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# Arid Ecosystems Strategic Monitoring Plan, 1991

Environmental Monitoring and Assessment Program

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## Environmental Monitoring and Assessment Program

Environmental Monitoring Systems Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Las Vegas, Nevada, 89143-3478

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**Environmental Monitoring and Assessment Program (EMAP)**

# STRATEGIC MONITORING PLAN: ARID ECOSYSTEMS

*Arid Ecosystems Resource Group*

William G. Kepner[3], Technical Director
Carl A. Fox[1], Principal Scientist

John Baker[5], Bob Breckenridge[4], Chris Elvidge[1], Virginia Eno[2], John Flueck[6], Susan Franson[3], Janet Jackson[1], Bruce Jones[3], Michael Meyer[1], David Mouat[1], Martin Rose[1], Carol Thompson[2]

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1 Desert Research Institute, Biological Sciences Center, Reno, Nevada
2 Desert Research Institute, Water Resources Center, Las Vegas, Nevada
3 Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada
4 Idaho National Engineering Laboratory, Idaho Falls, Idaho
5 Lockheed Engineering and Sciences, Environmental Program Office, Las Vegas, Nevada
6 University of Nevada, Las Vegas, Environmental Research Center, Las Vegas, Nevada

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ADDNET | Acid Deposition Data Network |
| ADP | Automated Data Processing |
| ADS | Acid Deposition System |
| AIRS | Aerometric Information Retrieval System |
| ARMA | Auto Regressive Moring Average |
| ASA | American Statistical Association |
| AVHRR | Advanced Very High Resolution Radiometer |
| AVIRIS | Airborne Visible and Infrared Imaging Spectrometer |
| AWUDS | Aggregated Water Use Data System |
| BBS | Breeding Bird Survey |
| BLM | U.S. Bureau of Land Management |
| CDD | Central Data Dictionary |
| CDF | Cumulative Distribution Function |
| CERCLA | Comprehensive Environmental Response Compension and Liability Act |
| COE | U.S. Army Corps of Engineers |
| CSIRO | Commonwealth Scientific and Industrial Research Organization |
| DBMS | Data Base Management System |
| DOE | Department of Energy, National Environmental Research Parks, and associated ecological regions. |
| DRI | Desert Research Institute |
| DSI | Data Set Index |
| DGAM | Designated Geographic Area Module |
| DOE | U.S. Department of Energy |

| | |
|---|---|
| EDA | Exploratory Data Analysis |
| EMAP | Environmental Monitoring and Assessment Program |
| EMAP-Arid | Environmental Monitoring and Assessment Program Arid Ecosystems Resource Group |
| EMSL-LV | Environmental Monitoring Systems Laboratory, Las Vegas, Nevada |
| EPA | U.S. Environmental Protection Agency |
| ESIS | Earth Sciences Information System |
| FLPMA | Federal Land Policy and Management Act of 1976 |
| FRAMIS | Forest Service Range Management Information System |
| FHS | fixed historical site |
| FWS | U.S. Fish and Wildlife Service |
| GAO | General Accounting Office |
| GIS | geographic information system |
| GLM | General Linear Model |
| HAPDEX | Hydrologic-Atmospheric Pilot Experiment |
| HBN | hydrologic benchmark network |
| IBP | International Biological Program |
| IDS | Integrated Data System |
| IHICS | Integrated Habitat Inventory and Classification System |
| IMPROVE | Interagency Monitoring of Protected Visual Environments |
| INEL | Idaho National Engineering Laboratory |
| LTER | Long-Term Ecological Research |
| LCTA | Land Condition Trend Analysis |
| MAP3S/PCN | Multi-State Atmospheric Power Production Pollution Study/Precipitation Chemistry Network |
| MSS | Multispectral scanner |

