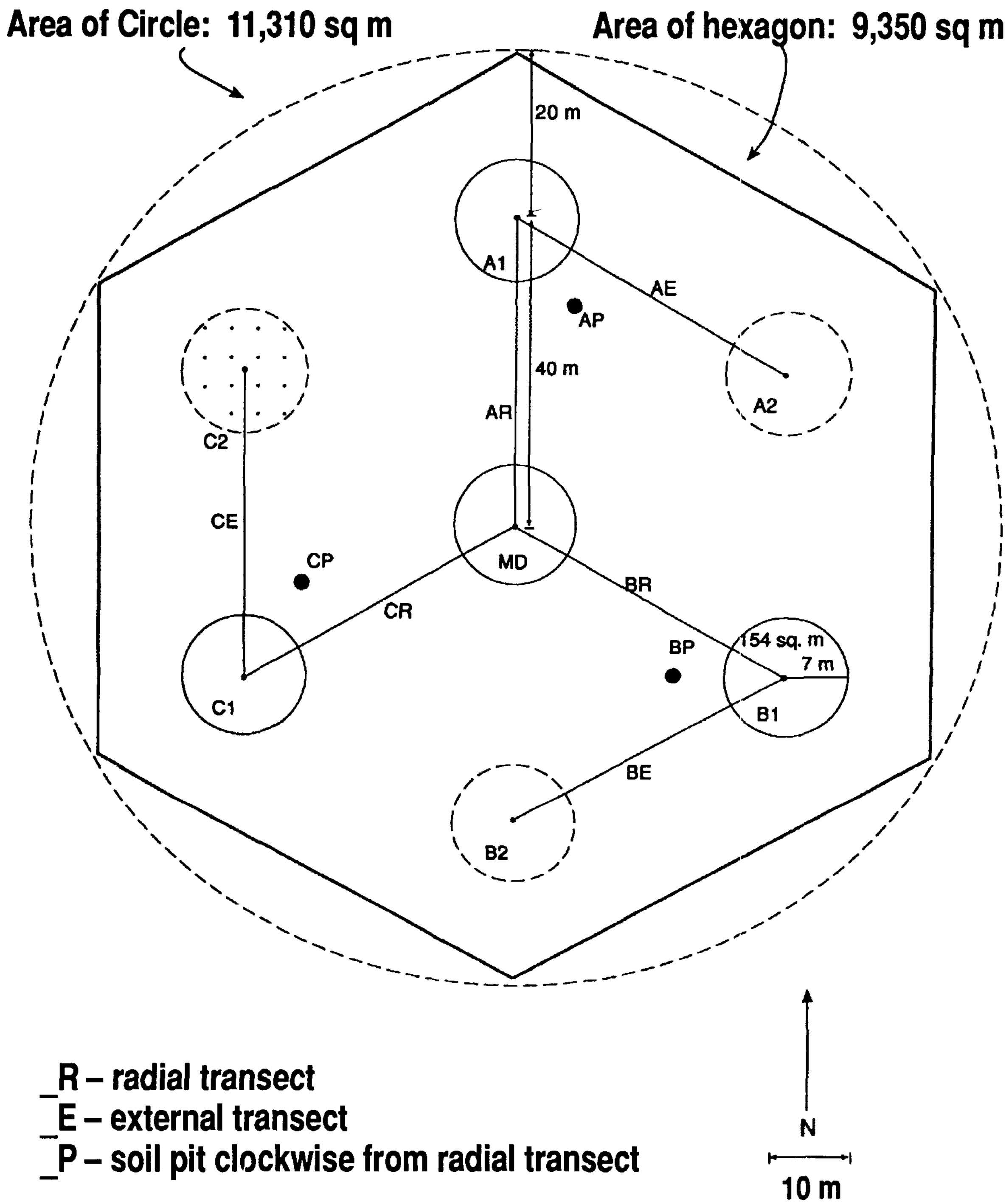


Figure 4–2. EMAP–Arid Sample Plot Conceptual Hectare.

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 allows for estimation of the sampling design components variance for each indicator, to be discussed in greater detail in Section 9, Analysis and Reporting.

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# 5.0 INDICATORS

## 5.1 INTRODUCTION

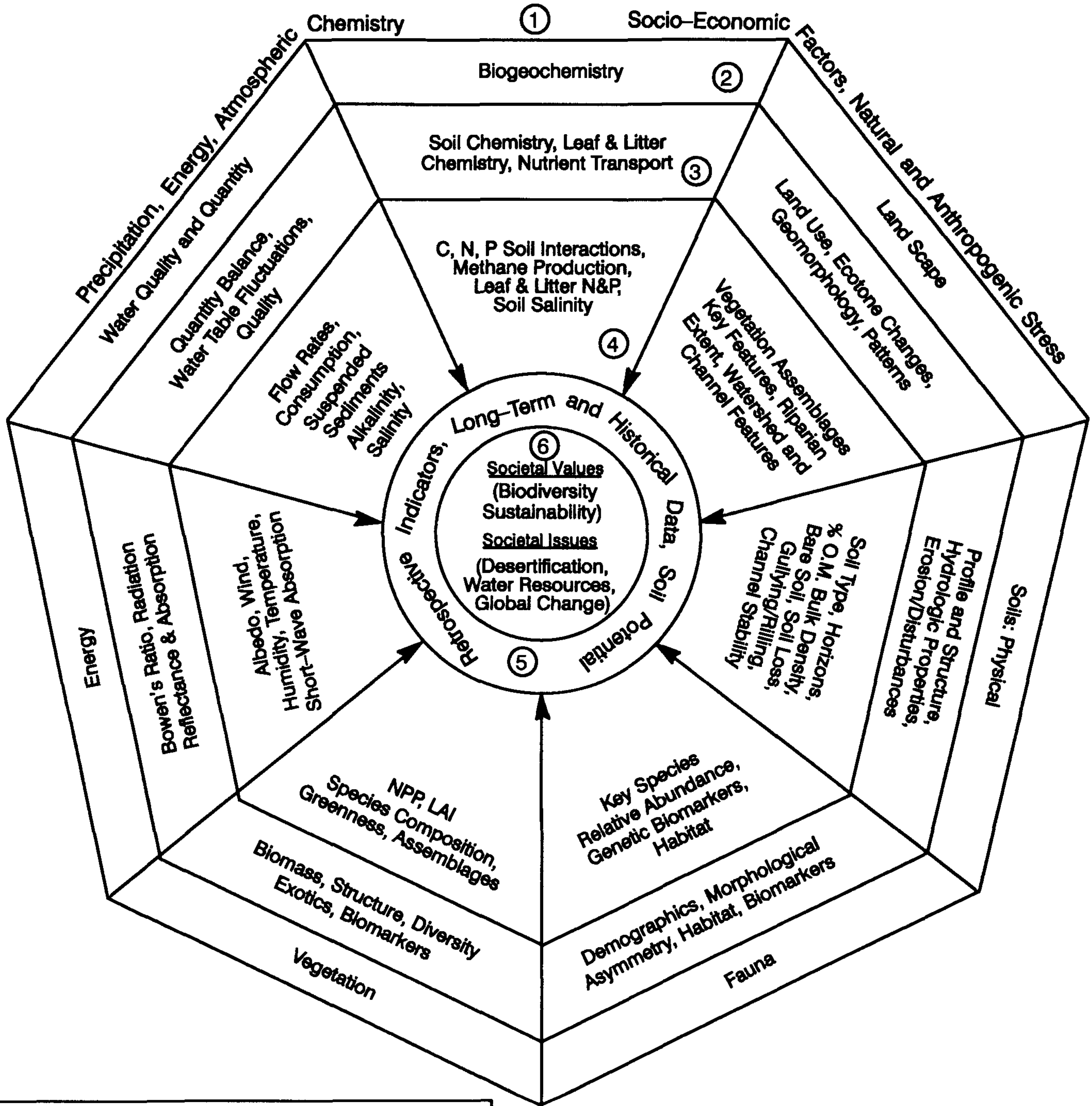
**(Robert P. Breckenridge)**

The following section discusses the relationship of indicators to the EMAP–Arid assessment endpoints and societal values. A conceptual approach (Figure 5–1) was used to identify the links between external components, stressors on ecological processes, and retrospective and existing data relative to making statements about the sustainability, biodiversity, and aesthetics of arid ecosystems. The EMAP–Arid Strategic Plan identified seven groups of indicators (Kepner and Fox, 1991). These groups were further evaluated by a group of arid ecosystem scientists at a workshop in Logan, Utah (October 28–30, 1991) to identify specific measurements and address peer review comments (related to focusing the indicator effort) from the Strategic Plan. Nine groups of indicators were evaluated at the Logan workshop. However, because of budgetary constraints, only a subset of indicators could be selected for testing in the pilot. All the indicator groups are discussed in this section so the reader can appreciate the scope of what is being considered by EMAP–Arid. However, only those being tested in the pilot will be discussed in detail.

### 5.1.1 Assessment Endpoints and Indicators

EMAP–Arid has identified three societal values that are of prime importance in determining the condition of arid ecosystems. These societal values are discussed in Section 1.0 (Figure 1–3) and include: 1) sustainability; 2) biodiversity; and 3) aesthetics. Societal values are difficult to measure directly; thus, a set of assessment endpoints associated with the various societal values has been selected.

The assessment endpoints are quantitative or quantifiable expressions of the environmental value considered in an analysis (Suter, 1990). Eight assessment endpoints have been identified for possible use in the EMAP–Arid monitoring program (Table 5–1).




Index of layer categories for Figure 5–1.

1 – External Driver Components
2 – Broad Resource Indicator Classes
3 – Major Indicator Components and Processes
4 – Measure Parameters to Assess Resource Status
5 – Resource Trend Analyses
6 – Ecological Risk Assessment

Figure 5–1. EMAP–Arid Conceptual Model. The model blends ecological modeling with the EMAP assessment strategy. To move through the model, start with the external components (layer 1) of atmospheric, stressors, and socio–economic factors, which drive the arid terrestrial system. The indicator classes (layer 2) respond to these drivers, and interact with each other via major indicator components (layer 3). Layer (4) holds examples of actual measurement parameters that reflect indicator components. These measurements are used to assess resource status. The current resource status is then put into a trend perspective (layer 5) by coupling to retrospective indicators, long–term historical data and soil potential. Ultimately, resource status and trend data are integrated into an ecological risk assessment (layer 6), to assess arid issues and endpoints.

These were identified through a series of workshops and peer reviews involving EMAP–Arid team members, the academic community, and various Federal resource agencies (Kepner and Fox, 1991).

TABLE 5–1. ASSOCIATION BETWEEN EMAP–ARID ASSESSMENT ENDPOINTS AND SOCIETAL VALUES

| | SOCIETAL VALUES | | |
|---|---|---|---|
| ASSESSMENT ENDPOINTS | SUSTAINABILITY | BIODIVERSITY | AESTHETICS |
| Assessment conducted to measure change in | | | |
| 1. Net Primary Productivity | X | X | |
| 2. Species composition and abundance | X | X | X |
| 3. Soil quality | X | X | X |
| 4. Landscape patterns/land use | X | X | X |
| 5. Community structures | X | X | |
| 6. Surface water quality | X | X | X |
| 7. Surface and subsurface water quantity | X | X | X |
| 8. Socio–economic factors | X | | X |

Indicators are characteristics of the environment that, when measured, quantify magnitude of stress, habitat characteristics, degree of exposure to stressors, or the degree of ecological response to an exposure (Hunsaker and Carpenter, 1990). Indicators serve as the basis for quantification of the assessment endpoints (i.e., the actual measurements to be made). For example, water holding capacity, bulk density, and surface soil morphological types are indicators that serve to quantify the assessment endpoint of soil quality. A decrease in water holding capacity, decrease in bulk density, and shift in soil morphological types (e.g., from Types I and II, litter, vegetation, and cryptogamic crusts, to Types III and IV, compacted desert pavement) (Eckert et al, 1986) could indicate a marked decrease in the soil quality assessment endpoint and suggest poorer societal values related to sustainability (desertification) and biodiversity. The associations of various candidate indicators to the assessment endpoints are identified in Table 5–2.

TABLE 5–2. ASSOCIATION OF INDICATORS AND THEIR TYPES WITH ASSESSMENT ENDPOINTS

| Assessment Endpoint | Indicator | Type of Indicator | Measurement Category | Status for Pilot |
|---|---|---|---|---|
| 1. Change in net primary productivity | Spectral reflectance – NDVI | Response | Synoptic/ sample | Included |
| | Biomass | Response | Sample | |
| | C:N:P ratio in plant tissue | Exposure | Sample | |
| | Energy balance using Bowen ratio | Response | Synoptic/ sample | |
| | Dendrochronology | Response | Sample | Possible inclusion |
| 2. Change in species composition and abundance | Breeding Bird Census | Response | Sample | |
| | Abundance of field mice | Response | Sample | |
| | Abundance and distribution of ground beetles | Response | Sample | |
| | Vegetation Composition and Abundance | Response | Sample | Included |
| 3. Change in Soil Quality | Bulk density | Exposure | Sample | Included |
| | Soil salinity – saturation extract electrical conductivity | Exposure | Sample | Included |
| | Extractable cations – Ca, Mg, Na, and K | Exposure | Sample | Included |
| | Extractable soil P | Exposure | Sample | Included |
| | C:N:P ratio in plant tissue | Exposure | Sample | |
| | Pedon description | Response | Sample | Included |
| | Water retention | Exposure | Sample | Included |
| | pH, carbonates, etc. (reaction) | Exposure | Sample | Included |
| | Sodium absorption ratio (SAR) | Exposure | Sample | Included |
| | Particle size analysis | Exposure | Sample | Included |
| | Surface soil roughness | Exposure | Sample | Included |
| | Surface soil cover | Exposure | Sample | Included |
| | Cryptogams/lichens | Response | Sample | Included |

Table 5–2. (continued).

| | | | | |
|---|---|---|---|---|
| | Soil erosion | Response | Sample | Possible inclusion |
| | Cation exchange capacity | Exposure | Sample | Included |
| | Water soluble anions $CO_3$, $HCO_3$, Cl, $SO_4$, and $NO_3$ | Exposure | Sample | Included |
| 4. Change in Landscape patterns/Land use | Habitat/cover type proportions | Habitat/ Stressor | Synoptic | |
| | Spatial distribution of agricultural and riparian vegetation per stream reach | Stressor/ Exposure | Synoptic | Possible inclusion |
| | Fractal dimension | Stressor/ Exposure | Synoptic | |
| | Abundance/density of key physical features | Stressor/ Exposure | Synoptic | |
| | Spatial distribution of grazing intensity | Habitat/ Response | Synoptic/ sample | |
| | Riparian condition | Response | Synoptic/ sample | |
| 5. Change in Community Structure | Vegetation composition | Response | Sample | Included |
| | Benthic macroinvertebrates assemblage | Response | Sample | |
| 6. Change in Surface Water Quality | pH | Exposure | Sample | |
| | Alkalinity | Exposure | Sample | Evaluate other agencies' data |
| | Conductivity | Exposure | Sample | Evaluate other agencies' data |
| | N, P, and organic carbon | Exposure | Sample | |
| | Toxins | Exposure | Sample | |
| | Benthic macroinvertebrates | Response | Sample | |
| 7. Surface and Subsurface Water Quantity | Annual Flow Duration Analysis | Response/ Stressor | Sample | Evaluate other agencies' data |
| | Mean Annual Discharge | Response/ Stressor | Sample | Evaluate other agencies' data |
| | Flood magnitude | Response/ Stressor | Sample | |
| | Low Flow Magnitude | Response/ Stressor | Sample | |
| | Ground water level | Response/ Stressor | Samples | Evaluate other agencies' data |
| 8. Change in Socio–economic factors | To be developed | | | |

EMAP has identified four types of indicators for determining ecological condition: response, exposure, habitat, and stressor. These categories have been provided as a guideline for use in the selection, evaluation, and development of the proposed indicators for EMAP–Arid.

- Response indicators are attributes that quantify the integrated response of ecological resources to individual or multiple stressors.

- Exposure indicators are physical, chemical, and biological attributes that can be used to suggest pollutant exposure and assist in the diagnosis of possible causes of stress.

- Habitat indicators are attributes that describe the condition of the environment. They are used to suggest whether alteration or disturbance of the physical habitat is the possible cause of poor condition in response indicators.

- Stressor indicators are economic, social, or engineering attributes that are used to identify the possible sources of environmental impairment or exposure to impact.

Table 5–2 lists candidate indicator measurements and their relative type proposed for the EMAP–Arid Pilot. Those indicators selected for the 1992 Colorado Plateau pilot are discussed in detail in Sections 5.2, 5.3, and 5.4. Two of the remaining candidate indicators, landscape and retrospective, are discussed in a general nature in Appendix A to provide the reader with a better understanding of where EMAP–Arid is headed under full implementation. Selection of indicators for the pilot is discussed in the following section.

### 5.1.2 Selection of Potential EMAP–Arid Indicators

EMAP has adopted a process to move indicators from the candidate to the core level (Figure 5–2). EMAP–Arid is at the initial stage of this process. At the recommendation of peer review comments on the EMAP–Arid Strategic Plan (Kepner and Fox, 1991), a workshop was held in Logan, Utah, to reduce the broad list of candidate indicators from the Strategic Plan to a more selected subset (e.g., what was going to be measured). As a

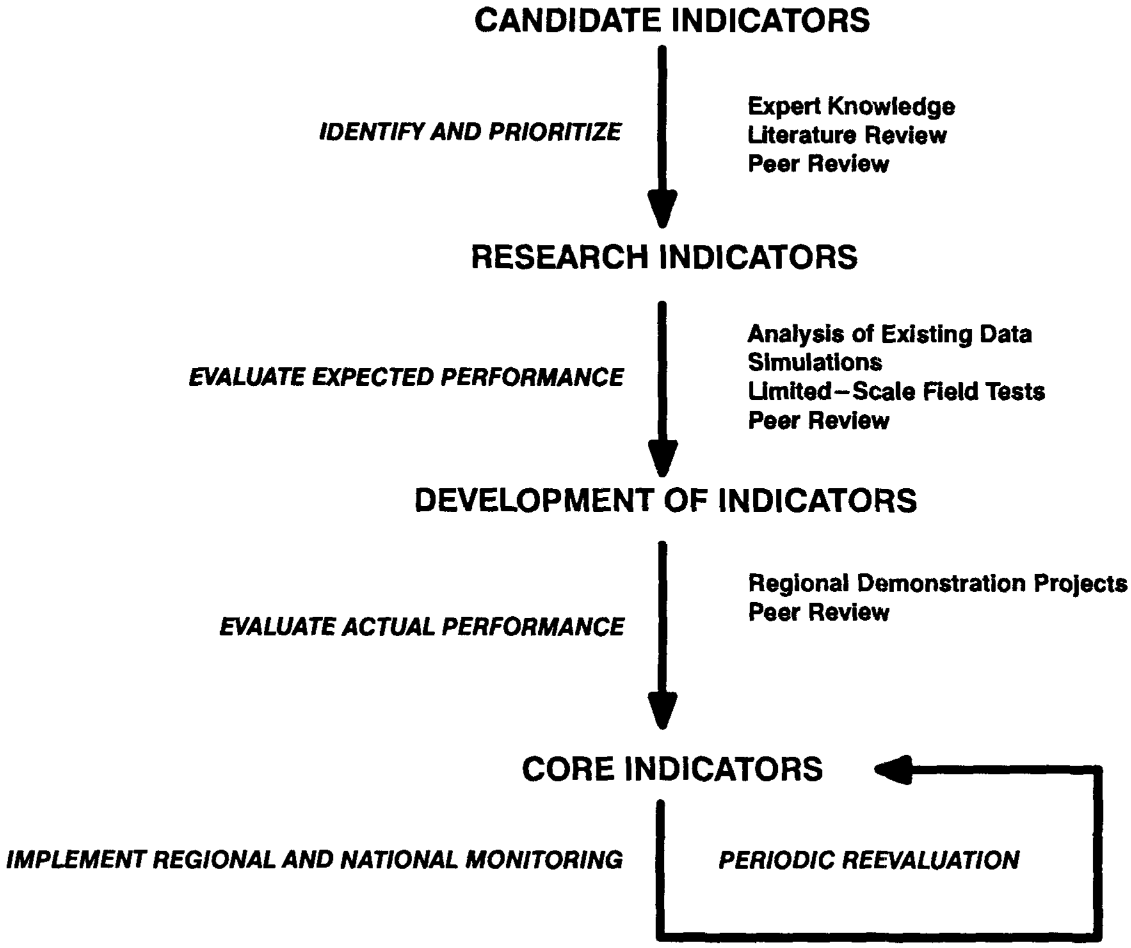



Figure 5–2. Indicator Selection, Prioritization, and Evaluation Approach for EMAP.

result of the workshop, the following indicator categories and specific indicators were recommended for consideration by EMAP–Arid.

1. Spectral Properties – including albedo and the Normalized Difference Vegetation Index (NDVI) – measured using spectral reflectance and verified with ground measurements.
2. Vegetation – composition and cover – including Leaf Area Index (LAI) as a measure of productivity.
3. Biogeochemistry – including C:N:P ratio, soil, litter, and vegetation samples.

4. Energy Balance – includes air temperature, monthly precipitation, Bowen's Ratio, and Palmer Drought Severity Index (PDSI) for assessing energy balance.
5. Landscape Patterns.
6. Water Quality – conductivity, N,P,K, organic carbon, alkalinity, and benthic macroinvertebrates.

   Water Quantity – water balance on watershed and ground water basin level.
7. Retrospective Index – developed using dendrochronology and PDSI records.
8. Fauna – including the Breeding Bird Census, ground beetle abundance and composition, and field mouse (*Peromyscus maniculatus*) abundance.
9. Erosion index – developed using soil loss values from wind and water loss equations.
10. Soil physical profile characterization – includes surface and soil profile description and physical properties.

### 5.1.3 Selection of 1992 Pilot Indicators

Because the 1992 pilot has several primary objectives (Section 2.2), a balance was required between the selection of indicators, available financial resources, and other aspects of the project. The indicator categories identified from the Logan EMAP–Arid Indicators Workshop were evaluated for inclusion in the 1992 pilot at a follow–up workshop (held in Las Vegas, November 19, 1991). The K–T analysis described in Section 3.1.2 was again used as a decision tool to allow workshop participants to come to a logical, documented decision as to the indicators which could be tested in the 1992 pilot.

A set of criteria was developed to guide the pilot indicator selection process. The criteria were separated into primary criteria that the proposed indicators must satisfy ("musts") and those the workshop participants wanted ("wants") the indicator to meet. A list of the "musts" and "wants" is presented in Table 5–3. The "must" criterion is a mandatory requirement to advance through the decision process. If a proposed indicator did not address the "must" criterion, then it would not be further considered. All proposed indicators addressed the "must" criterion.

The "wants" were then weighted according to their relative importance in meeting the pilot objectives (see Section 2.2). The most important was given a weight of 13. All others were then weighted in comparison to the first, from 13 (equally important) down to a possible 1 (not very important). The weighting scale was used to make visible the relationships among "wants" (i.e., what mattered most and what could be done without, if necessary). The mean weight and standard deviations from 12 participants at the Las Vegas workshop are presented in Table 5–3.

TABLE 5–3. LIST OF "MUSTS" AND "WANTS" FOR SELECTION OF CANDIDATE INDICATORS FOR 1992 EMAP–ARID PILOT. WEIGHTS ON "WANTS" ARE MEANS AND (STANDARD DEVIATION) FROM N=12.

MUSTS

1. Address the issue of sustainability (focus on desertification and/or climate change) in arid systems

WANTS

1. Applies to a broad range of biogeographic provinces, BLP formation types, and ecotones; 11.17 (2.04)
2. Connects or integrates with other indicators (as is); 9.25 (2.93)
3. Remote/automated monitoring (minimal field presence); 5.75 (2.56)
4. Cost effective; 6.17 (3.29)
5. Data availability (preferably electronic or summarized); 6.75 (2.99)
6. Connectivity – can relate or associate on site data collection with remote sensing measurements; 5.08 (3.00)
7. Responsiveness to change; 9.75 (3.47)
8. Environmental impact of data collection efforts; 3.92 (3.06)
9. Methods with documented protocols including QA approach that could be put directly into Implementation Plan; 6.00 (2.73)
10. Has documented sampling plot design; 4.83 (2.86)
11. Has existing information on variance; 4.5 (3.95)
12. Diagnostic of the general state of ecosystem health or specific distress syndromes; 10.17 (3.51)
13. Serves data needs of other agencies for national/regional policy, planning and management decisions; 7.67 (4.23)

The candidate indicators were then evaluated relative to each other, against all "want" criteria one at a time. A value of 10 was assigned to the indicator that came closest to meeting the "want" criterion and all other indicators were scored relative to it. Once the indicators were scored, a weighted score was generated for each candidate indicator by multiplying the weight of each "want" criterion by the score for the indicator and summing for all "wants" criteria. For example, spectral properties received the following scores:

| "Want" | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weights | 11.17 | 9.25 | 5.75 | 6.17 | 6.75 | 5.08 | 9.75 | 3.92 | 6.00 | 4.83 | 4.5 | 10.17 | 7.67 |
| | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Score for spectral indicator meeting "want" | 9.14 | 8.29 | 9.71 | 9.43 | 8.71 | 8.57 | 8.00 | 9.86 | 8.17 | 6.00 | 6.80 | 7.29 | 7.29 |
| Weighted Score of 750 | | | | | | | | | | | | | |

The weighted scores for the different candidate indicators were as follows:

| Indicator | Weighted K–T Score |
|---|---|
| Spectral Properties | 750 |
| Vegetation Composition and Cover | 710 |
| Biogeochemistry | 625 |
| Energy Balance (Bowen's Ratio) | 676 |
| Landscape Patterns | 620 |
| Retrospective | 511 |
| Erosion Index | 628 |

The final step in the K–T decision process was to explore consequences of not selecting one of the candidate indicators. Several indicators were excluded from the evaluation process: water quality/quantity, soil physical characterization, fauna, and socio–economic. Water quality/quantity was excluded because the group determined that data suitable for EMAP usage may be obtained by cooperating with other Federal agencies (e.g., USGS monitoring programs), EMAP–Surface Waters, or from state water monitoring programs. Once data from these are obtained and evaluated, a decision will be made on how complete existing water data are and how well they can be used to meet EMAP objectives.

While socio–economic indicators may well be tied with ecological condition, they were deferred for the pilot because this linkage is not well understood, may be very indirect, and involves political considerations well beyond the expertise of the scientists involved in the project. It is hoped that such indicators may be developed in the future with the collaboration of economists.

Faunal indicators were deferred for the pilot because scientists at the Logan workshop felt that animals in general may not be as directly diagnostic for change as the other research indicators. This is due to the fact that only 10–25% of the energy input to arid systems passes through animals. Key species may be very diagnostic of change, however, such key species are not generally present in many different habitats across a region. An approach that relies on guilds of animals that perform specific functions within ecosystems needs to be identified. Animals were identified as being good indicators for toxins and will be considered for this in the future. In addition, data from the Breeding Bird Census will be evaluated for coverage in arid areas. If adequate, a similar census could be incorporated by EMAP–Arid in the near future.

Soil physical profile characterization was determined to be a core indicator that is needed to make associations with spectral properties and vegetation composition. Thus, it was decided that soil profile data would be collected at each site along with descriptors of surface soil characteristics. Soil profile physical and chemical aspects were identified as baseline measurements that would only be resampled at follow–up site visits if the surface characteristics indicated change.

At the conclusion of the K–T decision process, the workshop participants decided that adequate funds would only be available to test 3–5 indicators. Thus, the decision was made to test spectral properties; vegetation composition, structure, and abundance; and soil properties in the 1992 pilot. Upon additional consideration, the group decided to include the erosion index as part of the soils properties indicator. This was done because the erosion index could be calculated using data from the literature or collected via the vegetation and soil properties indicators. The only additional data needed would be slope and management practices for the plot.

## 5.2 SPECTRAL PROPERTIES INDICATORS

**(David A. Mouat)**

### 5.2.1 Introduction

The purpose of this indicator is to test and evaluate the use of spectral measurements for the purpose of deriving information about arid ecosystem vegetation and soils. Spectral measurements of vegetation and soils from satellite platforms will be compared to concomitant spectral measurements obtained through the use of field instrumentation and ground–based measurements of vegetation and soils. These ground–based measurements will come from the vegetation and soils activities described elsewhere in this Implementation Plan.

Electromagnetic radiation can provide information about the physical and chemical properties of materials. While the spectral reflectance properties of objects tend to be wavelength dependent, the determination of these relationships is critical for characterizing or discriminating the objects. Vegetation, soils, and other materials have spectral responses that are a function of a diverse array of properties of those materials. These properties might include moisture content, shadowing, presence of other materials, etc. Nevertheless, the overall spectral response of a material is largely a function of the material itself.

Figure 5–3 illustrates the typical spectral response patterns of three different types of materials: vegetation, soils, and clear water, from 0.4 to 2.4 um. The Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) bandpasses have been superimposed on

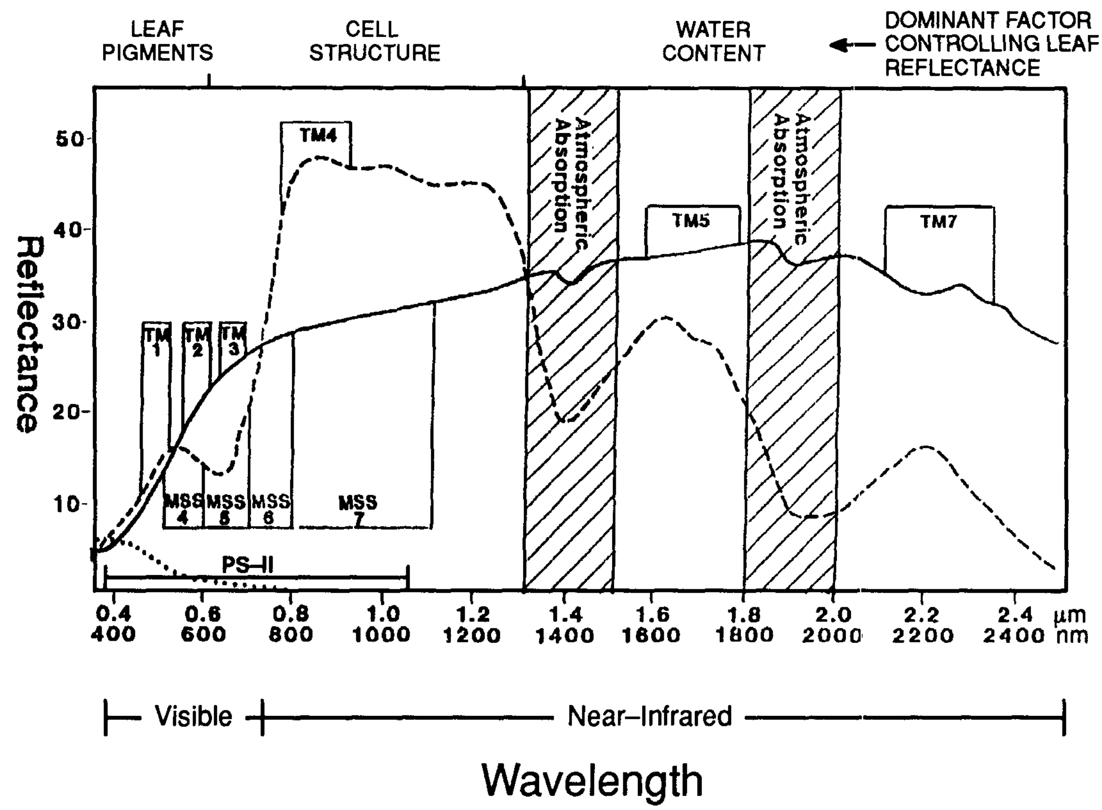



Figure 5–3. Typical Spectral Response Curves of vegetation, soils, and water from 0.4 to 2.4 μm. Landsat MSS and TM bandpasses within the spectral region have been superimposed on the graph for reference.

these spectral response patterns. In the visible portion of the spectrum, vegetation response is largely a function of plant pigments such as chlorophyll, xanthophyll, carotene, and beta–carotene; in the near infrared, vegetation response is largely a function of internal leaf (mesophyll) structure; and in the shortwave infrared, vegetation spectral response is largely a function of internal moisture content. The vegetation response curve illustrated depicts a typically healthy green leaf. The strong chlorophyll absorption in red is accompanied by a concomitantly high response in the near infrared. Soil spectral response is a function of moisture and organic content throughout the reflectance spectrum and chemical content at varying places, specifically in the shorter visible spectrum, the 400 to

900 nm and in the 2000 to 2400 nm portions of the spectrum. Red soils, depicted in the figure, have iron oxide absorptions in blue and green and thus appear red. The ability to derive information about these surface materials based on their spectral reflectance properties is a function of the spatial (the pixel size), spectral (both the placement within the electromagnetic spectrum and the width of the bandpass), radiometric (the ability to discern brightness), and the temporal (the timing and repeatability of measurements) resolution properties of the remote sensing systems used.

Remote sensing involves measurements made in the electromagnetic spectrum using instruments placed on satellite or aircraft–hosted platforms to characterize land, water, and/or atmospheric phenomena. While the most widely known and used form of remote sensing is the aerial photograph, other sensors using a variety of technologies can also be useful. Multispectral scanners hosted on aircraft and satellites can derive information about earth surface properties in parts of the spectrum beyond the capability of aerial photography, preserved in digital format, and having much higher radiometric resolution than photography. These systems, when placed aboard a satellite, can image wide areas. One very common system, the Landsat satellite, images a swath 185 km wide. The digital data recorded from these satellites are highly amenable to processing and interpretation in a digital form, thus allowing consistent and repeatable measurements.

If ecosystem variables can be measured with any degree of accuracy from the synoptic perspective of a satellite sensor, then a most effective and efficient method of ecosystem structure and function may be obtained in a spatial context. A number of researchers have investigated relationships among remote sensing – derived indices and ecosystem variables.

### 5.2.2 Relationships Between Remote Sensing Measurements and Ecological Variables

A number of researchers have shown very strong relationships between ecosystem structural (such as biomass or LAI) and functional (such as Net Primary Productivity (NPP)) features (e.g., Gholz, 1982; Waring et al., 1978). Gholz (1982), in reporting research on a transect of coniferous forest ecosystems in west central Oregon, reported relationships between LAI and Overstory NPP with an $R^2$ of 0.96.

A rather extensive literature exists on the use of remote sensing technology for the assessment of ecological processes including biosphere functioning (Hobbs and Mooney, 1990). A host of remote sensing measurements are used in this endeavor. Among these is the use of vegetation indices based upon relationships involving a near infrared (NIR) and a red (Red) channel. The relationships may take the form of a simple difference, NIR – Red; simple ratio, NIR/Red; or a dimensionless index such as NIR–Red/NIR + Red (Cihlar et al., 1991 and Running, 1990). The last relationship is known as the Normalized Difference Vegetation Index (NDVI). This index has been used extensively to characterize vegetation and has had a considerable history in remote sensing investigations of ecosystem processes. Peterson et al. (1987) found strong relationships ($R^2 = 0.91$) between Landsat Thematic Mapper NIR/Red ratios and LAI in closed canopy, pure conifer forests in west central Oregon. Nemani and Running (1989) used an Advanced Very High Resolution Radiometer (AVHRR) – derived NDVI to estimate LAI (LAI = 3 to LAI = 10) in conifer stands in Montana with an $R^2 = 0.88$. Figure 5–4 illustrates the relationship between LAI and remotely–sensed indices in forested ecosystems. Other researchers (reported in Running, 1990) have shown that vegetation index and LAI relationships behave differently in arid and semiarid environments (e.g., grasslands) than in more mesic environments (e.g., forest ecosystems). An important element of this indicator pilot will be the development of similar relationships for arid ecosystems.

Clearly a number of problems are inherent in using satellite derived vegetation indices (e.g., NDVI) to estimate ecosystem variables. The optimal approach would be an intensive research study similar to those cited above. Spectral reflectance measurements would be obtained from trees and shrubs using a LI–COR LAI 2000. Light transmission derived using Beer–Lambert's laws would be estimated, and LAI in turn estimated. Leaf sampling of

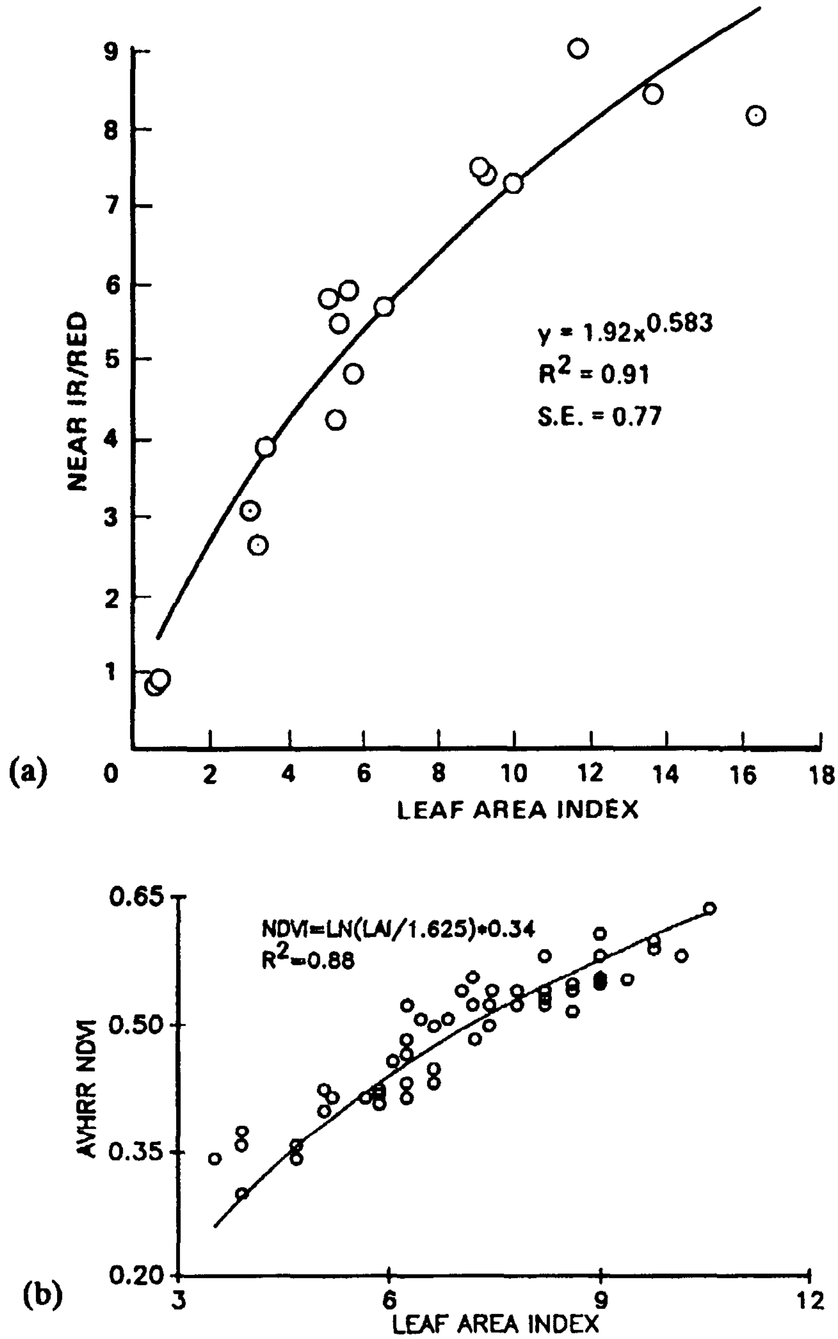



Figure 5–4. Relationship Between LAI and Two Vegetation Indices a) illustrates LAI vs. Landsat TM derived near IR/Red and b) illustrates LAI vs. AVHRR NDVI (from Running, 1991).

those same trees and shrubs would provide an independent estimate of LAI. This would serve to calibrate the estimates of LAI made from spectral reflectance measurements.

Such an intensive research evaluation is beyond the scope of this pilot. Rather, we will rely on findings of other researchers to calibrate our spectral reflectance measurements with LAI until such time as funding allows these intensive calibration studies within the EMAP–Arid program.

The pilot will focus on correlating the spectral reflectance measured on the ground with that determined from various satellite platforms to estimate vegetation and soils features.

### 5.2.3 Image Acquisition and Remote Sensing Measurements

The EOSAT Corporation will be the primary data source for the primary satellite imagery. EOSAT provided data will be augmented from data acquired through the Utah State University Fish and Wildlife Cooperative Unit of the FWS GAP Program and by the EPA's North American Landscape Characterization (NALC) Program.

Satellite data for the approximate time of the field activities will be acquired. The optimal time of data acquisition could be determined by an exhaustive study of the phenological status of vegetation in the study area. Instead, an examination of local weather station records, short–term AVHRR image assessment, and discussions with local and regional university, NPS, FS, and BLM personnel will establish an approximate optimal time for image acquisition. As the purpose of this pilot is to test selected indicators, this strategy should be appropriate.

The contemporaneous AVHRR, MSS and TM imagery will be compared with similar imagery, but from earlier years, in an attempt to determine image variance on an annual basis. The use of imagery from similar dates but from different years could prove extremely useful in applying these indicators on a regional basis. Imagery will be obtained from EOSAT, the EROS Data Center, and other sources.

### 5.2.4 Details for Specific Spectral Properties Indicators

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

The EMAP–Arid Pilot will include the testing and evaluation of spectral properties of vegetation (primarily NDVI but other indices may be used or developed and tested) and of soils (albedo) as determined by the use of satellite–hosted sensors. These sensors will include AVHRR, TM, and MSS. Pixels extracted from the data sets will be chosen in such a way that they coincide with ground observations and EMAP design grid center points. The number of pixels needed to adequately characterize a given sample point will be tested and evaluated. It has been suggested (Mike Scott, pers. comm., 1992; Mike Spanner, pers. comm., 1992) that a 2 x 2 matrix may be adequate for the AVHRR pixels while a 3 x 3 matrix is probably necessary for the TM and MSS pixels.

In the 2 x 2 matrix, an assumption will be made that the center of that matrix will coincide with the given EMAP grid point. In the 3 x 3 matrix, the assumption is that the center pixel contains the EMAP grid point. That grid point, and its surrounding area, will be sampled by the vegetation sampling team for vegetation composition, structure and abundance and surface attributes (e.g., extent of bare soil). The variability of NDVI data as gathered by the TM will provide an understanding of AVHRR NDVI variability.

### 5.2.5 Ground–Based Measurements of Spectral Properties

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

Ground spectral data will be obtained for half of the study sites (randomly selected) during the field sampling activity. A Personal Spectrometer II (PS–II) will be employed in the field. This instrument, with a spectral range of 400 to 900 nm and a spectral resolution of 2 nm, is a highly portable (3 kg) instrument capable of acquiring spectra in as little as 1/23 second. The PS–II will be used to acquire spectra within the circular subplots and quadrats along transects of plants, litter, shadows, surface soils, and surface lithology for the purpose of characterizing the sample site. This information will in turn be used to correlate the satellite–derived information with the other ground measurements. The PS–II measurements will also be used to determine the basic spectral properties of the materials themselves. Spectral analysis software together with other statistical packages (Quattro Pro) will be used to determine the spectral properties of the ground materials being examined.

Sampling for spectral properties will proceed at each vegetation transect and at each of the seven subplots described in Section 4.4 (Figure 4–1). A square grid of 4 x 4 points with horizontal and vertical distance of 3 m between points will be centered on each circular subplot center. On each vegetation transect, every other quadrat beginning with the first quadrat will be sampled for a total of 6 quadrats. Each sample quadrat will be measured 3 times. Figure 5–5 illustrates the position of spectral measurements relative to a transect and the circular subplot at each end. At each point the PS–II will be positioned approximately 1 m above the surface and a set of 10 spectra acquired, averaged, and recorded. The PS–II has a field of view approximately 30 cm in diameter from a height of 1 m.