| | |
|---|---|
| NADP/NTN | National Atmospheric Deposition Program/National Trends Network |
| NAPAP | National Acid Precipitation Assessment Program |
| NASA | U.S. National Aeronautics and Space Administration |
| NASQAN | National Stream Quality Accounting Network |
| NATSGO | National Soil Geographic Database |
| NAWDEX | National Water Data Index |
| NAWQA | National Water Quality Assessment Program |
| NCBP | National Contaminant Biomonitoring Program |
| NCSS | National Cooperative Soil Survey |
| NDDN | National Dry Deposition Network |
| NDVI | Normalized Difference Vegetation Index |
| NERP | National Environmental Research Parks |
| NGDC | National Geophysical Data Center (Boulder, CO) |
| NOAA | U.S. National Oceanographic and Atmospheric Administration |
| NPS | U.S. National Park Service |
| NPS | National Park Service Monitoring Sites Interagency Monitoring of Protected Visual Environment (IMPROVE) and Visibility Monitoring Programs |
| NRC | National Research Council |
| NRDS | National Range Data System |
| NRI | National Resource Inventory |
| NSF | National Science Foundation |
| NWI | National Wetlands Inventory |
| NWWRC | Northwest Watershed Research Center |
| PSDI | Palmer Drought Severity Index |

| | |
|---|---|
| PCA | Principal Components Analysis |
| qA/QC | Quality assurance/quality control |
| RAIDS | Riparian and Aquatic Information Data Summary |
| RCRA | Resource Conservation and Recovery Act |
| RGIM | Resource Group Information Managers |
| RPA | Resource Planning Assessment |
| SCS | U.S. Soil Conservation Service |
| SSURGO | Status of Soil Survey Geographic Database |
| STATSGO | Status of State Soil Geographic Database |
| STORET | Storage and Retrieval of Water Quality Data |
| T&E or T/E | threatened and endangered |
| TEDS | Threatened and Endangered Data System |
| TM | Thematic Mapper |
| TSAM | Time Series Analysis Model |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USGS | U.S. Geological Survey |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey NASQAN Sampling Sites |
| USGS | U.S. Geological Survey Hydrologic Benchmark Sampling Stations |
| USFWS | U.S. Fish and Wildlife Service National Wildlife Refuge System sources for arid lands are protected and managed through statutes such as the Wilderness Act of 1964, the Land and Water Conservation Fund Act of 1965, Wild and Scenic Rivers Act of 1968 and the Soil and Water Resource Conservation Act of 1977. Other public laws, such as the Clean Air Act and Safe Drinking Water Act, address mostly human health issues, but are limited in their protection of ecological systems. |

| | |
|---|---|
| WATSTORE | National Water Data Storage and Retrieval System |
| WDMS | Water Data Management System |
| WORDS | Wildlife Observation Report Data System |

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# 1.0 INTRODUCTION

Degradation of the environment as a result of man's activities is not a recent phenomenon. The development of agriculture about 10,000 years ago gave rise to settled societies and placed tremendous strains on local ecosystems. As populations increased so did the demand for food and other resources. Short-term demands outweighed any considerations for long-term ecological stability. Eventually extensive deforestation, salinization, and soil erosion brought about a severe decline in productivity and dramatic changes in the Earth's ecosystem. The Mediterranean region is a good example where, beginning about 2000 B.C., 90 percent of the original oak, beech, pine, and cedar forests were replaced by olive trees, vines, low bushes, and strongly scented herbs in less than 2,000 years as a result of increasing demands for timber and land.

While in the past man's impact on the environment was generally restricted to local and regional areas, the scale of current environmental problems spans the globe. Environmental issues such as global climatic change, acidic deposition, and toxic wastes are and will continue to be of great worldwide economic, political, and social concern during the coming decades. Ecological pressures on the Earth's limited natural resources are anticipated to increase as man's activities continue to alter the Earth's ecosystems. Years of scientific study have heightened environmental awareness and revealed the complexity of the Earth's ecosystems and their response to natural and anthropogenic perturbations. Unfortunately, there has been a tandency of deal independently with environmental issues related to land, air, and water resources. Because these components of the environment are intricately linked and often codependent, dealing with them independently has led to the environmental degradation of both natural and developed areas (Viessman, 1990).

Environmental degradation has also resulted from the inability to detect ecosystem change. Much of this inability stems from a poorly documented environmental data base upon which to base comparisons regarding environmental change. Thus, while it is generally perceived that current policies and programs are protecting and improving the quality of the environment, it is difficult to quantitatively prove it with the available data.