The 16 spectral measurements made on each subplot will be used to estimate the value and spectral variance for each of seven TM pixels. Three subplots can be combined to estimate the value and spectral variance in a 2 x 2 pixel cluster (replicated 4 times), or all seven subplots can be combined to estimate the value and spectral variance in a 3 x 3 pixel cluster. The 220 measurements on the plot also can be used to estimate the value for a 3 x 3 pixel cluster. Similarly, TM pixels can be randomly selected from MSS or AVHRR pixels (or clusters of pixels) to estimate the values and spectral variance in the MSS or AVHRR pixels or clusters. Thus, the spectral properties indicator portion of the pilot study will evaluate the relationship between on–ground spectral and satellite spectral measurements.

The spectral measurements of each quadrat can be related to the vegetation composition and abundance and surface attributes of that quadrat. The 18 spectral measurements for the entire transect can be combined and related to the vegetation composition and abundance and surface attributes of that transect. The 220 spectral measurements for the entire plot can be combined and related to the vegetation composition and abundance and surface attributes of the entire plot. Similarly, the spectral

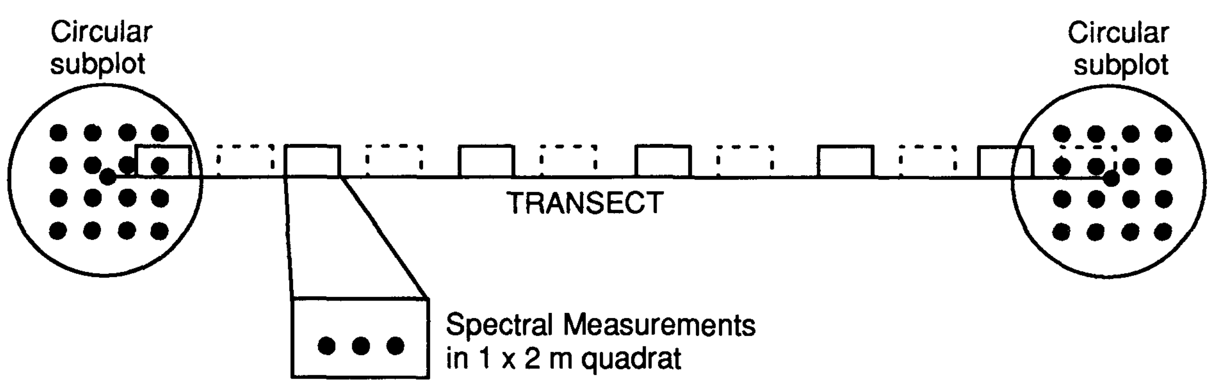



Figure 5–5. Positions of Spectral Measurements.

properties measured from satellite imagery (TM, MSS, or AVHRR) for the entire plot can be related to the vegetation composition and abundance of the plot. Thus, vegetation properties and surface attributes can be related to spectral properties determined both from on–ground measurements and satellite imagery.

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

## 5.3 VEGETATION COMPOSITION, STRUCTURE, AND ABUNDANCE INDICATORS

**(Stephen G. Leonard and Robin J. Tausch)**

### 5.3.1 Introduction

The composition, structure, and abundance of vegetation have been recognized as useful indicators of environmentally induced changes in arid vegetation. The proposed measures for the determination of these indicators are estimation of 1) the percent cover and 2) height of the green vegetation on the site by species. Together, these can provide an index of leaf area. These measures can provide sensitive indicators of change in biological condition at the organism, population, community, and ecosystem levels. This occurs through the relationships of cover and height to water availability and production (Nemani and Running,1989; Tausch and Tueller, 1990; Tausch and Nowak, 1991). Ground–based cover measurements can be related back to, and used for ground truthing of, remotely sensed spectral properties when specific timing requirements are met. The proposed vegetation methods are rapid, have demonstrated levels of precision with proper training, and are familiar to all land management agencies. Related site and soil characteristics will be collected simultaneously with, and as a part of, the vegetation sampling (Section 5.4).

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

### 5.3.2 Details for Specific Indicators

Vegetation Cover – Percent vegetation cover by species on a site provides information on abundance, relative composition, and dominance in the community. We propose to sample using the Daubenmire cover class method. The method will be modified as described by Baily and Poulton (1968) by adding a seventh cover class (<1%) to better indicate trace occurrences.

TABLE 5–4. 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% |

Vegetation Height – Average height of each species on a site. Determined by species and subplot or quadrat, provides information on species dominance and vegetation structure in the community.

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

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

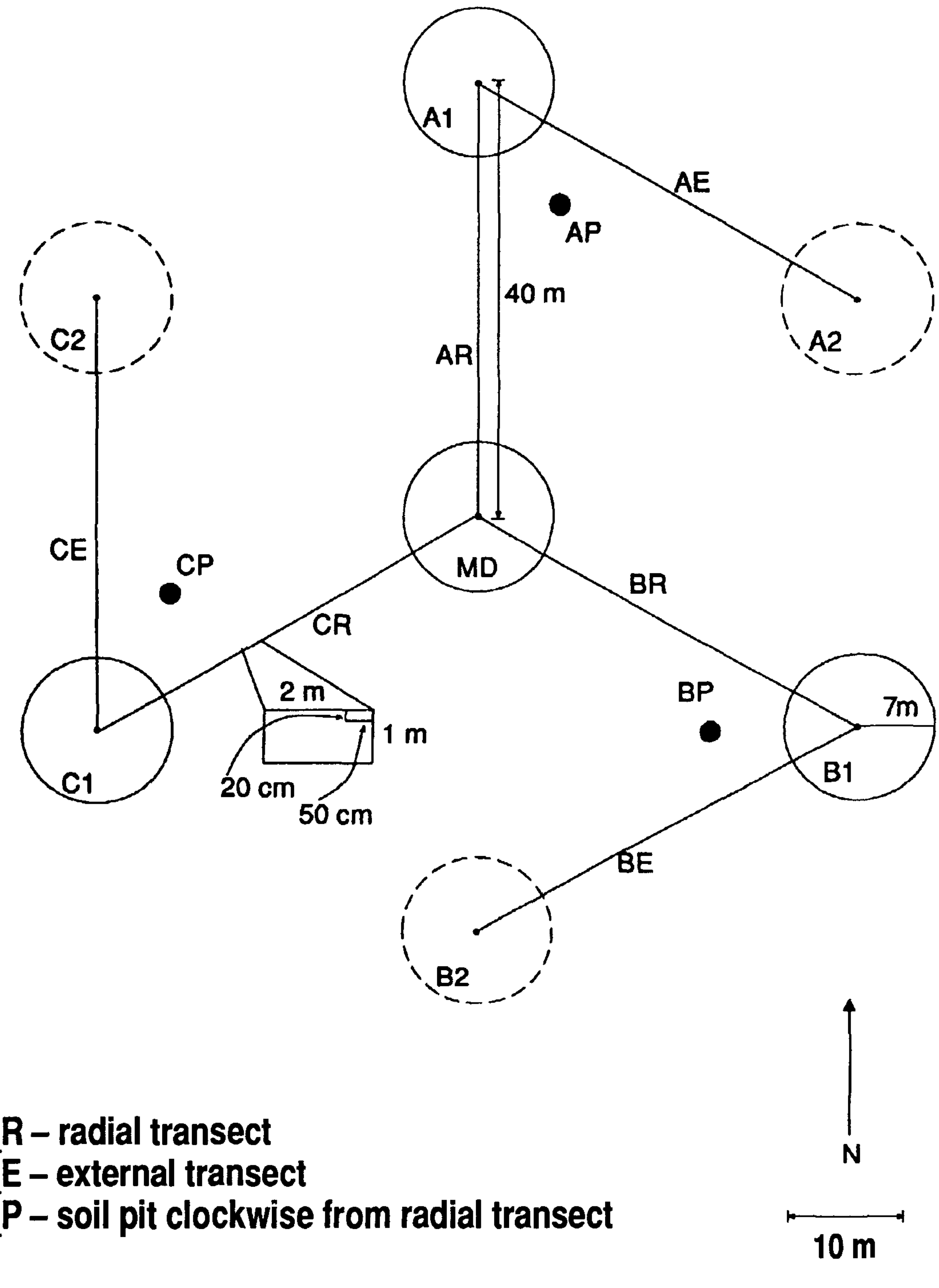
Species Composition – Through both quadrat sampling and site survey, the species composition of each site can be determined and monitored.

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

Biomass – is an essential indicator for environmental conditions related to climate change, desertification, and other processes. Biomass can be related to remotely sensed data for monitoring purposes. However, sample based measurement will not be included in this pilot because of cost and logistic constraints.

### 5.3.3 Sampling Design

Sampling design is similar to that for the EMAP–Forest and maintains functional compatibility with it. It has been modified for the more spatially heterogeneous arid/semi–arid communities to be sampled. Sample plot layout is a nested quadrat design (Figure 5–6). Trees (>1.5 m in height) and widely spaced, large shrubs (>1.5 m in height) will be measured in four fixed area subplots. Subplots are 7 m in diameter with one centered on the plot center and with the centers of the remaining three 40 m from the plot center on radial transects spaced 120° apart. All individual trees and large shrubs in each




_R – radial transect
_E – external transect
_P – soil pit clockwise from radial transect

Figure 5–6. Nested Quadrat Design.

subplot will be measured for two crown diameters (Meeuwig, 1979), height, and either diameter root crown or diameter breast height. The crown diameter measurements will be used to determine percent cover by species in each subplot.

Shrubs, other than those sampled in the circular subplots, will be sampled by cover class in the 1 m x 2 m quadrats systematically located along each of the three radial transects and three exterior transects (Figure 5–6). Herbaceous forb and grass species will be sampled by cover class in 20 cm x 50 cm quadrats nested within each 1 m x 2 m quadrat. Data for surface features (total vascular plant cover, litter, rock, bare soil, and cryptogams) are also collected in these 20 x 50 cm quadrats. This provides a total sample of 72 for each quadrat size. All sample subplots and quadrats are located within a hexagon of approximately 1 hectare. The entire hexagon will be used for the site description write–up and searched to locate and identify all plant species present.

Standard practice of sampling programs of many land management agencies and other ecological studies requires that plots be located entirely within the same vegetation community/soil type for the resulting data to have adequate precision (Bonham, 1989). In cases where the plot falls on different vegetation/soil complexes, the common practice is to shift the plot location so that it is within only one vegetation/soil type. This shifting of plots, while entirely appropriate for studies of a particular vegetation type, is inappropriate in the setting of a probabilistic sampling design such as that employed for EMAP.

In order to maintain the systematic random grid and preserve the probabilistic nature of the EMAP–Arid design, the plot will not be shifted so that it is within only one vegetation/soil type. Instead, the plot will remain where specified by design and for plots that contain more than one vegetation/soil type, additional data will be collected to ensure adequate precision. For all vegetation/soil types that represent at least 16.7% of the total plot (12 quadrats of 72), a minimum of 30 quadrats (each 1 x 2 m quadrat with its nested 20 x 50 cm quadrat is counted as one) will be sampled for surface features and vegetation composition, structure, and abundance. These quadrats will be located along extensions of the existing transects. In addition, if the site is to have a complete soil profile (to 1.5 m or bedrock), then a complete soil profile will be completed in the secondary vegetation/soil type. If no soil pit falls within the secondary vegetation/soil type, an additional soil pit will be added for either complete soil profile or surface soils, whichever is appropriate for the site. Protocols that document the decision rules for when and how to extend transects to add additional quadrats are included in the Field Operations and Training Manual.

Vegetation sampling will follow a procedure adapted from Rangeland Monitoring Trend Studies (USDI, 1985).

The following data will be recorded within the 20 x 50 cm quadrat:

1. Cover class (see Table 5–4) 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: I, II, III, IV, and unclassified (Figure 5–7)

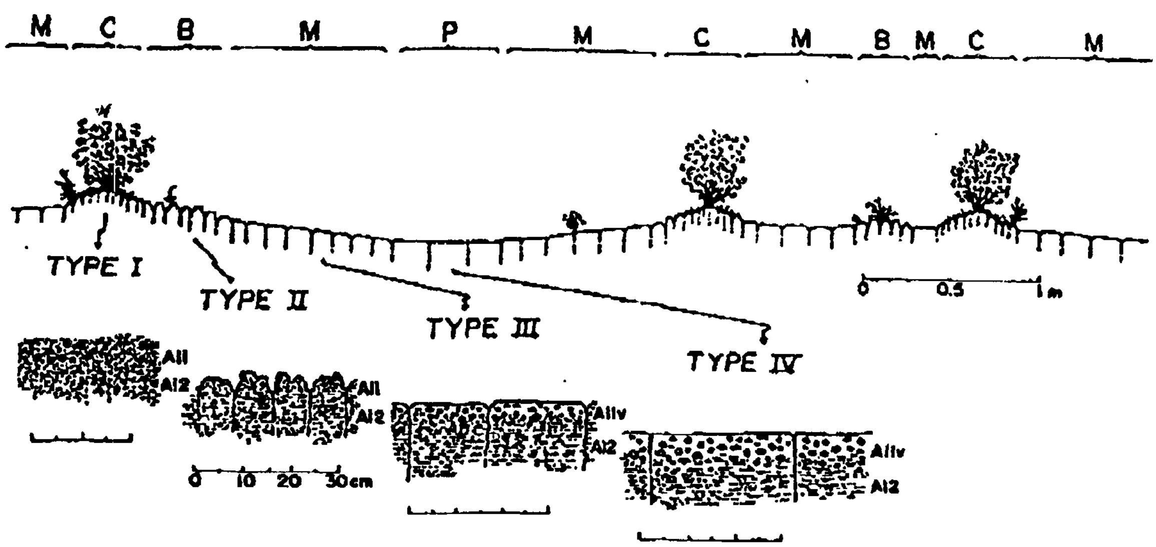



Figure 5–7. Surface Type Classes (from Eckert, et. al., 1986).

- 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/forb species.

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

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

The following data will be recorded within the 1 x 2 m quadrat:

1. Plant species identification for each shrub (plants < 1.5 m in height) species.

2. Cover class of canopy for each shrub species.

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

The following data will be recorded within the 7 m circular subplots (MD, A1, B1, and C1, Figure 5–6) for each individual tree and shrub >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 (>1.5 in height). When trees or shrubs have multiple trunks measure all trunks.

For each tree species within each 7 m circular subplot, the number of seedlings and saplings <1.5 m high will also be recorded.

Voucher specimens for any unknown species will be collected and preserved in a plant press for later identification. Such species will be assigned a sample number to be used on data forms until species identification can be confirmed.

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

## 5.4 SOIL PROPERTIES INDICATORS

**(George J. Staidl, Robert P. Breckenridge, Richard D. van Remortel, and Nancy L. Hampton)**

### 5.4.1 Introduction

Soil quality is an important assessment endpoint that is closely associated with EMAP–Arid societal values of sustainability and biodiversity. This endpoint is not measured directly, but is directly associated with a number of indicators that are measured directly (Table 5–2). The primary objectives of soil sampling in the 1992 field season are to:

- Demonstrate that the soil property indicators can be successfully implemented in two different Brown, Lowe, and Pase formation types using a cooperative effort among multiple agencies.
- Evaluate the variance components of surface soil parameters.
- Assess the benefit of describing a soil profile and collecting soil samples relative to: 1) interpreting other EMAP–Arid indicators (e.g., vegetation); 2) comparing soil profile data to existing published soil survey data to determine the most cost effective manner for obtaining soil descriptions; and 3) determining associations with assessment endpoints and societal values.
- Determine the cost–effectiveness and logistical feasibility of doing a complete profile lab analysis versus selecting a subset of parameters.

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

A conceptual model was used to identify the linkages between soil properties and the other arid indicators. Wood (1988) provides a conceptual model showing relationships between land management practices and plant characteristics, soils, and infiltration rates. This model was modified (Figure 5–8) to show the links among EMAP external driver components (precipitation, energy, atmospheric chemistry, socio–economic factors, and natural and anthropogenic stress), land management practices, and infiltration rates with other key components (biogeochemistry, landscape, fauna, energy, water resources, and vegetation).

### 5.4.2 Soil Properties Indicators

Three soil properties indicators will be measured in the 1992 pilot (Table 5–5): 1) Soil profile (a) description and (b) analysis – the characterization of a vertical section of the soil through all its horizons and extending into the parent material, 2) Soil surface (a) description and (b) analysis – the top two soil layers, and 3) Surface soil attributes – description of attributes of the topmost soil surface including vascular vegetation, rock fragments, cryptogams, bare soil, litter, surface type, and surface roughness. Soil properties encompassed by these three indicators control both soil moisture and susceptibility to erosion processes.

Measurements associated with these three soil property indicators are discussed in detail in the Field Operation and Training Manual. These measurements will be incorporated with vegetation and spectral properties data to allow application of the Water Erosion Production Project (WEPP) (Lane and Nearing, 1989; Flanagan, 1990, 1991), Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), or revised USLE (RUSLE) (Mills et al., 1985) and Wind Erosion (WE) (Fryrear, 1992) modules for development of an Erosion Index as discussed in Section 5.5.

# SOIL (PHYSICAL) INTERACTIONS BETWEEN KEY COMPONENTS

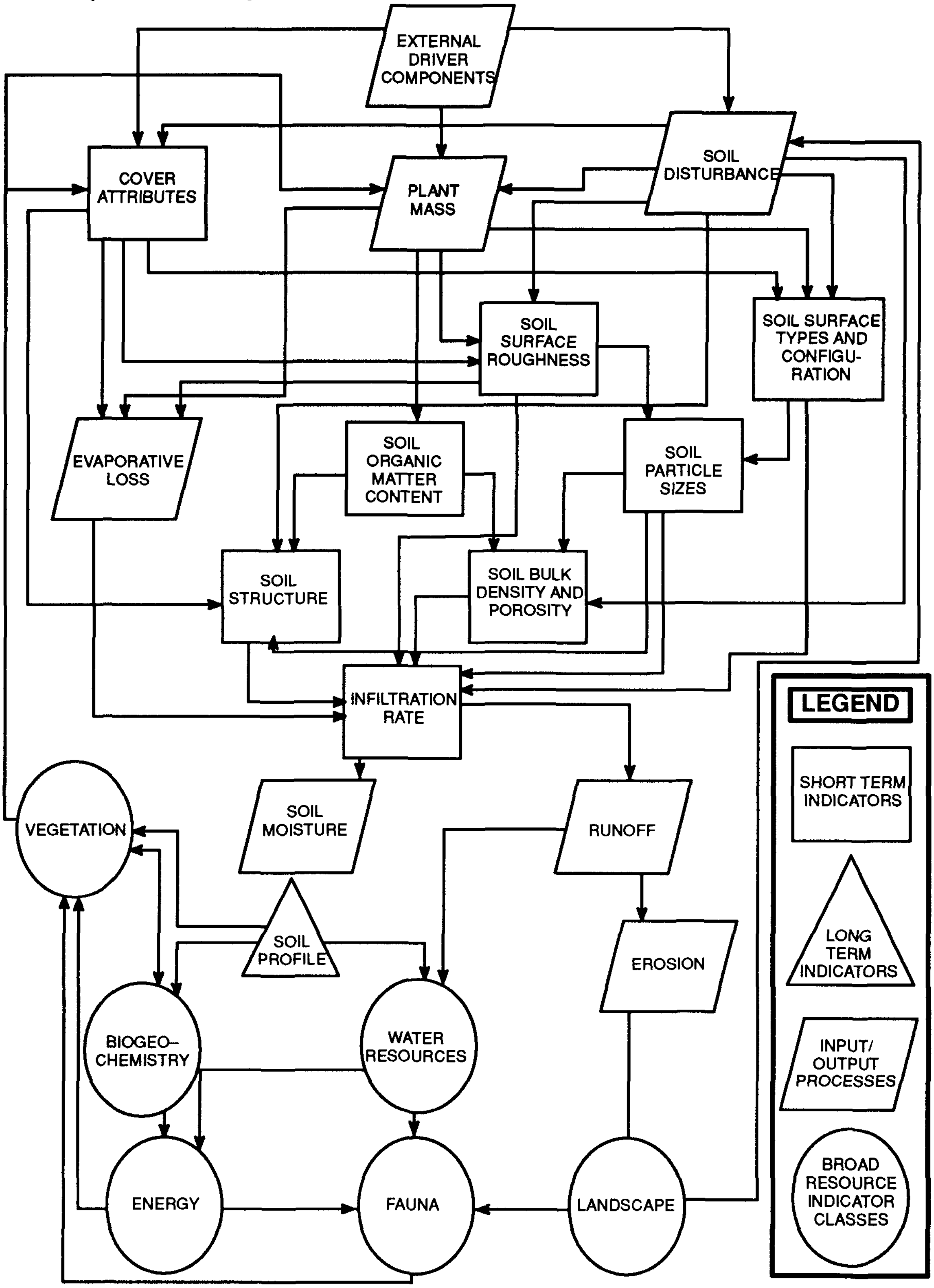



Figure 5–8. Conceptual Model (adapted from Wood, 1988).