Recognizing the gap in the availability of baseline environmental data and the need for an integrated approach to address environmental issues, the U.S. Environmental Protection Agency (EPA), at the recommendation of the Agency Science Advisory Board, established the Environmental Monitoring and Assessment Program (EMAP). This Program is part of the EPA's Office of Research and Development (ORD) and represents the foundation for the ORD Ecological Risk Assessment Program. When fully implemented in cooperation with other government agencies that share resource monitoring responsibilities, EMAP will provide information needed to: (1) document the current condition of the Nation's ecological resources; (2) understand why that condition exists; and (3) predict future ecological conditions under various management scenarios (EPA, 1990).

## 1.1 OVERVIEW OF EMAP

The Environmental Monitoring and Assessment Program is designed as an interagency, interdisciplinary program to characterize and evaluate the Nation's ecological resources on regional and national scales over long periods of time. The overall goal of EMAP is to monitor the status and assess trends in the condition of the Nation's ecological resources in order to help evaluate current environmental policies and identify emerging environmental problems before they become widespread or irreversible. EMAP provides a strategic approach to meet the growing need to identify and bound the extent, magnitude, and location of degradation or improvement in environmental condition. EMAP focuses specifically on regional-scale conditions over periods of years to decades. EMAP is not intended to describe all components or attributes of an ecosystem or resource type. It is not a process-oriented research program and will not describe how systems function. It will, however, provide information on specific indicators measured during a specific index period, as a "snapshot" of the overall condition of a system.

The EMAP approach to environmental monitoring is designed to: (1) ensure broad geographic coverage; (2) enable quantitative and unbiased estimates of ecological status and trends; (3) facilitate analyses of associations among measurements of habitat condition, pollutant sources and exposure, and biological condition (indicators); and (4) have sufficient flexibility to accommodate sampling of multiple types of resources and to identify emerging environmental issues (EPA, 1990). Specific EMAP objectives are to:

- Estimate the current status, extent, changes, and trends in indicators of the condition of the Nation's ecological resources on a regional basis with known confidence.
- Monitor indicators of pollutant exposure and habitat condition and seek associations between human-induced stresses and ecological condition.
- Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

To meet these objectives and insure the efficient execution of the program, EMAP is organized into four major elements: resource monitoring, integration, coordination, and developmental research (Figure 1-1).

*Resource monitoring focuses on the collection and interpretation of field data on the* ecological condition of eight resource categories: agroecosystems, arid ecosystems, forests, estuaries, Great Lakes, coastal waters, surface waters, and wetlands. These resource groups were established by ecosystem type to assemble scientific teams with specific areas of expertise and to facilitate interagency cooperation. EMAP scientists fully recognize that the activities of these resource groups will have to be integrated due to the interacting nature of these systems in the environment. Field and remote sensing-based biological, chemical, and physical measurements will be made by each resource group on statistically selected sampling sites for each resource class, e.g., oak-hickory forests, emergent estuarine wetlands, or sagebrush desert. These measurements will be evaluated in conjunction with data on atmospheric deposition, climate, and

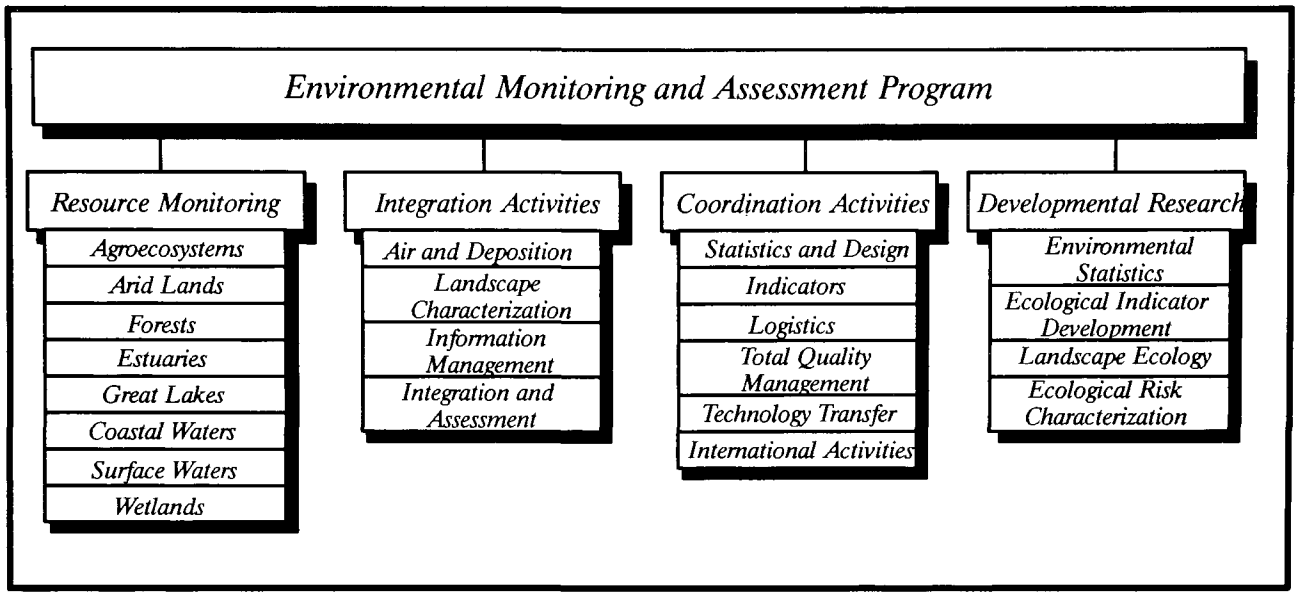



Figure 1-1. Organization of the Environmental Monitoring and Assessment Program into the four major elements.

other environmental stressors in order to assess associations between environmental stress and ecological condition.

Integration activities in EMAP will center around several functions that facilitate the acquisition, management, and interpretation of monitoring data. Atmospheric deposition data, landscape pattern and composition information, integration of monitoring data from non-EMAP networks, and EMAP information management are some of the responsibilities of the Integration Team. The Integration Team will also ensure that the scientific information collected during various field activities is translated into a form that can be used to answer management questions regarding environmental problems at regional and national scales.

Coordination activities of EMAP include network design and statistical analysis; indicator selection, testing, and evaluation; logistics; and quality assurance. The Coordination Team will implement the concept of "total quality management" by providing guidance, support, oversight, and planning assistance to the resource groups on quality assurance and quality control protocols. The Coordination Team will ensure that data collection activities by the resource groups are conducted in standardized ways. Other coordination functions include technology transfer and liaison activities with other state, federal, and private agencies, the EPA regions, and international institutions and organizations (e.g., Commonwealth Scientific and Industrial Research Organization.

The developmental research component is designed to be responsive to new issues and improve scientific understanding. Research programs will include environmental statistics, ecological indicators, landscape ecology, and ecological risk characterization. Additional studies advancing monitoring methods, data analysis, and information transfer will be part of the research

program. All of the research conducted within the EMAP framework will be integrated with the ORD's Ecological Risk Assessment Program and similar programs in federal, state, and private agencies and institutions. EMAP recognizes that research is a strong component of the overall monitoring and assessment concept and will devote considerable resources to maintaining a state-of-the-art capability.

## 1.2 ECOLOGICAL ASSESSMENT FRAMEWORK

The paradigm upon which EMAP is based is risk assessment. Risk assessment is the scientific process in which facts and assumptions are used to estimate the potential for adverse effects on the environment that might result from exposures to pollutants and other stresses. In the past risk assessment relied almost exclusively on single species and single chemical toxicity bioassays and media-specific exposure models. EMAP, however, will collect data that will be used in the development of ecological risk assessments at the ecosystem, regional, or national scale. EMAP will provide a foundation for the ecological risk assessment process consisting of six major elements (Figure 1-2):

- Environmental monitoring and assessment (hazard identification)
- Ecological exposure (exposure assessment)
- Ecological effects (dose-response)
- Ecological risk characterization
- Ecosystem restoration and management (risk management)
- Risk communication

EMAP will take an epidemiological or top-down approach to ecological risk assessment. If an effect is observed through monitoring, then associations will be made with exposure information to identify potential hazards or stressors. The EMAP monitoring tools (indicators) will generally be anticipatory rather than predictive of environmental effects. This approach enhances the likelihood of detecting cumulative impacts of natural and anthropogenic influences on ecological resources (Knapp et al., 1990).