TABLE 5–5. LIST OF SOIL INDICATORS AND ASSOCIATED MEASUREMENTS FOR SOIL QUALITY ASSESSMENT ENDPOINTS AND THEIR IMPORTANCE TO SOCIETAL VALUES

| INDICATOR | 1992 PILOT MEASUREMENTS | | | SAMPLING SCHEME FOR 1992 PILOT | IMPORTANCE TO SOCIETAL VALUES |
|---|---|---|---|---|---|
| | DESCRIPTION | FIELD | LAB | | |
| 1a. Soil profile description | Soil Taxonomy | X | | Full soil profile will be described in 20 of the sampling hexagons. Half will be in conifer woodland, half in desertscrub. Selection of the full profile sites will follow the statistical design considerations discussed in Section 4.0. At each site 3 holes, made using a 4" bucket auger, will be used to verify that the soils are within the range of characteristics of the same series. The hole most representative of the soils unit will be dug out for full profile description. The other 2 holes will be described as in 2a. The remainder of the 20 hexagons that do not get full profile descriptions will be described from 3 holes per site, each made using a 4" bucket auger. | Status of the soil profile description is key to sustainability and diversity of a site for human, animal, and vegetative life. The soil profile would be described initially for a site, and then resampled only if short–term indicators (e.g., surface layers, vegetative composition) show a dramatic change. Changes in soil profile would be associated with major climatic, land use, or land disturbance activities. Soil profile is considered a long–term baseline indicator for EMAP–Arid without which other short–term changes may not be interpretable. |
| | Major land resource area | X | | | |
| | Slope (%) | X | | | |
| | Physiography | X | | | |
| | Water Table | X | | | |
| | Land use class | X | | | |
| | Surface rock fragments (%) | X | | | |
| | Rock outcrop (%) | X | | | |
| | Hydraulic conductivity class | X | | | |
| | Drainage class | X | | | |
| | Elevation | X | | | |
| | Parent material | X | | | |
| | Hydrologic group | X | | | |
| | Erosion/runoff class | X | | | |
| | Particle size | X | | | |
| | Horizons | X | | | |
| | Color, moist/dry | X | | | |
| | Texture | X | | | |
| | Consistency | X | | | |
| | Structure | X | | | |
| | Mottles | X | | | |
| | Roots | X | | | |
| | Pores | X | | | |
| | Chemical reaction properties (e.g., pH, Ca $CO_3$, etc.) | X | | | |

TABLE 5–5. (continued).

| INDICATOR | 1992 PILOT MEASUREMENTS | | | SAMPLING SCHEME FOR 1992 PILOT | IMPORTANCE TO SOCIETAL VALUES |
|---|---|---|---|---|---|
| | DESCRIPTION | FIELD | LAB | | |
| 1b. Soil profile analysis | Following 1a, collect soil samples from each layer of a soil profile and submit for analysis for: | | | Samples collected in 20 of the hexagons at the same sites where full profile description pits are dug. | These physical and chemical analyses are used to describe how well a soil can be used to sustain plant or animal production or diversity. Changes in values from nominal to subnominal indicate overuse or climatic shift towards desertification. Changes from subnominal to nominal indicate conservation and good land management. Some of these may be better indicators of change (e.g., organic carbon, SAR, bulk density, CEC), but the suite of analyses is recommended by SCS for interpreting a soil relative to its erosion rates, sustainability, and biodiversity uses. |
| | Particle size distribution | | X | | |
| | Fabric Related Analyses | | | | |
| | Bulk Density | | X | | |
| | Water Retention | | X | | |
| | Water Retention Difference | | X | | |
| | Plasticity Index | | X | | |
| | Ion–Exchange Analyses | | | | |
| | Cation Exchange Capacity (CEC) | | X | | |
| | Sodium Absorption Ratio (SAR) | | X | | |
| | Exchangeable Sodium Percentage (ESP) | | X | | |
| | Chemical Analyses[1] | | | | |
| | Organic Carbon | | X | | |
| | Total Carbon | | X | | |
| | Nitrogen | | X | | |
| | Extractable Bases and Sum of Bases | | X | | |
| | Extractable Acidity | | X | | |
| | Calcium Carbonate | | X | | |
| | Gypsum | | X | | |
| | Soluble Cations and Anions | | X | | |
| | Mineralogy | | | | |
| | Crystalline Mineral Components | | X | | |
| | Grain and Amorphous Mineralogy | | X | | |
| | Miscellaneous Analyses | | | | |
| | Soluble Salts | | X | | |
| | Total Soluble Salts | | X | | |

[1] *Note:* Not all chemical analyses will be run for all sites. Decisions on chemical analyses will be based on the type of soil encountered. At some sites, conditions may not warrant use of analyses.

TABLE 5–5. (continued).

| INDICATOR | 1992 PILOT MEASUREMENTS | | | SAMPLING SCHEME FOR 1992 PILOT | IMPORTANCE TO SOCIETAL VALUES |
|---|---|---|---|---|---|
| | DESCRIPTION | FIELD | LAB | | |
| 2a. Soil surface horizons description | All parameters as listed in description in 1a. | X | | At each site, soil–surface profile will be described at 3 different locations. All holes will be dug to 50 cm and the top layers described to 50 cm. An auger will be used to describe the soil material below 50 cm to a depth of 1.5 m or bedrock. Locations of the holes are as described in the design section (4.0). | Surface soil physical and chemical properties should be the first to change relative to natural and anthropogenic stresses. These will be important indicators of changes in land use, soil moisture, erosion processes, decay of organic matter, and biodiversity relative to sustainability of an area. Changes in status relative to desertification should initially be noted in surface soil indicators. However, long–term trends may best be detectable by changes in the soil profile. Dramatic events (e.g., floods, fires, short–term drought) can be noted via changes in surface parameters. Long–term changes (e.g., shifts in water table, climatic shifts) may be better noted in deeper soil profiles. |
| 2b. Soil surface analysis | Collect soil samples from the top two layers for analysis of the following parameters | | | Surface soil samples will be collected from the top two layers at three different holes at each site. | Same as above |
| | Particle size distribution | | X | | |
| | Organic carbon | | X | | |
| | CEC | | X | | |
| | Soluble salts | | X | | |
| | Bulk density | | X | | |
| | Water retention | | X | | |
| | Water retention difference | | X | | |

TABLE 5–5. (continued).

| | | | | | |
|---|---|---|---|---|---|
| Surface soil attributes | Place a 20 x 50 cm plot frame at 12 locations along six 40 m transects. This is the same frame used for vegetative sampling. Inside frame record measurements on: | | | These attributes will be measured along the sampling transect established for sampling vegetation. They will be described with the same 20 x 50 cm sampling frame used to assess vegetation type and distribution. Descriptions will be made along six 40 m transects at each site. Coordination with the vegetation group is imperative to avoid duplication of data gathering. | Changes in surface attributes have been associated with seedling survival of sagebrush communities (Eckert et al. 1986). Presence or absence of cryptogams, lichens, or rock fragments are good indicators of how much a site has been disturbed by natural, man induced (4–wheelers), or grazing activities. These can be associated with sustainability and biodiversity. |
| | Surface morphology type (collected with vegetation parameters) | X | | | |
| | Surface cover type (collected with vegetation parameters) | X | | | |
| | Surface roughness | X | | | |
| Erosion Index | Calculate T using field data and compare to SCS Soil Survey value | X | X | Collect slope, vegetative and surface cover data from plots | Areas with excessive erosional rates will have reduced sustainability and biodiversity and be more prone to drought |

Due to a variety of considerations (i.e., budget, logistics), not all soil indicators will be measured at each hexagon–site. The sampling plans for the various indicators in the pilot are described in Table 5–5. Relative to soil indicators, all hexagon–sites will fall into one of two groups (A or B). The following indicators will be measured for each group:

Group A – at each site conduct:

- 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 2 satellite locations.
- Surface soil attributes described along six 40 m transects (these data are collected by the vegetation group).

Group B – at each site conduct:

- Auger hole description of soil profile at three locations.
- Soil–surface description and analyses at three locations.
- Surface soil attributes described along six 40 m transects (these data are collected by the vegetation group).

These groups were established based on cost and the rationale that the collection of complete profile descriptions at 10 sites per formation type (20 total Group A) when considered with the 20 sites with auger hole description will provide enough information on variability to evaluate the status of the indicator categories. Soils in the remaining hexagons (Group B) will be described in sufficient detail to make associations with vegetation and spectral properties indicators.

The sampling plot design is presented in Figure 5–6. Plot location, layout, and field procedures are discussed in detail in the Field Operations and Training Manual. Estimated costs and labor requirements associated with the two different types of sites A and B are presented in Table 5–6.

### 5.4.3 Erosion Index Indicator

**(Robert P. Breckenridge)**

Soil erosion is almost universally recognized as a serious threat to the sustainability of ecosystems and man's well–being. This is shown by the fact that most governments in the world give active support to programs of soil conservation.

The objectives of testing the erosion index indicator are to:

1. Determine if field data collected by EMAP–Arid personnel can be used (along with published data) to calculate wind and water erosion rates for arid ecosystems.
2. Compare calculated erosion rates for a soil series to those published in SCS Soil Surveys to determine condition of a site relative to erosion rates.
3. Compare two water erosion models (USLE/RUSLE) for their precision and cost effectiveness to provide EMAP level data to make large scale statements on erosional condition of arid lands.

## TABLE 5–6. ESTIMATES OF COSTS AND LABOR REQUIREMENTS FOR SOIL PROPERTIES INDICATORS FOR 1992 PILOT STUDY.

| Indicators | Group A – Full Profiles Description and Laboratory Analysis | | | | Group B – Soil Description | | | |
|---|---|---|---|---|---|---|---|---|
| | Status[a]– #holes/ site | Cost/Site | | | Status– #holes/ site | Costs | | |
| | | Labor hours | Supplies[b] | Analytical[c] | | Labor hours | Supplies[b] | Analytical[c] |
| 1) SOIL PROFILE DESCRIPTION AND ANALYSIS | | | | | | | | |
| 1a. Pedon description in field – all layers or horizons (typifying) | X–1 | 6 | | | | | | |
| 1b. Laboratory evaluation of all layers or horizons[d] | X–1 | 1 | $30 | $928 | | | | |
| 1c. Site profile description using bucket auger | X–2 | 2 | | | X–3 | X–3 | | |
| 2) SOIL–SURFACE HORIZON DESCRIPTION AND ANALYSIS | | | | | | | | |
| 2a. Field description of top 50 cm | X–3 | 2 | | | X–3 | 3 | | |
| 2b. Laboratory Evaluation of top 2 surface layers | X–2 | 1 | $10 | $432 | X–3 | 2 | $15 | $648 |
| 3) SURFACE SOIL ATTRIBUTES | X | 3 | | | X | 3 | | |
| 4) EROSION INDEX<br>USLE/RUSLE parameters<br>Slope characteristics (WEPP)<br>Rangeland Management Data | Some data exist in other agencies and additional data will be collected as part of the vegetation sampling activities. | | | | | | | |
| Subtotal per hexagon | 3 | 14 | $40 | $1360 | 3 | 9 | $15 | $648 |
| Total per hexagon | | | | $1400 | | | | $663 |
| Total for 20 hexagons | | | | $28,000 | | | | $13,260 |
| GRAND TOTAL FOR ALL SOIL INDICATORS | | | | $41,260 | | | | |

[a] X = will be measured

[b] Cost of sample containers, tape, and packing material.

[c] All laboratory analysis conducted by USDA, Soil Survey Investigation Lab in Lincoln, Nebraska, following all SCS QA protocols.

[d] Cost based on analysis of an average of 5 layers/pedon.

Soil erosion from wind and water can be measured directly or calculated using a variety of models. To obtain accurate field measurements, extensive instrumentation and sampling of a plot are often required (Larson et al., 1983; Breckenridge et al., 1991). Thus, EMAP–Arid has decided to use modeling as an alternative approach to determine site erosion. Three models will be evaluated as part of the Pilot Study: (1) the Universal for Revised Universal Soil Loss Equation (USLE/RUSLE); (2) the Water Erosion Prediction Project (WEPP); and (3) the Wind Erosion (WE) equation. These models will be evaluated for their ability to construct an erosion index for a site. The erosion index (presented in tons per acre per year) will be specific to a soil series and map unit. The calculated index will be a combination of the water and wind contributions to the total site erosion rate. The index will be compared to the erosion factors (T) found on the physical and chemical properties of soils table (which is Table 12 in all soil surveys) in each of the published USDA soil surveys for the various counties of the pilot area (see data sources for soil indicator Section 5.4.3). The T factor is an estimate of the maximum average rate of soil erosion by wind or water that can occur over time without affecting vegetative productivity over a sustained period. This value is in tons per acre per year.

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

| **Site Calculated Values (Tons/ac/yr)** | **SCS Recommended Value** | **EMAP Association** |
|---|---|---|
| Water erosion + Wind Erosion | $\leq$ T | = nominal |
| | > T | = subnominal |

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

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

**E = I x C x K x V x L** (Israelsen et al., 1980) in which:

E = soil loss by wind in tons/acre/yr
I = soil wind erodibility factor
C = local wind erosion climatic factor
K = soil surface roughness factor
V = vegetative factor
L = length of the unshielded distance parallel to wind in the direction of the wind fetch.

The inputs to these parameters will be obtained from field data or by using standard values (Israelsen et al. 1980). Details of field collection techniques will be presented in the Field Operations and Training Manual.

The USLE is a well established equation for water erosion originally developed in 1940 to predict long–term soil loss through sheet and rill erosion. USLE is widely used by the SCS and conservation planners to determine appropriate soil management strategies. The 1977 National Resource Inventory data base on erosion was derived form the USLE (water erosion component) and WE (wind erosion component) models. The USLE is a simpler equation than the WEPP. The USLE calculates soil loss as a product of six factors.

**A = R x K x L x S x VM x P** (Israelsen et al., 1980) where:

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

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

WEPP is a new project designed to generate improved erosion prediction technology on rangelands for use by multiple federal agencies. EMAP–Arid will collect the required inputs for WEPP that include:

- Climate
- Soil properties
- Topography
- Land use

WEPP (Lane and Nearing, 1989; Flanagan, 1990, 1991) is being designed ultimately to replace USLE/RUSLE, but is in its trial stage.

EMAP–Arid will collect the required input for the WE, USLE/RUSLE, and WEPP for those pilot sites that have published soil surveys (an exception could be bare rock). Based on available funds, field data will be input to the 3 equations and erosion values calculated. These values will then be compared to published T values from the soil surveys. Data evaluation will be conducted to determine cost effectiveness of different models and precision between USLE/RUSLE and WEPP.

### 5.4.4 Data Sources and Additional Data Requirements for Soils Indicators

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

Existing data pertinent to the sample sites in the pilot area will be obtained from the Utah State SCS. Additional data specific to the pilot study area will be obtained from SCS field offices, BLM State or District Offices, and the FS Forest or Range District Offices. The

SCS offices will be the main source of soil data because they are charged with soil correlation, soil database maintenance, and manuscript publication responsibilities.

The soil data required for proper soil series identification at the sampling site are available for: Grand County except for the area from Book Cliffs north; San Juan County except for the southern section including the Navajo Nation; Eastern Garfield County, including Escalante and Boulder and the Henry Mountains area which includes eastern Garfield and Kane Counties; and southern Wayne County. The Emery County Castle Valley is also available, but the balance of Emery County is in process. Soil Surveys for Grand and San Juan Counties can be obtained from the Moab SCS office (801–587–2481); for Emery County and Wayne County from Leland Sass – Price SCS Office (801–637–0041); and for Garfield and Kane County from Gordon in the Cedar City SCS Office (801–586–2429). This information includes the soil maps, map unit identification legend, map unit descriptions, table of soil classification, typical soil pedon descriptions, soil laboratory data, and soil interpretation tables or form SCS–SOI–5 for each soil component in a map unit where the sample sites are located.

Access will be sought to the SCS–State soil survey database and existing GIS soils data pertinent to the sampling sites. This is an important source of information that identifies existing soil properties for the pilot area. The pilot will test the utility of existing soils information.

Due to the kind, amount, and complexity of interpreting existing and collecting new data, a journeyman level soil scientist familiar with soil survey field procedures and data input and analysis will be on each field crew to collect data. Existing data will be used to identify soil series at the sample sites. The SCS soil map for Utah will be used for the initial determination as to whether the sample site is located on a homogenous soil series and vegetation community. If not, soils will be sampled for all vegetation/soil types represented on the site as discussed in Section 5.3.3. Determination of the field site will use the existing soil data to pinpoint location, soil series, and vegetation community. Soil data collected on site will be compared with existing data to determine similarities or dissimilarities and fill data gaps where EMAP is not collecting soil samples for further analysis. The pilot will test the access, storage, and retrieval aspects of having EMAP–Arid soils data in the SCS–National or State Soil Survey databases. This would provide a common database for use by all agencies.

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# 6.0 LOGISTICS

**(Nita G. Tallent–Halsell)**

## 6.1 *DESIGN CONSIDERATIONS*

Field activities for EMAP–Arid will begin in June 1992 with a pilot study in the southeastern Utah portion of the Colorado Plateau. The following assumptions are being used for logistics planning and implementation of the Colorado Plateau Pilot Study.

1. The index period will be June, July, and August; a sampling window of approximately ten weeks.
2. Approximately 40 sites will be sampled.
3. Selection of sample sites does not consider site access.
4. Four–wheel drive vehicles, backpacking, and helicopters will be used for site access.
5. Field mobile laboratories are not required, sample preparation in the field will be minimal.
6. Samples will be shipped to the laboratory weekly.
7. A field crew will consist of at least four people: a field supervisor, a soil scientist, a botanist, and a field technician. A spectrometer technician will accompany the crew to sites where spectral properties are to be measured. In addition to the field crews, a field coordinator will be located at the base site to coordinate activities and communications, ship data and samples, and obtain site access permission. Responsibilities of each team member are given in Table 6–1. There will be two crews employed for the pilot.
8. EMAP–Arid will use and train qualified personnel selected from the permanent staff of the NPS, EPA, SCS, BLM, and other Federal agencies.

Based on these assumptions a field crew will evaluate proposed field methods at each site. The terrain of the sample sites varies greatly, therefore, the best access methods will also be evaluated. Sampling schedules will be tentative and subject to change as needed. Sites difficult to access will require additional time and/or staff.

TABLE 6–1. RESPONSIBILITIES OF FIELD CREW MEMBERS.

| TEAM PERSONNEL | POSITION DESCRIPTION |
|---|---|
| Field Supervisor (2) | Scientist with responsibility for sampling effort of one crew (performance & safety). Makes final decisions concerning in–field protocol deviations or failure to sample site, conducts and records daily debriefing, interacts with field coordinator, transmits information for weekly reports, assists with sampling. Preliminary verification of field forms and sample condition prior to giving to field coordinator. |
| Soil Scientist (2) | Performs soil sampling and directs field technician in soil measurement activities. Responsible for verification and transmittal of soil data collected and care and maintenance of field equipment for soil sampling. |
| Botanist (2) | Performs and directs vegetation sampling. Responsible for verification and transmittal of vegetation data collected and care and maintenance of field equipment for vegetation sampling. |
| Field Technician (2) | Assists soil scientist (and botanist as needed). Assists field coordinator with supply inventory and shipping. Responsible for charging batteries and maintenance of GPS, PDR, and radios, and care and maintenance of field equipment. |
| Spectrometer Technician (1) (for sites where spectral properties are to be measured) | Performs spectral properties measurements. Responsible for for care and maintenance of Personal Spectrometer (PS–II) and downloading data from PS–II. Assists botanist when not taking spectral measurements. |
| Field Coordinator (1) | Ensures that permission to access sites has been obtained. Assumes custody for samples. Processes and ships samples. Photocopies and transmits completed data forms. Coordinates daily and helicopter schedules. Maintains inventory of supplies. Coordinates communications among field crews and EMAP–Arid management. Arranges for repair or replacement of equipment. |

Two field crews will sample all sites within the index period. Subsets of sites will be sampled and/or resampled to evaluate the utility of various collection and measurement techniques. An evaluation of activities will be conducted through daily debriefings to ensure smooth operations throughout the sampling period. A final debriefing after the field study will be part of the overall evaluation of the field sampling activities.

## 6.2 SAMPLE SITE ACTIVITIES

Crews will file an itinerary with the Field Coordinator before departing for the site. Crews will contact the BLM District Office at Moab upon arrival at the site, at midday, and before leaving the sampling site as a part of routine safety procedures. Daily activities for the EMAP–Arid sampling crews are detailed in the Field Operations and Training Manual (Franson and Pollard, 1992) are summarized in the following discussion and outlined in Figure 6–1. Activities will start each morning by checking and calibrating the instruments and ensuring (via equipment checklists) that all necessary equipment and supplies are loaded into the vehicles.

At the site, the field crew will verify their location based on topographic maps, landscape features, aerial photographs (if available), and GPS information (if satellite coverage is available). If the site must be accessed by foot or helicopter, crews will reinventory equipment prior to departure from a suitable vehicle parking or staging area. Sampling protocols will remain consistent regardless of transport mechanism.

Upon arrival at the site, the formation type will be determined. If the site is Great Basin Desertscrub or Great Basin Conifer Woodland, it will be sampled; if not, the site will not be sampled. If the site is Great Basin Desertscrub or Great Basin Conifer Woodland but cannot be sampled safely (e.g., due to cliff condition), an alternate site will be chosen from the same formation type within 1 km of the designated site.

The plot will be established and permanently marked and the site characterization form completed. Eight 35 mm color photographs will be taken to document the location of

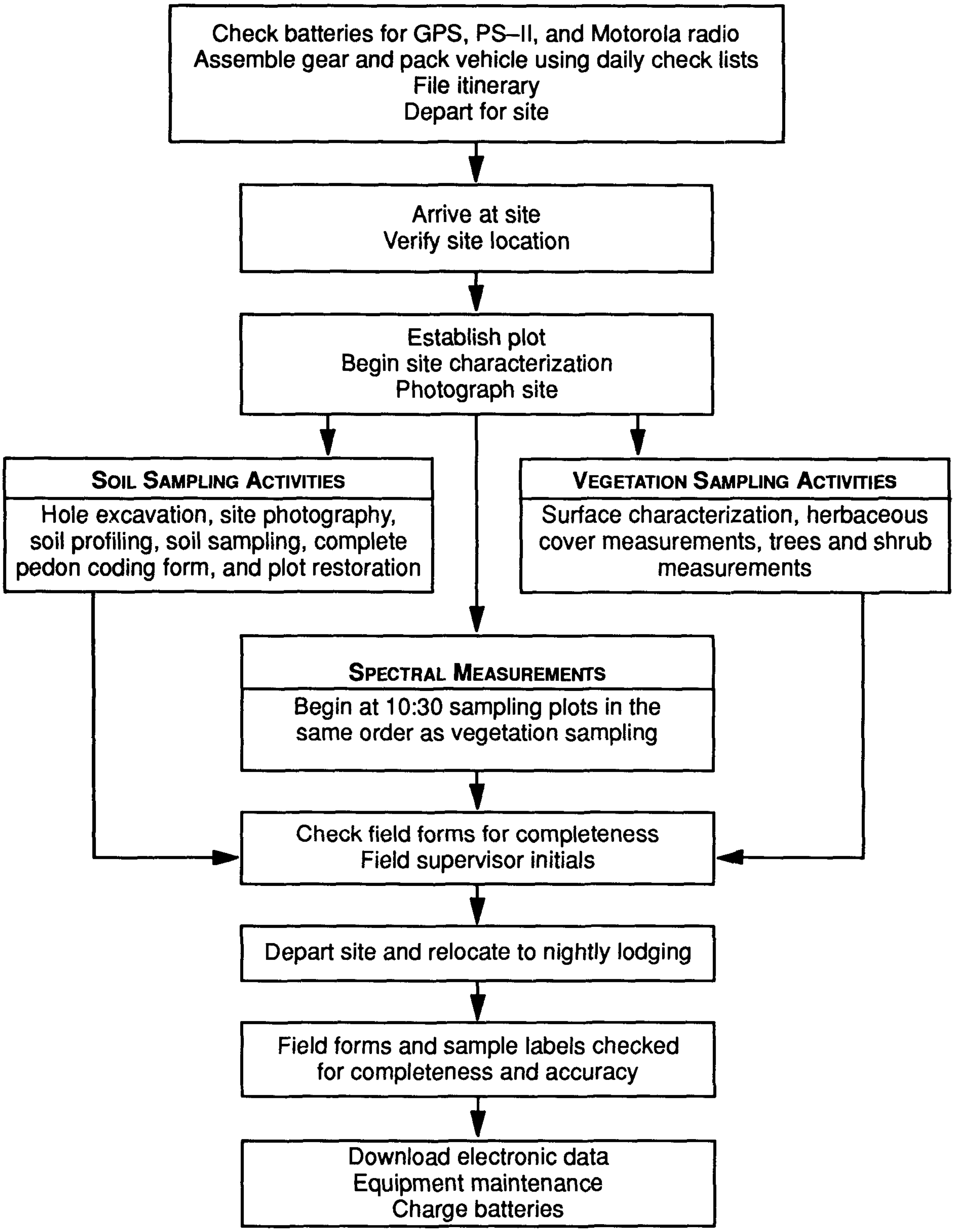


Figure 6–1. Flow Chart of Daily Activities.

each site for ease in future visits. Sampling activities as described in Sections 5.2, 5.3, and 5.4 will proceed concurrently. Upon completion of sampling activities, data forms will be reviewed for completeness, sample labels checked, the plot restored, and all equipment collected prior to returning to the vehicles.

Upon relocation to nightly lodging, the Field Supervisor will debrief the sampling crews and check the data forms, sample labels, and the condition of the samples. The sampling crews will clean and prepare equipment and supplies for the next day. The Field Supervisor will perform administrative tasks to prepare for ensuing sites.

Data forms will be held by the Field Supervisor until reunion with the Field Coordinator. Data forms will be reviewed by the Field Coordinator, photocopied, and the copies mailed to the Information Manager weekly for data entry. Original data forms will be kept on file in the field office individually for each site. Soil and vegetation samples will be shipped to the analytical laboratory by the Field Coordinator weekly.

## 6.3 REFERENCES

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# 7.0 QUALITY ASSURANCE

**(Richard D. McArthur)**

## 7.1 INTRODUCTION

It is EPA's policy that environmental data collected under its auspices must be of known and documented quality. Because of the magnitude and complexity of the EMAP data collection effort, a quality assurance (QA) plan must be developed that ensures that the type, amount, and quality of the data are adequate to meet EMAP's objectives. The draft EMAP Quality Assurance Program Plan describes the overall QA strategy for the program. EMAP–Arid will have its own specific QA plan, to be set forth in a Quality Assurance Project Plan (QAPjP). The final document will be completed before the full–scale monitoring and assessment effort begins. A draft QAPjP for the pilot study is provided as an appendix to the Field Operations and Training Manual (Franson and Pollard, 1992).

The pilot study that EMAP–Arid will conduct in 1992 is intended primarily as a field test of a selected set of indicators. A rigorous QA program is not necessary or desirable at this stage of the project. Thus, the level and scope of QA for the pilot study will be considerably less comprehensive than will be necessary for the larger scale efforts to be carried out in the future. Information obtained in this pilot study will be crucial in further developing the QAPjP for future efforts.

## 7.2 APPROACH TO QUALITY ASSURANCE

The QA plan for EMAP–Arid will be based on a philosophy of guidance and assistance rather than enforcement. The commitment of personnel at all levels to maintaining and improving the quality of data is a key element of this approach. QA is not the responsibility of any one person in the program. Rather, the responsibility is distributed among all personnel, each of whom has a specific role. Those roles must be clearly defined and organized to ensure that an adequate level of quality is attained.

Each indicator lead will be responsible for the data quality for that indicator. This responsibility will ultimately include defining Data Quality Objectives (DQOs), developing standard operating procedures, training personnel, verifying data, and planning audits and performance evaluations. The indicator leads will work closely with QA personnel in planning and conducting these activities.

## 7.3 DATA QUALITY OBJECTIVES

EMAP is committed to the use of DQOs as a means of assuring data quality. DQOs for EMAP–Arid will be defined in accordance with overall EMAP objectives and ecosystem data requirements. At this early stage of the project, however, information is not adequate to define DQOs on such a high level. The focus for the pilot study will be on Measurement Quality Objectives (MQOs).

MQOs are defined for specific measurements. They may address a number of attributes of data quality, including detectability, precision, accuracy, representativeness, completeness, and comparability:

- Detectability – the lowest concentration of an analyte that a specific analytical procedure can reliably detect.
- Precision – the level of agreement among multiple measurements of the same characteristic.
- Accuracy – the difference between an observed value and the true value.
- Representativeness – the degree to which the data collected accurately represent the population of interest.
- Completeness – the quantity of data collected with respect to the amount intended in the experimental design.
- Comparability – the similarity of data from different sources.

Some of these attributes can be assessed relatively easily, while others (particularly representativeness and comparability) will likely be extremely difficult and costly to determine.

Each indicator lead will be responsible for defining the MQOs for the measurements made during the pilot study. If existing data are not adequate for defining an MQO for a particular measurement, one of the objectives for the pilot study should be to obtain such data.

## 7.4 QUALITY ASSURANCE OBJECTIVES

The specific QA objectives for the pilot study reflect the preliminary nature of the study:

Section 2.2 lists a number of questions that the EMAP–Arid 1992 pilot will address. The primary purpose of the QA program during this pilot is to ensure that the data collected during the study are of sufficient quality to be useful in answering these questions.

The general objectives of the QA program may be stated as follows:

- establish criteria to control and assess the quality of data collected in the pilot study.
- ensure that sampling, analytical, and data management methods and procedures are documented.
- use assessment samples and procedures to verify the quality of the data.
- perform field audits to ensure that all activities are properly performed and that discrepancies are identified and resolved.
- evaluate the QA data and document the results.
- establish procedures for documentation and data verification and validation.

## 7.5 QUALITY ASSURANCE DURING THE 1992 PILOT

### 7.5.1 Training

A crucial element of quality control is sufficient training of the staff. An overall EMAP orientation and task–specific training program will be conducted before the field study begins to ensure that the field crews are technically competent and fully understand the standard operating procedures. The training will be provided primarily by the indicator leads and support personnel. The indicator leads will be responsible for evaluating members of the field crews after training and certifying that they are able to do the necessary tasks.

### 7.5.2 Site Location QA

When EMAP–Arid begins regional–scale monitoring, it will be important that the crews be able to locate predetermined sites with a known degree of accuracy. The sites used in the pilot study will not be resampled in the future, and locating them accurately is not so important. The only QA effort directed at locating the sites during the pilot will be to ensure that the protocol for using the GPS is written and followed. A site check exercise, where each crew is sent to resample a site already done by the other crew, will test how well a site can be relocated and thus give some indication as to how much effort should be given to site verification in future studies.

### 7.5.3 Vegetation Composition, Structure, and Abundance QA

The quality of the vegetation data will be assessed primarily by resampling. The resampling program will include two elements: plot checks and site checks. This activity leads to estimates of crew comparability.

- Plot checks: Both field crews, and an expert if one is available, will visit the same plot on the same day. All will measure the vegetation on the 6 transects and 4 subplots. Their results will then be compared to determine how well the field crews agree with each other and with the expert.

Suggested measurement quality objectives for this exercise will be presented in the QAPjP appended to the Field Operations and Training Manual. Failure to meet some of these objectives could mean that the crews need to be better trained or that the objective is unrealistic. The appropriate action to be taken will be determined by the indicator lead.

Plot checks ideally would be made in each habitat type at the beginning of the study and during both the third and the final week of the field season. This may not be possible, but at least two plot checks will be conducted. Because the checks will cause aconsiderable amount of disturbance to the plots, they will be done at sites that are not part of the main pilot study.

- Site checks: At least once during the field season for each formation type, each crew will be sent to locate and measure a site that has already been measured by the other crew. This exercise will not be a QA procedure in the strict sense because the crews will probably not be sampling precisely the same subplots and transects, and it will not have any measurement quality objectives. However, it will give a preliminary indication of the amount of variability to be expected when sites are revisited, information that will be essential later on when trends and changes are to be assessed.

### 7.5.4 Spectral Properties QA

The primary procedure for quality assurance of spectral measurements is ensuring that the PS–II is calibrated properly and frequently. In addition, repeat measurements to determine diurnal variability will be made on the two or more days devoted to plot checks by the vegetation and soil crews. On these days, spectra will be recorded at the same spot (for multiple spots) every 30 minutes from 10:30 am until 3:30 pm to see how much the readings vary during the course of a day. In addition, the first quadrat of transect AR (Figure 4–1) will be measured before beginning measurement of each transect and when all measurements are completed (a total of 4 times during the sampling of the plot). Variability among operators of the PS–II may also be evaluated during the pilot study.

Precisely how the spectra obtained during the repeat measurements will be compared, and what criteria will be used to judge how "close" they are to one another, will have to be specified by the indicator lead.

### 7.5.5 Soil Properties QA

The consistency of soil descriptions between field crews will be assessed during the resampling exercises. At the test plot, each crew will dig a 1.5–m deep soil pit and prepare a site and profile description. The crews will then change places and prepare a description for the other pit. The two descriptions of each pit will be compared by the indicator lead, who will also establish the criteria for judging them.

Measurement quality objectives for the analytical results will be determined by the indicator lead and the laboratory. The SCS Soils Laboratory has established QA procedures for analysis of soil samples.

External QA on the soil analyses will be provided through reference and duplicate samples. The reference samples will provide a check of the consistency of the laboratory analyses over the course of the study. The duplicate samples will allow the variability of the analytical results to be estimated.

The reference soil will be obtained from a soil pit dug during training exercises. A volume of at least 24 l will be removed from the pit, air dried, and mixed as thoroughly as possible by hand. Eight aliquots of 3 l each will then be sealed in plastic bags similar to those used to store the samples collected in the field. One bag of reference soil will be included in each batch of field samples sent to the laboratory.

A duplicate sample will be collected from the deep soil pit dug at each site where a full profile description is completed. The sample collected from one of the horizons in the pit will be twice the usual volume. It will be mixed as thoroughly as possible by hand, then divided between two sample bags. The choice of horizon for the duplicate sample is left up to the field crew.

The labels attached to the bags of QA soil will be coded in such a manner that the samples cannot be recognized as QA samples by the laboratory.

Results from the QA samples will be monitored by the QA Coordinator during the study and reported at the end of the study. No corrective action will be taken unless extremely unusual results appear.

### 7.5.6 Field Audits

Each field crew will be audited at least once during the pilot study. The auditors will interview members of the crew to make sure they have a clear understanding of the standard operating procedures and are complying with them. They will also review data forms and logs to verify that data are being recorded and documented properly. The audits will be conducted by people who are not actively involved in the QA program. The results will be reported to the Technical Director, the QA Coordinator, and the indicator leads.

Several corrective actions can be taken if the audits reveal problems, including improving staff training and reviewing and revising the standard operating procedures. Determining and taking the appropriate action will be the responsibility of the indicator lead in consultation with the Technical Director and Statistician. A follow–up audit will be performed to verify that the problem has been remedied.

### 7.5.7 Pilot Study QA Reports

The results of the plot check exercises will be evaluated by the QA Coordinator and reported to the indicator leads and the Technical Director as soon as possible after each exercise is completed. Prompt reporting of these results is essential so that any problems found can be corrected before the field season ends.

After the pilot study is completed, the QA Coordinator will prepare a written report for the Technical Director. The report will include documentation of changes made in the QA Project Plan during the study, results of quality assessments and audits, discussion of problems encountered and their resolutions, and discussion of whether measurement quality objectives were met.

## 7.6 REFERENCES

Franson, S.E. and J.E. Pollard, eds. 1992. Environmental Monitoring and Assessment Program: Arid ecosystems 1992 indicator pilot study: Colorado Plateau: field operations and training manual. U.S. Environmental Protection Agency, Washington, DC. (In press).

# 8.0 INFORMATION MANAGEMENT AND GIS

(Carol B. Thompson and Timothy B. Minor)

## 8.1 ROLE OF INFORMATION MANAGEMENT

Information management plays a significant role in EMAP, EMAP–Arid, and the Colorado Plateau Pilot Study. Its role is not defined by other aspects of the project. Instead it shares complementary roles with the research objectives and quality assurance to define how the project will be implemented. Information Management helps tie the research effort together from data collection, through data analysis and trend assessment, to the use of the information by decision makers and the public.

The efforts of Information Management in this pilot will not be as extensive as those expected in later demonstration studies or in full implementation. Other EMAP resource groups have had the opportunity to work through some of the same functions that EMAP–Arid requires and EMAP–Arid will use those lessons learned where they are applicable. There are specific lessons to be learned by EMAP–Arid because of its unique monitoring requirements and a team with new partners that needs to learn how it can best assign functions to make EMAP efforts effective and efficient for arid ecosystems.

One objective of the Colorado Plateau Pilot Study is to be able to determine how well EMAP–Arid can actualize the functions necessary to accomplish its objectives on larger scales. For this pilot, Information Management will test the following functions:

- use of GPS,
- utility of forms in the data collection effort,
- use of PDRs in selected data collection efforts,
- transfer of data between the field and central office,
- beginning requirements for the EMAP–Arid Information System,
- beginning requirements for interacting with other agencies regarding existing data sets and providing assistance with new

data sets (e.g., the SCS will be entering soils data during the laboratory analysis),

- hardware and software requirements,
- information management needs of the design, quality assurance, logistics, and statistics elements, and
- interactions of data into a GIS for spatial analysis and cartographic presentation.

The focus will be to test these functions and to have the data available for evaluating the results of the pilot study. The objective of EMAP–Arid Information Management will not include testing the distribution of the pilot study data outside of EMAP–Arid.

## 8.2 OPERATIONAL ASSUMPTIONS

The following assumptions are the basis for the modes of operation to be described in the procedures and the following sections:

1. The allowable error in locating a site is 100 m. This assessment does not need to be made in real time.
2. Paper forms will be the primary mechanism for data collection. Paper forms will serve as a backup mechanism when PDRs are used for data collection.
3. Transfer of information from the field to the central office can be on a weekly basis rather than daily basis.
4. Changes to field computer programs will be kept to a minimum after the beginning of the field season.
5. The data collected will not be considered suitable for distribution as EMAP assessment data. They will be used to evaluate indicators and as a measure of performance for the chosen mechanics of implementation in this pilot.

## 8.3 OVERVIEW OF INFORMATION MANAGEMENT FUNCTIONS

The functions carried out by information management in this pilot study fall into five categories: Pre–field; Field; Central Office; External Data Sets; and Assimilation, Review, and Assessment.

The Pre–field functions relate to the tools required for data collection, both paper forms and software, hardware set–up, and identification and coding schemes. The Field functions include the use of equipment, methods for tracking the collected information, backup of information taken, and transfer of information from the field to the central office. Central Office functions include the tracking of information received, verification of data, organization and archival of data sets, and transfer of information to the data base. External Data Set functions include the coordination of the transfer, QA, and assimilation of data sets that may be used in conjunction with the pilot data or are part of the pilot study data and computerized by another agency. Assimilation, Review, and Assessment functions include final documentation of the data processes and support for use of the data by the researchers and project management.

## 8.4 PRE–FIELD FUNCTIONS

The functions in this category are developed before the field activities begin or relate to activities that take place before work on a given site is begun. The following addresses types of functions in this category for which procedures or documentation will be developed.

The development of paper forms for data collection and instructions for completing those forms is a combined effort of the Information Manager, indicator leads, and Statistician. Forms must be designed to capture all information efficiently in the field and set up to allow for efficient data entry. All forms are placed in an individual site packet with the assigned site and soil sample numbers to be distributed to the Field Coordinator approximately one week prior to scheduled sampling for that site. This is the first step in data tracking.

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

Hardware set–up activities primarily include developing protocols for the testing of the GPS, spectrometer, PC, and PDR; the charging or replacement of batteries; reloading software; and replacement of PDR memory cards.

Identification and coding schemes must be developed to allow for the tracking of film rolls and site photography; PC disks; PDR memory cards; data forms; soil samples and voucher specimens of unidentified plant species; sites, transects, pits, plots, and points; and data file names.

## 8.5 FIELD FUNCTIONS

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

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

Tracking information collected in the field is accomplished in part by providing forms and predetermined site and sample numbers. Protocols have been developed for the continuation of soils data and vegetation data on additional pages when necessary and are included in the procedures in the Field Operations and Training Manual.

In addition, instructions for recording vegetation composition, structure, and abundance data with the PDR will be developed. These procedures will include basic data collection; completing a partial save of data when there is an interruption of data collection; handling a total loss of information; the continuation of a data set with PDR/PC; and editing data. Similar procedures for collecting spectral properties data with the PS–II have been developed along with procedures for naming data files and recording data file names.

Tracking of samples is provided by having soil and plant specimen sample labels included in each site packet with the basic site number and sample identification included. A shipping form, included in each site packet, is used to track the samples sent in a given shipment.

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

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

## 8.6 CENTRAL OFFICE FUNCTIONS

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

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

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

## 8.7 EXTERNAL DATA SETS

There are several functions that will be carried out in the use of external data sets, including: assimilation of this information in the data dictionary, catalog, and directory (DCD); tracking the versions of data sets received; assimilation with pilot study data; making these data available for pilot study measurements; and QA on data sets (annotations about data quality are stored in the DCD).

## 8.8 ASSIMILATION, REVIEW, AND ASSESSMENT

Following the pilot, the main task of information management is to provide support for the reporting process and to document the steps taken and data sets and information created in the process. The EMAP–Arid information management system will be improved and expanded based on experience of the pilot study. Interactions with the overall EMAP information management will be continued so that future data collected by EMAP–Arid may be made easily accessible by other EMAP groups and interested researchers.

# 9.0 ANALYSIS AND REPORTING

**(Susan E. Franson and Robert O. Kuehl)**

## 9.1 INTRODUCTION

The focus of the EMAP–Arid Colorado Plateau Pilot Study is to evaluate selected indicators and the logistical, QA, and Information Management requirements of implementing them. Ultimately, the indicator evaluation will determine which of the tested indicators are retained and moved to a higher indicator category and further tested in a demonstration project, and which will require more development and testing before implementation. While this evaluation will rely heavily on statistical analyses of the variance components of each measurement and indicator, other statistical analyses and subjective considerations will be taken into account.

The evaluation will answer the questions posed in Section 2, Conceptual Approach. This section will repeat each question and present the approach for data analysis to answer each.

## 9.2 QUESTIONS THAT THE PILOT IS DESIGNED TO ANSWER.

Objective 1: *To gather and evaluate information to move selected ecological indicators from the "research" category to the "development" stage in the indicator implementation process.*

1) Are the indicators for a) spectral properties, b) vegetation composition, structure, and abundance, and c) soil properties separately or in combination, correlated with independent evaluations of site condition?

The site component of variance provides a measure of the variability for a measured characteristic over the sample study area. If site variance is large, then there is variation in that characteristic over the sample area. Relating that variation to the variation in condition among sites requires an independent measure of condition.

BLM, NPS, FS, SCS, and the Navajo Nation all have condition assessments for arid lands in the study area. These assessments are based on different sets of criteria and do not necessarily exist for all of the pilot study plots. Available data from other agencies will be acquired and the pilot study results will be compared with these other condition assessments to evaluate the selected indicators for their ability to relate to condition. Because the data of other agencies are not available at this time, the exact form of these comparisons cannot be detailed.

2) What is the correlation between the remotely sensed spectral properties data from AVHRR, MSS, or TM, and field sampling of spectral properties data acquired through field sampling using a personal spectrometer?

This question is perhaps the most exploratory of all those to be evaluated in the Arid pilot. As described in the Spectral Properties Section, 36 ground–based measurements will be collected from each of 7 square grids placed in the subplots. Each grid could represent a single TM pixel, with 7 pixels of the 9 pixel cluster sampled; data from 3 subplots can be combined to represent a 4 pixel cluster, with 6 possible resamplings (although the resamplings would not be independent); or the entire collection of 7 subplots could represent the 9 pixel cluster. Similarly, the plot data could be tied to clusters of different numbers of TM pixels (4, 16, 25, etc.). Thus, ground–based measurements can be linked with the TM measurements. The degree of correlation in each case will be determined.

In these analyses, it is recognized that differences between the spatial resolution of ground–based measurements and satellite imagery lead to problems of georeferencing the two measurement types. In general, the center point of the ground–based sampling grid will be considered to coincide with the center of the TM pixel. The validity of this assumption can be evaluated in the process of considering the size of the pixel cluster that is most representative of particular collections of ground–based grid data.

For MSS and AVHRR data, the entire plot must be considered as a sample of a single pixel or the 4 (9, 16, etc.) cluster of pixels. TM pixels can be used as samples of MSS data and TM or MSS pixels can be used as samples of AVHRR data. In this manner, ground observations can be linked directly with MSS or AVHRR data or indirectly through the TM data.

3) Do remote measures of spectral properties correlate with other field measured indicators of vegetation and soils or existing assessments done by the NPS, FS, SCS, and BLM?

Correlating spectral properties with existing assessments done by the NPS, FS, SCS, and BLM is part of answering question 1 above. In addition, spectral properties will also be correlated with the vegetation and soils indicators measured in this field study.

The field estimates of proportion of cover of specific plants and surface types on a site can be used as weights for the spectra of the component plants and surface types (from the library of spectra acquired during the pilot study) in an equation to derive an estimate of the spectrum that a remote sensor will record for that site. A correlation of these derived estimates with remote spectra for the 40 sites will provide information about how accurately remote data can measure on–ground vegetation (and surface) composition and abundance.

Various indices (e.g., NDVI) will be calculated from the remote spectral data. These indices also can be correlated with the ground–based measurements of soil and vegetation indicators. The strength of these correlations will determine the feasibility of using remotely sensed indices for estimating condition synoptically rather than relying solely on ground–based sampling.

4) Which of the remote platforms (AVHRR, MSS, or TM, or a combination) appears to be most effective in obtaining the required spatial and temporal data necessary to link remotely sensed indicators with ground measures and existing data?

The discussions in 2 and 3 above apply to data from all three remote platforms. Comparisons of the results from the three platforms will allow a determination of the relative precision and accuracy of the various platforms. However, a complete evaluation will require both statistical analyses of variance, precision, and accuracy of remotely sensed spectral properties, and a consideration of the relative costs of the imagery from various satellites. Contemporaneous TM data are very expensive, with MSS and AVHRR data being much less so. However, if it is determined that remote data do not need to be current, but can be from previous years, then remote data acquisition cost could be greatly reduced.

Objective 2: Evaluate the utility of using classified Thematic Mapper (TM) imagery and other data acquired from the USFWS GAP Program to select frame materials for the pilot study and future studies and to provide data for extent estimation of arid ecosystems.

5) Do the BLP Biotic Communities Map (Reichenbacher and Brown, 1992) and the GAP data correctly identify the plant communities found at each of the pilot study sample grid points? If not, what is the level of misclassification and can this level of misclassification be compensated?

The Biotic Communities Map of North America developed by Brown and Reichenbacher (Brown and Reichenbacher, 1992; Reichenbacher and Brown, 1992) has been digitized. The EMAP–Arid sample grid points will be overlaid on this map, and the BLP formation type for each point documented. This will be compared with the data collected from the field visits for all 40 sites, and a percentage accuracy calculated.

Similarly, the vegetation map of the Utah State University Fish and Wildlife Cooperative Research Unit component of the FWS GAP program will be used to determine the formation type of each of the 40 pilot sample sites, and a percentage accuracy will be calculated.

Based on only 40 sites, realistic accuracy assessments of the Biotic Communities map or the GAP vegetation mapping are not possible. However, such information will be useful in evaluating whether in implementation, certain sites identified as not being arid by either or both existing maps could be excluded from site visits. This could provide valuable cost savings, providing that information was not lost.

6) Do the GAP data provide adequate information to describe the extent of arid ecosystems in the pilot study area?

As above, 40 sites cannot be considered as an accuracy assessment of the GAP vegetation maps. Indeed, the GAP program is performing its own accuracy assessment. Rather, a qualitative judgement of whether the GAP program and the EMAP–Arid program definitions of specific formations types concur will be made. If they are judged to be sufficiently similar, the EMAP–Arid program will explore the possibility of relying on the GAP program information to provide estimates of extent of arid ecosystems and subpopulations.

Objective 3: Evaluate sampling plot designs appropriate to the selected indicators.

7) What are the sampling design between site, subplot, and sample variance components of each of the selected indicators?

The nested structure of the design allows this question to be addressed in a standard fashion. Sites occur within one of two formation types and subplots are nested within a site, with many samples being collected from each subplot and in some cases replicate samples being taken.

Two assumptions will be made: (1) although the subplots are fixed relative to the plot center point, the subplots will be considered random samples of the plot; and (2) similarly, the samples will be considered as random samples of the subplot although their locations are fixed when the subplot is established. The issue in this case is spatial correlation between observations of samples and subplots and finite versus infinite population assumptions. These issues will be addressed and spatial correlation determined as a part of the data analysis, but for the following discussion, random samples (subplots) from an infinite population will be assumed.

Ultimately, observations on samples are averaged over all subplots for a mean value to represent the site. The variance of a single observation, var(y), is:

$$var(y) = var(ft) + var(s) + var(sp) + var(b)$$

where var(ft) is the between formation type variance; var(s) is the site to site variance; var(sp) is the subplot variance within a site; and var(b) is the sample variation within a subplot. If replicate samples are included, an additional term for replicate variance is needed. If only one sample is taken from a subplot (as in the case of some soil measurements), then the sample variation term is removed.

The analysis of variance components will include the site, subplot, and sample components. Where appropriate, the contributions of formation type, laboratory replicates, teams, and time to the overall variance will also be considered.

The components of variance will provide information required to establish DQOs for implementation. If the measured characteristic is combined with one or more other measurements to arrive at an indicator value, then the site component of variance for the indicator is what is of interest and the variance of the individual measurements is of lesser importance.

8) What are the costs associated with indicator measurement?

Costs to be evaluated include labor, equipment, laboratory analyses, imagery acquisition and processing, data analysis, etc. Costs will be evaluated relative to specific sizes of sampling units, subplots, samples, lab replicates, etc., as well as overhead costs for a site.

The subplot and sample components of variance reflect the precision of measurement at a site and will be used to arrive at a cost and time effective and statistically efficient estimate of a measured characteristic at that site.

If ybar is the mean of the observations over all samples on all subplots of a site, then the variance of the estimate is:

$$var(ybar) = var(b)/r + var(sp)/nr$$

where n is the number of samples per subplot, r is the number of subplots per site, var(sp) is the variance of samples within a subplot and var(b) is the variance of subplots within a site. This equation can be extended for cases where there are replicate samples.

The total cost for measuring a characteristic at a given site is:

$$C = rC1 + nrC2$$

where C1 is the cost of establishing a subplot and C2 is the cost of collecting the sample and measuring or analyzing the sample once the subplot is established. Once the plot center is located, the C1 cost includes all the time it takes to lay out the subplots and all other activities up to, but not including, establishing and measuring the samples.

The optimum number of samples per subplot is determined by minimizing the variance for a fixed cost, or minimizing the cost for a fixed variance. In either case, the optimum number of samples is

$$n = sq.rt.(C1*var(sp)/C2*var(b)).$$

If the allowable cost per site is fixed at C0, then the number of subplots is taken as:

$$r = C0/(C1 + nC2) .$$

If the allowable variance of the site mean is fixed at V0, then the number of subplots is taken as:

$$r = [var(b) + n * var(sp)]/n*V0 .$$

Costs of laboratory replicate analyses can be considered in a similar fashion.

9) What are the optimum numbers of subplots and samples to determine each indicator?

The pilot design is thought to provide for oversampling of the vegetation and spectral properties indicators at most sites. Thus, the variance components of the indicators will be closely examined to determine if the number of samples per subplot or the number of subplots can be reduced for implementation. The radial transects and the exterior transects subplots for vegetation sampling will be compared for their ability to characterize the site.

BLM sampling procedure for vegetation sampling includes an on–site calculation of the coefficient of variation after sampling a given number of quadrats. Based on the result of that calculation, additional quadrats may be sampled to reduce the site variation to a predetermined acceptable level. This approach has the advantage of limiting sampling to what is required to achieve a sufficiently low variation. However, the approach means that indicator values from different sites may not be based on the same support area and thus adjustments for differing inclusion probabilities are required in combining these estimates into regional estimates of condition. Through data manipulations after the pilot study, this approach will be evaluated for its effect on EMAP–Arid data collection.

10) How many sites cross a vegetation/soil complex boundary? Does the addition of quadrats provide a large enough sample to allow for estimates of the vegetation indicators?

As mentioned in Section 5.3.3 on the sampling design for vegetation indicators, standard practice of sampling programs of many land management agencies and other ecological studies calls for shifting sampling plots so that plots are entirely within one vegetation/soil type. This ensures that the resulting data have adequate precision (Bonham, 1989) but is not in keeping with the probabilistic nature of the EMAP design. The pilot study will evaluate a compromise design for plots that cross a vegetation/soil boundary, leaving the plot in the place predetermined from the EMAP grid and extending the transects to sample additional quadrats so that at least 30 quadrats are sampled for each vegetation/soil type that comprises at least 17% of the site.

A count of sites that cross a vegetation/soil boundary will answer the first part of the question. Data will be evaluated in several ways. The additional quadrats will be excluded to determine the estimates and their variances that would have resulted from a strict application of the EMAP design. The data from quadrats that represent the individual vegetation/soil types will be evaluated separately to determine if values for each type are adequately estimated. Inclusion probabilities needed to combine supplemented plots with standard plots for "regional" estimates will be determined.

Objective 4: Evaluate the logistical, quality assurance, information management, data analysis, and reporting requirements and constraints on the pilot study data.

11) What specific logistical constraints restrict the implementation of each indicator? What logistical attributes favor or enhance indicator measurement (e.g., use of a helicopter)?

This will be a qualitative evaluation based on notes from field log books, crew debriefings, etc. The evaluation will include: site access, both permission and accessibility constraints; performance of protocols for measurements; time requirements for plot sampling, traveling to sites, calibration of instruments, site restoration, data and sample processing, etc.

12) Based on the results of the pilot study, can data quality objectives be established for each indicator tested?

Formulating data quality objectives depends upon estimates of the variance components of each of the indicators. Whenever possible, variance estimates will be used to establish data quality objectives for the indicators.

13) Does the information management system effectively and efficiently provide for the movement of data from the field to the analysis stage?

Again, this will be a qualitative judgement based on the results of the pilot study. For the pilot, it is expected that data for at least one indicator will be recorded electronically using Personal Data Recorders (PDR). The operation of these PDRs and steps required to upload data to Personal Computers for storage on disks will be evaluated. Time and cost of entering data collected onto field data collection forms will also be evaluated.

During the process of data analysis, the Information Management system will be further evaluated for its ability to provide data in a reliable and efficient format. During this process, the benefits of GIS for data evaluation and display will also be evaluated.

14) Do the methods of collecting and analyzing data meet the reporting requirements for an EMAP pilot study?

The results of the pilot study will appear in a report (described below) compiled after the data collection and sample and data analyses are completed. This report will be subjected to peer review to determine if the pilot study met its objectives. This process will determine how well the methods for collecting and analyzing data meet the reporting requirements for EMAP. A goal of EMAP is to have statistical summaries available nine months after the field activities for that season are complete. The process of data analysis and reporting for this pilot study should lead to the development of computer programs that will aid EMAP–Arid to meet this nine–month reporting goal in the future.

15) What are the special logistical requirements involved with fielding multi–agency sampling crews?

This will be a qualitative assessment derived from experiences during the pilot study.

## 9.3 REPORTING

Following the pilot study, sample analysis, and data analysis, a report will be prepared presenting the results of the pilot study. The questions presented above will be addressed and any additional information that is relevant to indicator evaluation will be included. This report will be peer reviewed and published as an interagency effort within the EPA publication series.

Perhaps the most important result of the pilot study will be the information that will go into the development of the demonstration study. It is expected that the implementation plan for the demonstration study will build on this pilot study plan and incorporate many of the results of this pilot. Thus, the implementation plan for the 1993 demonstration could be viewed, in part, as a report of this pilot study.

The Field Operations and Training Manual (with its component Safety Plan and Quality Assurance Plan) developed in draft form for this pilot study will be revised on the basis of the findings of this study and will form the basis for a similar manual for the 1993 demonstration study.

No attempt will be made to make an assessment of the condition of the study area, the Colorado Plateau, or arid ecosystems. However, the data collected during the pilot will be used to begin to design the formats for Yearly Statistical Summaries and Interpretive Reports that are to be the products of EMAP–Arid implementation. This exercise will allow analysis programs to be written; formats, graphics, and tables for data presentation to be developed; and existing data needed for interpretation to be collected. These activities will speed the reporting process in the future so that EMAP–Arid can meet the EMAP goal of producing reports of results within nine months from the end of field data collection.

## 9.4 REFERENCES


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# APPENDIX A
# CANDIDATE INDICATORS

## 1.0 INTRODUCTION

The Implementation Plan describes those indicators that will be a part of the 1992 EMAP–Arid Colorado Plateau Pilot Study. In the process of discussions and workshops, several other indicators were proposed that have great promise for monitoring arid ecosystem condition. However, budgetary constraints limited the number of indicators that could be field tested to the three described in Section 5.

This appendix presents information on two indicators (landscape and retrospective) that the EMAP–Arid group intends to develop for implementation in the future. In both cases, these indicators could be derived in part from existing data or data being collected in the field as part of other indicator measurements. Therefore, they could be developed for the Pilot study after the field season, should funding allow.

## 2.0 LANDSCAPE INDICATORS

**(James D. Wickham and Vern Meentemeyer)**

### 2.1 Introduction

Landscape ecology has been described as the investigation of the ecological consequences of the spatial mix (Milne, 1988) and temporal dynamics of land cover patterns (Risser et al., 1984). This concept has been incorporated into the EMAP indicator selection process by categorizing landscape indicators as exposure/habitat rather than response indicators (Hunsaker and Carpenter, 1990). Thus, landscape indicators will serve as measurements that characterize the environmental "setting" under which response indicators, that more typically measure biotic and abiotic processes, are operating (Table A–1). By using landscape indicators in this fashion, they can be combined with response indicators to address EMAP's second objective to monitor indicators of pollutant exposure and habitat condition and seek associations between human–induced stresses and ecological condition (Hunsaker and Carpenter, 1990).

TABLE A–1. LEVELS OF CONSTRAINT FOR A SPATIAL HIERARCHY OF ECOSYSTEMS

| CONSTRAINTS | ECOLOGICAL CLASSIFICATION | EXAMPLES |
|---|---|---|
| Climatic heat, moisture, seasonality | Biome | Arid, Schlerophyll |
| Climatic heat, moisture, seasonality, topography, drainage, geology | Region | Sonoran Desert |
| Climatic heat, moisture, seasonality, topography, drainage, geology, local topography (slope, orientation, exposure, land use, land drainage, and soils) | Landscape | EMAP hexagon, watershed |
| Climatic heat, moisture, seasonality, topography, drainage, geology, local topography (slope, orientation, exposure, land use, land drainage, soils, nutrients/food, habitats, water, and competition) | Community | cottonwood–willow |

An important challenge in the selection of landscape indicators is the relative newness of some of the proposed indicators. Many are in the research category. EMAP–Arid examines these indicators and argue for the selection of a few promising indicators, and proposes measures of the parts of landscapes in the more arid portions of the U.S. which are vulnerable to change and degradation.

Another challenging problem is the inclusion of the spatial dimension in the models and descriptions of how ecosystems function across landscapes. Function across a spatial scale is a problem somewhat different from the point measurements proposed for the other portions of EMAP. Furthermore, one must deal with processes that "appear" to be slow. Small (point) systems appear to change rapidly, but big systems such as landscapes appear to change slowly (Meentemeyer and Box, 1987).

With the change in scale from individual organisms and species comes the task of identifying higher level, aggregated units suitable for landscape scale analysis. A critical problem is the degree to which changes in these units represent true changes in the landscape. This change may be "natural" or it may be anthropogenic. Simple change may not be degradation. The first step is to select a landscape metric from the several that have been developed (e.g., O'Neill et al., 1988; Forman and Godron, 1986; Burgess and Sharpe, 1981; Patton, 1975). These metrics link landscape patterns with ecological processes (Turner, 1989).

### 2.1.1 Levels of Constraint

To better visualize the unique problem of identifying landscape metrics, a hierarchical framework is beneficial. For each level, levels of constraint can be identified (Table A–1). These constraints (or constraint variables) dictate the location, extent, and spatial characteristics of the system at that level. The spatial characteristics of a biome are controlled mostly by the broad scale constraints of climate (i.e., temperature, moisture, and seasonality). For a biotic region such as the Great Basin, spatial patterns may be set by climate, as well as additional factors such as geology, topography, and drainage. For a landscape within this region, additional controls on spatial patterns could be attributed to local topography and drainage, soils, and land use. It is at this scale that the spatial patterns regulated by people become most evident. Within a landscape, communities and populations can be identified as well as the detailed ecological processes in operation.

It seems logical then to identify metrics at the landscape level and to search for information about landscape change by examining selected species at the level immediately below — communities or land use types. For communities this should perhaps be the common but vulnerable systems, such as riparian systems. A common land use type in the EMAP–Arid region is grazing.

## 2.2 Landscape Indicators in EMAP–Arid

### 2.2.1 Introduction

Six landscape indicators are proposed to be evaluated by the EMAP–Arid group. Listed in order of their priority for evaluation, they are: (1) habitat/cover type proportions, (2) spatial distribution of agriculture and riparian vegetation per stream reach, (3) fractal dimension, (4) abundance/density of key physical features, (5) spatial distribution of grazing intensity, and (6) riparian condition. These proposed indicators are rank ordered according to the degree of development and the cost/benefit of implementation. Riparian condition, spatial distribution of grazing intensity, and spatial distribution of agriculture and riparian vegetation per stream reach are newly proposed; the remainder have been previously proposed for EMAP and are discussed in detail in Hunsaker and Carpenter (1990).

### 2.2.2 Habitat/Cover Type Proportion

Habitat or cover types can be mapped and the proportion of the area in each type calculated. From such measures landscape diversity and the change among types can be assessed. It is a prerequisite for calculation of the connectivity of habitat types across landscapes (Hunsaker and Carpenter, 1990). This may be the most important and basic of all landscape metrics. It provides perhaps the most basic indicator of landscape change. Land use and its change can be viewed as a zero–sum game because a change in one type must occur at the benefit or cost of other types. Such changes can be used to determine trends and the broad–scale geography of these trends across the EMAP–Arid region. It is likely that this metric is exceptionally sensitive to human activities. It is robust because it can be universally applied, it is simple to understand, and the types in a region not only can change, they can be newly added or disappear entirely. Furthermore, land use and cover types have a large impact on the distribution of pollution and sediment source and sink patterns.

The habitat proportions will be generated using standard spectral pattern recognition techniques applied to Landsat Thematic Mapper (TM) data. This technique encompasses generation of spectral statistics using either a supervised or unsupervised approach to represent the land cover categories being mapped. These statistics are then used as input into a maximum likelihood classification algorithm. (A complete description of these image classification techniques is provided by Lillesand and Kiefer, 1979).

EMAP–Landscape Characterization (US EPA, 1990) has proposed a combined supervised–unsupervised approach, in which a clustering algorithm (unsupervised) is used to generate spectral statistics which are then matched to the desired land cover categories. These spectral statistics are then augmented by analyst–derived (supervised) spectral statistics. Both sets of statistics are then used as input into the maximum likelihood algorithm.

### 2.2.3 Spatial Distribution of Agricultural and Riparian Vegetation Per Stream Reach

White et al. (1981) estimated increases in sediment yield, nitrogen (N), and phosphorus (P) as a result of increases in the amount of land devoted to crop production in Georgia between 1973 and 1976. Sediment yield was estimated to have increased 95 percent on lands newly devoted to crop production. The position of land cover types (e.g., forest, residential, agriculture) can have a significant effect on the net release of these materials into the watershed. Peterjohn and Correl (1984) have shown that the presence of riparian vegetation between streams and cropland significantly reduced N, P, and sediment input to the stream compared to values expected with no riparian vegetation (based on the export rates of these materials from the cropland). The studies of McColl (1978), Schlosser and Karr (1981a,b) and Lowrance et al. (1984) have produced similar results.

The relationship between terrestrial/aquatic nutrient flux and land use pattern provided by these studies suggests that a landscape measure that incorporates the amount of agriculture and riparian vegetation should serve as an index of exposure against which water quality sample data can be associated. Using Geographic Information Systems (GIS), a data base could be constructed containing land cover, streams, watershed boundaries, and soils and topographic information (at a minimum). Several indices could be generated using these data, such as total stream length minus the stream length bordered by riparian vegetation, or the ratio of stream length bordered by agriculture (cropland and rangeland) to the stream length bordered by riparian vegetation. For example, to estimate the ratio of riparian–bordered stream length to agriculture–bordered stream length for an entire watershed, a GIS proximity analysis could be applied to the stream data, and then this data could be overlaid with the land cover data. The result of the GIS overlay analysis would then be "clipped" to the extent of the watershed to determine the ratio values.

### 2.2.4 Fractal Dimension

Fractal dimension measurements have been used in conjunction with geostatistics to interpret the complexity of environmental gradients (Phillips, 1985; Palmer, 1988), to estimate home range or territory size of raptors (Pennycuick and Kline, 1986; Loehle, 1990), and perhaps most commonly to describe landscape geometry (Turner, 1990; O'Neill et al., 1988; Krummel et al., 1987; Gardner et al., 1987). The interest in describing the geometry of land cover patterns arises from the observation that human and natural processes appear to operate at different scales (Krummel et al., 1987). In general, complex patch shapes have been associated with natural processes (or the absence of human influence), while more simple, regular shapes have been associated with anthropogenic processes.

Krummel et al. (1987) have provided the first empirical evidence of reduction in size and simplification of patch shape as a result of anthropogenic impact by computing the change in fractal dimension of forest patches as a function of patch size. A sharp increase in the fractal dimension was found at a patch size range of 60–73 hectares. Since patches smaller than the 60–73 hectare threshold range were significantly less complex in shape than patches above this threshold range, it was inferred that these smaller patches were largely the result of anthropogenic processes. As patch size decreases, nutrient cycling patterns may change as a result of changing edge to interior ratios; species typically found at the forest's edge may have a greater likelihood of being found at more interior positions within the patch; species diversity may decrease (Forman and Godron, 1986); and stand dynamics may change. Rex and Malanson (1990) note that king–nut hickory (*Carya laciniosa*) and swamp white oak (*Quercus bicolor*) develop only on interior sites and are relatively rare in Iowa.

It is proposed that for each natural cover type category the fractal dimension of the "individuals" or patches of that cover type be computed to generate an index of anthropogenic exposure. Per cover type fractal dimension will be calculated by regressing the log transformation of patch area (the "X" or independent variable). Starting with a 10 percent subset of the smallest patches the fractal dimension (equal to 2x the slope of the equation) will be iteratively computed by replacing the smallest patch with the next largest patch. The change in fractal dimension will then be plotted against the change in patch size to determine at what patch size anthropogenic impact is most apparent. The methodology follows the approach taken by Krummel et al. (1987).

An additional benefit of this technique for calculating fractal dimension is that it requires that patches are sorted by size. Information on the frequency distribution of patch size will likely provide a picture of landscape heterogeneity. Patch size as an indicator was previously recommended and discussed in Hunsaker and Carpenter (1990).

### 2.2.5 Abundance/Density of Key Physical Features

The abundance/density of key physical features as a landscape indicator is justified because certain physical features such as rock outcrops, cliffs, springs, and talus slopes and structural elements such as downed logs can control animal diversity. For example, Short (1986) has noted that interpreted aerial photographs are useful for determining the presence of high cliffs and cliff faces, which are habitat for peregrine and prairie falcons (*Falco peregrinus* and *F. mexicanus*, respectively). However, the cost of obtaining the necessarily large scale aerial photography (to interpret such features) and EMAP's systematic sample design are not optimal for program–wide implementation of this measurement. This measurement would best be implemented on a species specific basis, selecting a keystone, endangered, or threatened species within the study region (for which there is time series population data of good quality), with the acquisition of the aerial photography directed by the synoptic coverage of satellite data and the species known habitat orientations. In the end, these prerequisites must be aligned with the EMAP sampling design.

### 2.2.6 Spatial Distribution of Grazing Intensity

Eighty–six percent of western and Great Plains ecosystems are grazed by domestic livestock (Short, 1986), but little is known about spatial distribution of range use (Senft et al., 1985). Senft et al. (1987) have postulated that domestic sheep and cattle and many other herbivores exhibit landscape–scale matching — a diet selection behavior where feeding areas are chosen based on available plant communities and other pasture characteristics. Senft et al. (1985, 1983) applied this postulate in constructing regression equations to predict the spatial distribution of range used by cattle. These are some of the first studies to quantitatively predict cattle spatial distribution. Smith (1988) has successfully applied this technique on control and experimental pastures in Australia. The results of these studies suggest that grazing impacts are not uniform, but instead are controlled by such factors as distance from water, topography, and availability of preferred browse.

These regression techniques are constrained, however, by having only local application and the cost of collecting of input and verification data (Smith, 1988; Rittenhouse, pers. comm.). By building a GIS model, based on the knowledge gained from these and other studies that rank orders areas according to their use intensity, the obstacles of cost and local applicability should be overcome. Such a model would not be unlike the GIS model constructed by Chuvieco and Congalton (1989) for forest fire hazard mapping. In this study, vegetation, slope, aspect, proximity to roads, and elevation were rank ordered (in this listed order), weighted as 100, 30, 10, 5, and 2, respectively, and used to generate a hazard index according to the equation:

$$H = 1 + 100v + 30s + 10a + 5r + 2e.$$

The coefficients for each category were assigned a value of 0, 1, or 2 based on the attributes of that category for each cell.

This ranking concept could be applied to develop a grazing intensity index. Based on previous studies, the important categories for development of this index would include distance from water, vegetation type or Resource Value Rating (RVR; BLM, 1984), distance from salt, and slope (Roath and Krueger, 1982; Senft et al., 1983 & 1985; Smith, 1988; Owens et al., 1991). The models could then be verified by field sampling fecal pat densities (Lange and Willocks, 1978; Senft et al., 1983).

The indicator measurement is in the developmental stage, and therefore requires initial testing on just a few hexagons. Construction of the model would require large scale aerial photography concomitant with detailed vegetation mapping, topographic data at a scale matching (or nearly so) that of the aerial photography, and data on location of water and salt sources. After acquiring these data, actual construction of the GIS model remains. The most efficient approach to testing the model would be to vary the weighting factors and then test the resultant accuracies using the above mentioned field reconnaissance of fecal pat densities.

### 2.2.7 Riparian Condition

Riparian vegetation in the western United States has been reduced to as little as 2 percent of its original extent, largely as a result of dam construction (Johnson and Simpson, 1985). Citing previous studies, Rex and Malanson (1990) report that only 23 percent of the pre–European settlement forests in Iowa remain. Removal of riparian vegetation constitutes elimination of perhaps the sharpest, naturally occurring environmental gradient in the western United States (Gregory et al., 1991). Kauffman and Kreuger (1984) note that western riparian vegetation supports higher plant and animal productivity, and higher diversity, while occupying the smallest areal proportion of the western landscape. Given the biological importance of riparian ecosystems and such extensive removal, the simple measurement of remaining riparian extent should be supported by determination of whether or not these remaining systems are in a self–maintaining state and measurement of variation in habitat quality.

The methodology for assessing the condition of extant riparian systems centers on construction of age distribution diagrams for important riparian tree species. Self–maintenance can be determined by constructing age distribution diagrams for dominant species, where descending J–curves represent a self–maintaining state (Whittaker, 1975). These population curves would then be related to the following landscape measures: patch size, patch distance to stream, and amount of anthropogenic edge.

Rex and Malanson (1990) noted that along the Iowa and Cedar Rivers human impact was more strongly correlated with riparian forest patch shape than measures of fluvial geomorphology. The authors also noted that human impact resulted in reduced patch area, and that some rare riparian tree species (*Quercus bicolor* and *Carya laciniosa*) only occurred on interior sites.

Brady et al. (1985) have hypothesized that mature cottonwood–willow communities form through coalescence of seedling–stage sand bars which were previously colonized by seepwillow and other shrubs. With a history of light and moderate flood volumes, these sand bars continue to aggrade and ultimately grow together at some distance from the stream. Glinksi's (1977) observations that all seedling cottonwoods occurred immediately along the watercourse support this hypothesis. Brady et al. (1985) also noted that mature cottonwood–willow stands showed no regeneration. Gebhart et al. (1990) have suggested that mature cottonwood–willow stands will be succeeded by ash or other self–perpetuating species. The measurements proposed to assess riparian stand development (discussed below) follow these authors.

Given these constraints to the formation of cottonwood–willow riparian communities, determination of a self–maintaining state requires time series mapping to document the rate of formation of seral and mature stages and relating this to flood history information. Through time series analysis, if it can be shown that seedling–stage sandbars coalesce to form mature cottonwood–willow formations, then interpretation of aerial photographs for the presence of these sandbars should prove to be a reliable indicator of a self–maintaining state.

The Habitat Linear Appraisal System (HLAS) should be considered as part of the riparian condition indicator because it serves as an exposure/habitat indicator for field measurement in riparian areas to determine variation in habitat quality. HLAS is a technique for calculating vertical and horizontal structural diversity of vegetation using point intercept techniques; it provides a comparatively simple way to calculate the vertical and horizontal dimensions of habitat.

HLAS measures density, frequency, and dispersion of vertical diversity (understory, midstory, overstory). It can be applied on a grid or transect design. For EMAP Arid, transects could be established across the width of the floodplain and measurement points be established that are appropriate to the community being sampled.

## 3.0 RETROSPECTIVE HISTORY

**(Harold C. Fritts, Martin R. Rose, and Peter E. Wigand)**

### 3.1 Introduction

A suite of retrospective historical and paleoenvironmental indicator measurements offers an objective, repeatable, and quantitative method for determining trends in ecosystem health. They also provide a framework for the understanding of natural variation and climate conditions. Instrumental hydrometeorological data, tree–ring series, pollen data, macrobotanical remains from packrat middens, and charcoal record can be used directly or indirectly to produce retrospective reconstructions of climatic, vegetative, and disturbance histories. Direct interpretation by statistical analysis of the observations available for each retrospective measurement, or indirectly by calculating its covariance with other response, exposure, or stressor indicators, can provide information about the mean of the process, its variability, and long–term trends, i.e., normal variation. In addition, because retrospective measurements offer a lengthy temporal perspective, they are helpful in formulating conceptual models of environmental change.

Retrospective indicators put current phenomena into the context of a longer time–frame, thereby providing the opportunity to evaluate slowly operating processes, past cyclic changes or unusual events, disturbance regimes, and historically constrained phenomena (Schoonmaker and Foster, 1991). The primary advantage of retrospective indicators is that they allow probabilistic evaluations of observations obtained in the first year or two of monitoring. They are also applicable to and compatible with the same type of observations made in other regions (cross–cutting); they make use of existing databases; they are scalable up and down in compatibility with the tessellated sampling design; and models can be created to establish their covariance with other non–retrospective response, exposure and stressor indicators.

The indicators proposed for evaluation include 1) tree–ring series, 2) instrumental hydrometeorological data, 3) pollen data, 4) macrobotanical remains from packrat middens, 5) charcoal record, 6) stable isotopes, and 7) repeat photography.

## 3.2 Retrospective Indicators

### 3.2.1 Tree–ring Series

Introduction – Tree rings from core samples can be visually compared to past rings on the same specimens and to dendrochronologies for the area to identify growth increases, decreases, or other morphological changes. A variety of ring features can be used to detect a wide range of environmental changes. Where changes in ring characteristics are noted in many individuals and sites, elaborate tests can be made using techniques from dendrochronology, chemistry, isotopic analysis, statistics, and tree–ring modeling to help identify the nature of the change and probable causes.

Time series of growth ring widths sampled from woody plants growing on climatically stressed sites provide a proxy of past climatic variability, including seasonal and annual temperature, precipitation, drought, and stream discharge. The long reconstructions (from

500 years to several thousand years) provide a sound basis for obtaining more reliable estimates of central tendency, variability, and time series characteristics than the normally short period of instrumental data. These reconstructions of past climate provided by tree and shrub rings can also be calibrated with other indicators of paleoenvironmental change sampled at reasonably high frequencies.

It is proposed that tree rings be included as a core indicator because they integrate factors limiting growth throughout the past life of the plant. EMAP–Arid program will be considering energy and material balance measurements such as the Bowen's Ratio, the atmospheric carbon dioxide record, the water balance, satellite information such as the greenness index, productivity of the ecosystem, and leaf production, which ultimately limit physiological conditions in the plant controlling ring growth. The ring features that integrate these causal factors can, in turn, be compared to the same features in past years to detect changes and trends. Other than tree–ring data, no other core indicator will combine the integration of current environmental conditions with a record of past conditions so that a change in the current year can be detected without waiting for future measurements. The isotopic composition of the rings will add information on water use efficiency and water stress. The tree–ring information can be calibrated with a variety of related variables and modeled to help evaluate whether the changing conditions are important and statistically significant. The tree rings can reveal decade and century long variations while other retrospective indicators can be used to relate the tree–ring variations to century and millennia long changes in climate, fire occurrence, and community structure.

Background – Most woody plants from temperate regions produce distinct annual growth layers in their stems and roots in response to the accumulation of photosynthates, absorption of mineral nutrients, and water status of the plant (Fritts, 1976; Schweingruber, 1988; Baillie, 1982; Cook and Kairiukstis, 1990). The annual growth rings are an important component of biomass, reflecting productivity of the local environment (Graumlich et al., 1989). When environmental conditions are nominal, few environmental factors are limiting, processes are optimal, many cells are produced, and large rings are formed often with a smooth transition from earlywood to latewood. When one or more limiting factors are subnominal for a long period of time, the rates of processes affecting cell production, enlargement, and wall thickening are more limited. Fewer cells are produced, and narrow rings are formed. Often distinct cellular features are produced that indicate when and what kind of factors have limited growth (Fritts, 1976; Schweingruber, 1988; Fritts, 1990; Fritts et al., 1991).

It is relatively easy to observe ring width, which reflects the number of cells that are produced in each growth layer (Fritts et al., 1991). Potential causes of ring width change include: (1) temperature, moisture, sunshine, and carbon dioxide variations important to the photosynthetic and growth processes, (2) toxic substances that inhibit growth (Cook, 1987; Fox, 1980; Fox et al., 1986; Kienast, 1985), (3) disease (Schweingruber, 1988), (4) insect infestation (Blais, 1958; Brubaker and Green, 1979; Swetnam and Lynch, 1989), (5) defoliation by ice storms or hail (Travis et al., 1989), (6) fire (Swetnam, 1990; Swetnam and Dieterich, 1985; Swetnam and Betancourt, 1990.), (7) earthquakes (Jacoby et al., 1988; Atwater et al., 1991), (8) landslides and other geomorphic changes (Scuderi, 1984), (9) floods (Gottesfeld and Gottesfeld, 1990; Henoch and Parker, 1972; Hupp, 1988; Payette, 1980; Yanosky, 1982 & 1983), (10) frost (LaMarch and Hirschboeck, 1984; Stahle, 1990), and (11) a variety of other disturbances both natural and anthropogenic (Brubaker, 1987; Conkey, 1984; Larson, 1990; Leavitt and Long, 1987; Payette et al., 1990). These include the effects of forest management practices (Crone, 1987), fertilization (Thompson, 1981), wind (Robertson, 1986 & 1991; Shiyatov, 1990; Wade and Hewson, 1979), as well as pollution.

A sampling of the many tree ring studies of pollution includes: (Alekseyev, 1990; Alekseyeve et al., 1988; Arndt and Wehrle, 1982; Baes and McLaughlin, 1984; Baes et al., 1984; Bauch et al., 1985; Cain, 1978; Cook et al., 1987; Freyer, 1979; Gemmil et al., 1982, Greve et al., 1987; Havas and Huttunen, 1972; Innes and Cook, 1989; Kienast, 1985; Lepp, 1975; McClenahen and Dochinger, 1985; McLaughlin et al., 1982; Peterson, 1985; Peterson and Wakefield, 1987; Peterson et al., 1987; Phillips et al., 1977; Puckett, 1982; Schweingruber, 1987; Serre–Bachet, 1987; Symeonides, 1979; Tan, 1980; Tessier et al., 1990; Tian and Lepp, 1977; Treshow et al., 1987; Valkovic et al., 1979; Vins and Pollanschutz, 1977; Waring, 1987; Yokobori and Ohta, 1983).

Often features other than ring width are clearly visible, such as frost rings, false rings, eccentric reaction wood, sudden growth changes, and scars due to many causes, such as fire, flooding, impact, or stripping of the bark. A simple hand lens can be used to identify these features from cores and disks, and with training, important features can be identified and recorded while in the field (Schweingruber, 1988; Fritts and Swetnam, 1989; Cook and Kairiukstis, 1990).

For example, Schweingruber et al. (1986) used a rapid sampling and analysis approach to study forest decline in Switzerland. They surveyed forest conditions by observing the surface of samples while in the field, including 6,000 cores and 3,000 stem disks, and they determined the percentage of trees exhibiting reduction or recovery together with the date of onset and duration of each growth change. Also, Baillie and Munro (1988) deduced large–scale climatic changes attributed to large volcanic eruptions from abrupt changes in dated ring widths from wood buried in bogs in Europe.

Data Analysis – A great deal of information from Retrospective Indicators (RIs) such as tree or shrub rings can be deduced from features along a core or cross section by simply using a hand lens. Most conifers (*Pinus, Junperus*) and deciduous angiosperms (*Quercus, Populus, Juglands, Fraxinus*) can provide reliable information, and shrubs like big sagebrush (*Artemisia tridentata* Nutt.) and antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) produce well defined annual layers (Roughton, 1962 & 1972). Others, such as true mountain mahogany (*Cercocarpus montanus* Raf.) offer potential but are difficult to work with (Roughton, 1972). Shrubs of tropical origin may not produce annual rings, but techniques have been developed (Flinn et al. personal communication) for bringing out growth rings in mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.).

Any abrupt changes in growth would be clearly visible as a marked reduction or increase in ring width of the outermost rings, and the percentage change in ring size can be approximated by eye, tabulated, and averaged to reveal the extent and direction of the changes (Schweingruber et al., 1986). The investigators making these surveys must be sufficiently acquainted with dendrochronological procedures and materials to crossdate them visually so that missing and double rings are identified and anatomical anomalies within the annual growth layers that indicate stress can be recognized.

The cores and cross sections gathered from the tessellated sampling scheme that show interesting changes can be processed further in the laboratory to gather more information on the possible causes. Various analyses might be done depending upon the species and type of change that was observed, drawing from techniques of dendrochronology (Cook and Kairiukstis, 1990), densitometry (Schweingruber, 1990), image analysis (Jagels and Telewski, 1990; Vaganov, 1990), chemistry (Baes and McLaughlin, 1984; Baes et al., 1984; Guyette et al., 1989 & 1991), isotopic analysis (Leavitt and Long, 1987; Leavitt. in press; Martin and Sutherland, 1990; Pilcher, 1990; Waring, 1987), statistics and modeling. The objective of these analyses would be to identify causal agents, quantify the relationships, examine longer–term variations, and test the changes for significance.

In addition, some fundamental baseline investigations will be necessary to test hypothesized changes. These may require further collection of replicated tree ring or paleoenvironmental samples from relatively undisturbed habitats. Analysis may include (1) various biophysical phenomena and observed cellular or chemical features mentioned in the previous paragraph but observed in the natural system, (2) statistical transfer function studies to relate and calibrate regional–scale RI data to large–scale biological, hydrometeorological, or other environmental indicators important to the EMAP program (Briffa et al., 1988; Briffa et al., in press; Fritts, 1976; Fritts et al., 1990; Fritts, 1991), and (3) simulation modeling of the tree ring growth and environmental variables to build a predictive capacity based upon known biophysical relationships (Dixon et al., 1990; Fritts, 1990; Vaganov, 1990; Fritts et al., 1991; Gay, 1989).

Chemical composition of rings including stable isotopes of carbon, hydrogen, and oxygen, detailed cell structure, density, and other features attributable to specific causes requires laboratory preparation, chemical or dendrochronological treatment, and rigorous analysis to identify and evaluate the actual conditions that produced them. A variety of dendrochronological techniques have been used to identify potential causes of growth change (Fritts, 1976; Baillie, 1982; Hughes et al., 1982; Schweingruber, 1988; Cook and Kairiukstis, 1990).

It is mandatory that any qualitative features used for EMAP assessment be studied carefully under conditions of known environmental changes to certify that the features and assumed relationships are based upon quantifiable real–world phenomena. In addition, some sites and species will be encountered in the first round of grid–point sampling for which there is inadequate dendrochronological and ecophysiological information. New chronologies may be required to evaluate these new species and environmental conditions. Available chronologies may require updating to make comparisons to current conditions. Some of this can be accomplished using materials collected in the tessellated sampling scheme. Chronology development is tedious and time consuming work requiring skilled dendrochronological workers.

Retrospective indicator applications can also be scaled up and down, in line with the telescoping framework of the sampling design involving three tiers. At Tier 1 characterization they can be coupled and calibrated with remote sensing information to evaluate the statistical significance of observations with respect to long–term baseline behavior. At Tier 2 studies and site visits, physical–chemical and biological measurements of some resources can be methodologically evaluated similar to Tier 1 characterization. Tier 3 special and intensive studies can be evaluated in terms of long–term trends using retrospective indicators.

Modeling Ring Characteristics and Environmental Relationships – Two dendrochronological growth models are being developed that could greatly facilitate the evaluation of newly detected environmental conditions, ecological changes involving the productivity of sites, or the presence (or absence) of stressors (Fritts et al., 1965; Fritts, 1990; Fritts et al., 1991).

The first is an empirical model that uses correlation, regression, or response function technology, as described above, to calibrate tree–ring chronologies for any species with associated monthly temperature, precipitation, Palmer Drought Severity Index, or any other time series linked to growth–limiting conditions. Both linear and non–linear relationships can be examined, and the calibration applied to questions of climatic change (Fritts and Dean, 1990) or pollution. The original measurements, estimates, or residuals from the first analysis can be extracted and subjected to further analysis or compared to results from other growth models. A Kalman Filter can be used to evaluate changing growth response over time.

This model is based upon empirical relationships, so it can be applied to species and sites where there is little ecophysiological information and can be used in its present form to address important EMAP questions involving environmental changes recorded by tree ring chronologies. The model is easily modified and new modules can be developed to tailor it to help answer other questions of importance to the EMAP program.

The second is a mechanistic model for conifer species. It uses biophysical relationships between cambial activity and daily temperature data and soil water balance to estimate cell growth and structure across a simulated radius of an annual ring. This model requires a basic understanding of the biophysical relationships including field measurements on specific sites. The coefficients of this model have been identified and validated for *Pinus ponderosa* from Arizona and *P. sylvestris* and *Larix siberica* from Siberia. The model can be calibrated with new sites and species as cell measurements for a species are obtained along with daily climatic data and information on the beginning and ending of the growing season. Ring–width estimates from this model can be compared to ring–width indices from independent tree–ring chronologies using the empirical model, which serves as a unique type of validation. The mechanistic model is more complex than the empirical model but it has a greater potential for simulation.

Modifications of the model are planned to simulate features of hardwood, as well as softwood species and cellular structure for an entire cross–section of a stem. Eventually the model should be applied to the three–dimensional form of a tree including stem, roots, and leaves to simulate both ring structure and the increment in biomass. The present version of the model includes a simple photosynthetic module but should be expanded to utilize the output from canopy models (Running and Coughlan, 1988; Weinstein and Beloin, 1990) to estimate ring features expected from current or altered environments. With adequate funding, an EMAP version could be developed and calibrated with known conditions, so that it would be capable of simulating and investigating possible effects of suspected stressors on woody plant growth in a resource sampling unit.

### 3.2.2 Meteorological Data

While tree–ring data provide site specific information, grids of tree–ring chronologies can be analyzed and used to reconstruct large–scale climatic variations. For example, Briffa et al. (1988, in press), Fritts et al. (1990), Fritts (1991), Stockton and Meko (1975 & 1983) use principal component analysis of tree–ring parameters from tree–ring grids to extract the large–scale variations through both space and time and to calibrate the variations with grids of climatic data. Independent data are used to validate the calibration. Then, tree–ring data from 1600–1900 are applied to the validated models to reconstruct seasonal variations in climate for time periods and regions that lack instrumental measurements. This has generated a 400 year long climatic record that can be used to evaluate the short–term variations to be observed in the EMAP grid–point sampling.

The Palmer Drought Severity Index (PDSI) is a useful climatic integration that can link modern climatic data to biological responses. It is a useful measure of recent (approximately

100 years) climatic variations and is derived from a combination of monthly precipitation, temperature, and soil moisture retention information. It offers an integrated measure of moisture availability (i.e., effective precipitation). It frequently exhibits a higher covariation than temperature or precipitation alone with a tree–ring series, because a tree–ring responds to the integrated effects of temperature and precipitation through its interface with the soil and atmosphere.

### 3.2.3 Pollen Record

Paleobotanical proxy data consisting of pollen data, as well as sub–fossil and fossil plant remains recovered from the same depositional contexts, have traditionally been used to reconstruct changes and long–term trends in past community composition and predominance, often in response to climate change (Bryand and Holloway, 1985). As such, fossil pollen records have served as retrospective indicators of long–term plant community response to climate change.

Fossil pollen studies traditionally have been used to examine changes in the dominance of certain plant communities on the landscape. The pollen record has been limited by: 1) level of taxonomic identification and 2) the resolution that can be obtained (Birks and Birks, 1980). At best, the pollen rain found in lake sediments can monitor only the appearance or disappearance of specific plant species from a region. Therefore, most pollen analyses consist of broad description of trends in community changes through time.

Because most pollen is identified only to genus (Moore and Webb, 1978), it is difficult to identify the climatic limits and thus to interpret the fossil record in terms of specific climatic conditions. At best it can be used only to estimate the direction of past climatic trends and to compare the general climatic conditions to those in modern times.

### 3.2.4 Packrat Middens

Paleobotanical evidence from pollen records and woodrat middens can be used to relate any change detected by tree ring analyses to century and millennia long variations in climate, the occurrence of fire, and changes in community structure (some yearly and decadal information is available).

The contents of fossil dens (middens) of woodrats (*Neotoma* spp.) in the arid American West are preserved due to the aridity of the region or protection in caves and overhangs. The woodrats are known to forage plant remains (twigs, flowers, seeds, etc.) from within a 50 m radius, thus providing information on the species growing in the neighboring area. The plant remains are identified, often to the species (information that pollen analysis cannot provide), are radiocarbon dated, and detailed lists are constructed to provide unique information on vegetational history for a very restricted locality at a specific point in time (Spaulding, 1980 & 1985; Mehringer and Ferguson, 1969; Wells and Jorgensen, 1964; Wells and Berger, 1967; Van Devender and Spaulding, 1979). Past climate and soil conditions may be deduced from this information (Spalding, 1985). Because the distribution of many plants is determined by specific moisture and temperature conditions, their occurrences in the past at elevations above or below today's distribution provide clues to changing temperature and precipitation patterns.

The geographical dispersion of fossil woodrat middens, although chronologically discontinuous, can be assembled to reconstruct a history of both local and regional vegetation response to climatic change (Spaulding, 1981; Spaulding, 1985). Fossil woodrat midden records can also be used to investigate past vegetation distributions and their change after the end of the Pleistocene and after fire (Wells, 1983; Thompson, 1990; Mehringer and Wigand, 1990). Rates of plant migration can be reconstructed based upon the changing occurrence of migrating species through time.

### 3.2.5 Fossil Charcoal Record

Fire, as well as disease and insect infestation, are disturbance phenomena reflecting plant community health. Charcoal obtained from fossil pollen records can be used to examine the relationships between climate, fuel build–up, and fire (Wigand, 1987). Therefore, increases in charcoal abundance in the pollen records recovered from lakes and bogs indicate periods when plant communities are weakened and have become susceptible to destruction by fire or when the climatic regime is more favorable to the generation of fires. Increased amounts of charcoal with respect to pollen within a sample may record changes in 1) the frequency of fire during a period, 2) a change in the extent of the fire, 3) proximity of the fire, or 4) a change in the fuel type. The contemporaneous pollen record provides clues as to which kind of change is responsible for the build–up of charcoal in the palynological record.

Charcoal records from the American West reveal a distinct pattern. Fire becomes more important during the wet periods of the early and late Holocene in the lower elevation woodland, lower sagebrush steppe, and desert scrub. Little evidence of fire is present for the middle Holocene (Mehringer and Wigand, 1987; Mehringer and Wigand, 1990). These fires do not occur when it is wet, but are confined to droughts that interrupt periods of generally wetter climate. Therefore, a pattern of fuel build–up during wet periods, followed by drought and fire, is followed by renewed fuel build–up during succeeding wet periods. This cycle seems to continue until a major shift to drier conditions occurs. At that time, fires apparently thin the vegetation, reduce the fuel load and leave little opportunity for significant fire activity during the succeeding period of dry climate.

Although fire is not an immediate indicator of community health, it is a proxy record of past community health that often precedes changes in plant community composition. Fire may be viewed as a key in opening niches for migrating species to occupy as a new climatic regime is established.

### 3.2.6 Stable Isotopes, Fossil Woodrat Midden Materials, and Tree Ring

The core of stable isotope research concentrates on the ecophysiological and environmental patterns of selected plant species. As with all RIs, calibration of the linkages between stable isotopic storage in plant tissues and climate is required before applying the analyses to fossil woodrat middens or to tree–ring chronologies (Long et al., 1990). This is accomplished by correlating isotopic measurements with environmental changes along environmentally sensitive transects or from one time period to the next.

Water is the key factor for study, because it is the primary limiting factor for growth and productivity in semi–arid environments (Smith and Nowak, 1990). Drought severity, as characterized by the Palmer Drought Severity Index, reflects potential evapotranspiration. Analyses of the hydrogen isotopic ratio ($^{2}H$:$^{1}$1H ($\delta D$)), the oxygen isotopic ratio ($^{18}O$:$^{16}O$ ($\delta^{18}O$)), and the carbon isotopic ratio ($^{13}C$:$^{12}C$ ($\delta^{13}C$)) should result in identificaiton of changes in effective precipitation and possible changes in water use efficiency which affect the growth and success of plants (Ehleringer et al., 1990; Farquhar and Richards, 1984; Toft et al., 1989; Long et al., 1990; Siegel, 1983; Morecroft and Woodward, 1990).

### 3.2.7 Repeat Photography as a Retrospective Indicator

The advent of photography during the last century has provided the opportunity to enhance the record of paleoenvironmental change provided by other retrospective indicators by visually documenting environmental change over a variety of time spans. Comparison of photographs of the same locality taken as much as a hundred years or more apart can be used to track changes in: 1) plant community distribution (*i.e.*, expansion and retreats of lower and upper tree lines), 2) erosional and depositional processes, and 3) human land use.

Environmental changes occurring over the last 150 years or so already have been followed with photo series that already exist (Hastings and Turner, 1965; Rogers, 1982; Rogers et al., 1984).

Time–lapse photography can track environmental change with intervals on the order of minutes, hours, days, months, years, decades, scores of years, or more. At the opposite end of the time scale, high–speed photography can be used to monitor much more rapid changes on the order of seconds or fractions of a second. Although the range of time that the environment can be monitored with photographs is limited to the last 160 years or so, this record can be extended with landscape paintings that depict environmental changes stretching back into the 1500s (Ladurie, 1971) (e.g., the winterscapes of the Dutch painter, Pieter Bruegel the Elder; and the depictions of greatly expanded glaciers during the "Little Ice Age").

Paintings or lithographs of lakes, mountain scapes, etc. of the early period of exploration of the American West often record conditions different than those that predominate today. This source of environmental proxy data was generated not only by artists on exploration and survey parties, but also by artists of the Romantic Style who were fascinated by the "pristine" or "primeval" nature of the American West. Whereas much of the exploration and survey photography and illustrations can be obtained from government sources, paintings, lithographs, and other illustrations are often housed in private collections or in local historical museums, which often curate historical photographs containing environmental data spanning the period of settlement of the American West.

## 3.3 Data Sources

The use of retrospective indicators is not limited exclusively to arid lands, nor even to the United States. This cross–cutting attribute is a desirable feature of EMAP indicators. Comparable, although sometimes less well developed, information exists on a continental and worldwide basis. An extensive tree ring network is available for arid regions from western Canada to northern Mexico, and there is reasonable coverage for the eastern United States. Between one and two thousand chronologies already exist, although not all extend to the present (as each year passes all existing chronologies are one more year out of date). For evaluating trends exceeding the age of trees and shrubs sampled as a part of the EMAP program, it will be necessary to update some existing chronologies and paleoenvironmental data. In addition, it may be necessary to develop new time series for evaluating changes appearing in the EMAP samples in cases where no paleoenvironmental time series exists today.

Long–term macroclimatic patterns are similar over wide regions, so the rings from climate stressed old trees growing on relatively undisturbed habitats in neighboring areas can be sampled and analyzed for their paleoclimatic information. These sites could include long–term ecological research sites (LTERs) where other baseline information has already been assembled that could be calibrated with the tree–ring information and related to past and current conditions.

### 3.3.1 Tree–ring Series Data Sources

An extensive database of tree–ring information is available from the NOAA National Geophysical Data Center (NGDC) in Boulder, Colorado. Seven hundred twelve chronologies are available from North America, with several hundred of those representing sites from the western United States. The chronologies specific to our study area need to be identified. Other sources have not been specified.

### 3.3.2 Packrat Midden Data Sources

While no formal data base exists for packrat midden data, numerous studies are ongoing and have been conducted and published (e.g., Betancourt et al., 1990). These are largely focused in arid ecosystems in the U.S. and provide a basis for utilizing midden data in the EMAP–Arid pilot study.

### 3.3.3 Pollen Data Sources

An American Pollen Database that will incorporate all North American pollen data (stratigraphic and surface–sample data) is under development. The database coordinator is Eric Grimm at the Illinois State Museum. Whether this database will be useful for the pilot is unknown.

## 3.4 Data Analysis

Analysis using retrospective indicators can be accomplished using both statistical techniques and simulation modeling. For example, a comparison can be made of the current year's shrub– or tree–ring index for a species and site with the time series of indices for the previous several hundred years. The current year's value can be evaluated with respect to long term central tendency, variability, and persistence structure; and a probabilistic value can be associated with its interpretation. In the absence of such retrospective information, the current year's observations can be compared only to spatial variation. If retrospective information is unavailable, it is impossible to state with any degree of confidence what the current year's values represent in terms of temporal behavior.

In addition, a statistical transfer function can be developed that will relate statistically independent variables of retrospective information (tree–ring indices) to dependent variables of seasonal or annual climate (Fritts, 1976; Fritts et al., 1990 & 1991; Fritts, 1991). This is accomplished using a portion of the recent period of common overlap between the two types of variables to calibrate the relationship and then using another portion to validate the relationship (Fritts et al., 1990). The transfer function can be applied to the tree–ring series predating the climatic record to reconstruct past climatic conditions for several centuries. A long–term record of a stressor indicator (climate) is produced against which future values can be evaluated. This technique can be used to reconstruct a variety of new retrospective indicators (NRIs) gathered by remote sensing or monitored at collecting stations as long as the variable is linked in some way to environmental factors directly affecting the retrospective indicators (RIs) (Fritts, 1976). For example, Fritts (1991) reconstructs spatial variations of sea–level pressure, as well as temperature and precipitation from a spatial grid of tree ring chronologies. Atmospheric pressure is not known to influence growth, but it is related to the movement of storms that deliver the precipitation, affect the sunlight, and control the winds influencing the temperature that, in turn, affect ring–width variations.

Including retrospective indicators (RIs) for as many resources as possible could supplant, or at the very least, complement the wait–and–see approach for a variety of important indicators. Such RIs observations already exist for decades, centuries, or thousands of years depending upon the variable and the RI. Timely interpretation of observations is pragmatic scientifically, because results can be introduced into peer review publications and subjected to wide distribution and criticism within a short time period. Such immediate statistical interpretation and evaluation of indicators could be an attractive marketing feature to funding sources (e.g., Congress) unwilling to wait years for results. It will take four years before sample results are available for all locations under current design guidelines. From a political survivability perspective it may be advantageous to be able to examine some measure of the relative changes or lack of changes (however limited) within the first few years of the EMAP effort.

### 3.4.1 Tree–ring Series Data Analysis

A variety of ring characteristics and climatic variables can be analyzed. Indices of maximum latewood density were used in the first two studies of Briffa et al. (1988, in press) to reconstruct warm–season temperatures over Europe and western North America. Fritts et al. (1990), Fritts (1991) used indices of ring widths to reconstruct seasonal and annual temperature and precipitation for North America and sea–level pressure for the North Pacific and North American sectors. Similar indices were used by Stockton and Meko (1975 & 1983), but they reconstructed Palmer Drought Severity Indices over the western United States. In addition, there are numerous dendroclimatic reconstructions for local regions, historical references to climatic conditions or events, and basic information from all RIs that can be assembled with the large–scale tree–ring reconstructions to study the range of variation for each region, time period, and variable. This can be used to generate a type of probability distribution to place confidence limits on the paleoclimatic estimates and to test observed changes.

Instead of developing transfer functions, the tree–ring index can be considered the dependent variable and climatic data the independent variables to obtain response functions. The index is calibrated with principal components of monthly climatic data and the resulting regression coefficients are multiplied by the eigenvectors of the climatic data to obtain response function coefficients identified with each monthly climatic variable (Fritts, 1976). However, in the original version, the errors of the response function coefficients were found to be biased because stepwise regression procedures were applied to collinear variables. This problem has now been resolved by using a bootstrap method (Efron, 1979,

1983) to obtain unbiased estimates of the response function coefficients. Response functions obtained by using this new technique or by using more conventional multiple regression techniques are used to assess the quality, structure, and amount of climatic information in tree–ring chronologies or to remove the climatic signal in the record so that the effects of non–climatic factors can be evaluated (Fritts et al., 1991). This approach can be used to calibrate a tree–ring chronology with climatic variation for a period known to be free of pollution and then to estimate the effect of climate on growth through the interval of possible pollution. Any differences between the growth estimated solely from climate and the actual chronology during the pollution period are identified as a possible effect of pollution (Fritts et al., 1991). The errors from the bootstrap analysis can be used to test the significance of the differences. The same technique can be used to detect the possible effect of rising atmospheric $CO_2$ on ring characteristics (LaMarche et al., 1986), as well as other growth promoting or inhibiting influences present in the tree–growth record.

Replicate cores, two radii per tree, are usually sampled from 20 to 50 old trees, growing under similar environmental conditions. These samples are mounted, the surface prepared, all rings crossdated, ring characteristics measured, and subjected to quality control to assure accuracy of dating and measurement. These data are standardized to remove trends due to increasing tree–age and stand dynamics, indices are computed, and the information combined to obtain a mean chronology. Autoregressive Moving Average (ARMA) modeling may be required to simplify the time–series characteristics. A variety of ring characteristics can be measured, some using simple optical procedures and others using more complex technology involving x–rays, image analysis, isotopic analysis, or analytical chemistry.

### 3.4.2 Pollen Data Analysis

The resolution of the pollen record is influenced by the deposition rates of the sediments, the accuracy of dating, and the sample collection process. Except for annual varved sediments, pollen cores can only be dated using radiocarbon of organic materials deposited in the sediments. Most pollen samples are taken at approximate 50 to 100 year intervals along the length of the sampled core because of the limitations of time and money. In addition, the pollen rain in a sediment may include several years due to the height of the column that is sampled and the annual turnover and redeposition of sediments at the bottom of the lake.

Deep steep–sided lakes with reducing conditions (meromictic lakes) physically prevent the annual turnover of sediments that mixes lake–bottom sediments and pollen. However, this still does not prevent materials from being redeposited from the slopes of the lake basin. Decreasing the distance between samples and reducing sample height will increase the resolution of the record, but not its precision. Use of x–rays to locate annual or semi–annual breaks in the record is possible but costly. However, even a slight decrease in the sample interval has beneficial results in changing the pollen record from one reflecting long–term plant community expansions and contractions to one reflecting near–annual changes in pollen production. This can be accomplished by finding a locality that has a very rapid deposition rate, e.g., 2 m per 1,000 years or so. In such a situation, greater detail can be achieved without decreasing sample spacing and height. When the number of years between samples is reduced, much shorter term variations in pollen production, unrelated to expansion and contraction of specific plant communities, may be revealed. These are the result of interannual changes in pollen production of already established plants and reflect changing climatic conditions (Grosse–Brauckmann, 1978). This change in pollen production from one year to the next can be applied both to modern and fossil pollen records to examine possible environmental changes and community health.

Multivariate transfer functions can also be established between a spatial array of locations where surface pollen has been collected and arrays of either quantitative vegetation information or climatic data. These types of analyses have been developed most extensively and convincingly in the eastern, northeastern, and central United States (Bernabo and Webb, 1977; Webb and Clark, 1977; Webb and Bryson, 1972). The transfer functions established with the spatial data arrays can then be used to interpret the time series of palynological data available from lake sediments, bogs, and other depositional environments with good preservation. However, different rates of plant migration after deglaciation also influence community structure and can seriously distort the climatic signal in some pollen samples.

### 3.4.3 Packrat Middens Data Analysis

In order to assess accurately the information contained in fossil woodrat middens, the collecting bias of the woodrat must be taken into account (Dial and Czaplewski, 1990). When the contents of modern middens are compared with surrounding plant communities there is not necessarily a one to one correlation. This relationship, as well as how plant species abundance may vary throughout the nest, must be studied carefully (Finley, 1990).

Unfortunately, community composition may lag behind climatic change due to the time required for plant migration. Thus, traditional fossil woodrat midden data appears to be insensitive to short–term climatic changes. The time required for species favored by a new climatic regime to enter into an area is affected by (1) distance from the area of dispersion, (2) dispersal mechanisms, and (3) the opening of niches for the new species to fill. In addition, because plant materials from fossil woodrat middens cannot be adequately quantified, and because their original incorporation within the nest is biased by the collecting behavior of the woodrat, their use as sensitive indicators of plant community change has been ineffectual.

However, isotopic analysis provides new possibilities of examining immediate and sensitive plant response to rapid climate change with fossil woodrat midden materials (Long et al., 1990). Information gained on the physiological responses of modern species to environmental variation can be used to deduce past plant responses that may indicate climate changes.

### 3.4.4 Fossil Charcoal Records Data Analysis

Increased abundance of charcoal followed by clear decreases in arboreal and shrub pollen and increases in grasses and weed pollen indicate local fire. Additionally, local fires often introduce larger charcoal into the record, because with distance the larger fragments have settled out. Significant increases or decreases in the mean size of charcoal through time in either local or regional fires also indicate a change in the kind of fuel being consumed. Changes in fire frequency only can be revealed through x–ray analysis of the pollen core, which may reveal changes in the number of charcoal laminae per time period being noted.

### 3.4.5 Stable Isotopes, Fossil Woodrat Midden Materials, and Tree Ring Data Analysis

The ratio $\delta D:\delta^{18}O$ in physical systems is inversely related to drought severity (Dansgaard, 1964; Hoefs, 1987). This also should hold true for plant systems (Yakir et al., 1990). Research presently being conducted by Dr. R.S. Novak of the University of Nevada, Reno is addressing this questions in order to verify that $^{13}C$ of plants is related to water use efficiency, leaf gas exchange measurements of photosynthesis, transpiration, and leaf conductance are being used to determine real time measurements of water use efficiency, as well as the slope of the relationship between photosynthesis and conductance. The relationship between $\delta^{13}C$ and growth also is being determined by correlation of the carbon isotope ratio with tree–ring measurements. Using this information, it will be determined if these isotopic ratios can be used to examine whether particular plant species are restricted to specific environments or not. For these relationships to be usefully revealed, species such as Utah juniper and pinyon pine, with wide spatial and deep time distribution, are being selected for study.

Unfortunately, changing abundance of individual plant species in a community may not evidence only the physiological response of an apparently homogeneous species, but it may reflect genotypic variation. Genotypic changes of this kind across space and through time can be monitored by studying DNA using Restriction Fragment Length Polymorphism

(RFLP) techniques on both modern materials and materials from fossil woodrat middens (Sambrook et al., 1989). This can provide information on conifer phylogeny, population structure, and genotypic distribution of natural populations (Kiem et al., 1989; Nybom and Schall, 1990; Strauss and Doerksen, 1990; Strauss et al., 1990) which can produce substantial differences in response over the EMAP sampling area.

Currently this diversity is being studied in three ways by Dr. R. Tausch (Project Leader for the Intermountain Research Station of the U.S. Forest Service). First, the geographical variation of a particular species across an area is being determined. Second, the role of topography in determining the geographical distribution of genetic patterns will be determined. Third, paleoecological materials will be examined to add information on variations through time. Such an approach provides the opportunity to integrate genetics, physiological ecology, palaeoecology, population biology, and dendrochronology in the EMAP program.

## 3.5 Conclusions

The cells in annual rings of woody plants serve as biomarkers of past limiting conditions. We must become aware of the many kinds of environmental information contained in the ring structures of woody plants and utilize this information in planning for and detecting future changes.

Thus, the annual rings of woody plants should be one of the EMAP core indicators. All materials should be examined at the time of collection and obvious growth changes or evidence of particular stress be recorded and tabulated. All samples should be saved for potential laboratory analysis of any changes that are identified.

Relevant literature should be reviewed and plant species identified that are likely to provide useful information. Additional species encountered in EMAP sampling should be investigated as to whether their rings also contain useful information.

Dendrochronological simulation models should be developed and applied to EMAP questions. This would help to identify ecosystem responses to past environmental changes that could be used to predict responses to future changes.

Grids of long tree–ring chronologies can be calibrated with appropriate diagnostic indicators to reconstruct base line conditions. This would extend the data sets over a longer period and provide for more rigorous interpretation and testing of future changes.

The seasonal and annual variability of climatic data can be reconstructed from dendrochronological data. Also, available climatic information about the past from all retrospective indicators and historical accounts can be assembled, compared, and summarized for EMAP evaluation of current climatic trends and conditions.

Pollen data reveal information on community structure which can sometimes be interpreted in terms of climatic history, but rates of plant migration following deglaciation also affect community structure. A finer sampling of sediments can reveal shorter–term changes related to yearly pollen production and changes in the local environments. Charcoal fragments in the pollen profile provide clues to periods of wetness and dryness that affect fuel loading and health of the community.

The potential of stable isotopic and DNA analysis of paleobotanical micro– and macro–fossil data and tree rings has afforded the opportunity to examine plant physiology at the organismal level through time. This has enhanced the use of these data for the detection of organismal response to environmental change and the use of this information for projecting future botanical responses to global changes. The method is not only relatively easy to perform, but it is also cost effective.

Repeat photography provides visual documentation of the environmental changes that are evidenced by other retrospective indicators. Not only can it record that change occurred, but it can be used to document the degree of change, so that the actual biotic response can be equated with the environmental parameters that caused them.

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