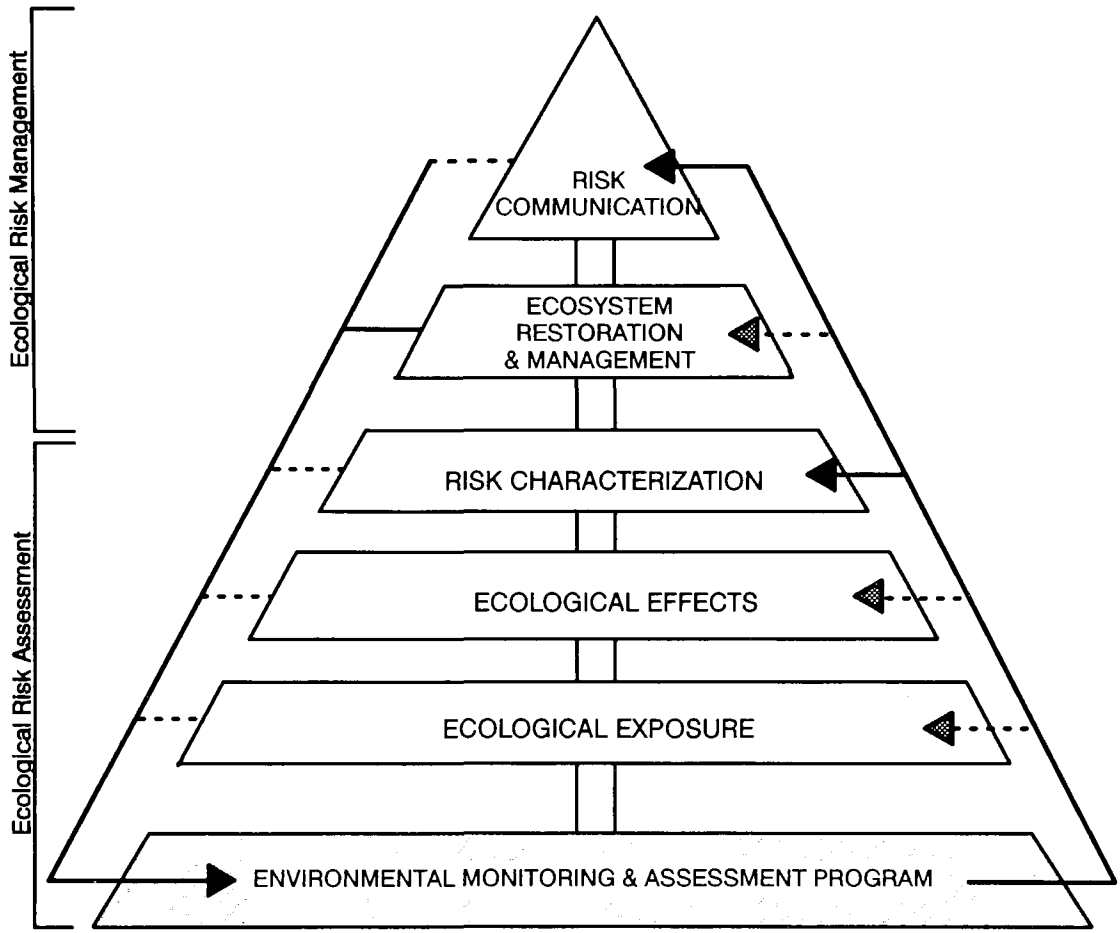



Figure 1-2. The Environmental Monitoring and Assessment Program provides a foundation for the ORD Ecological Risk Assessment Program.

## 1.3 EMAP DESIGN

The Environmental Monitoring and Assessment Program is designed to provide statistically unbiased estimates of the status and trends in the condition of the Nation's ecological resources. To accomplish this goal the EMAP design is probability-based and hierarchical with four distinct tiers (Figure 1-3). Tier 1 is the broadest monitoring tier with the greatest extent of spatial coverage.

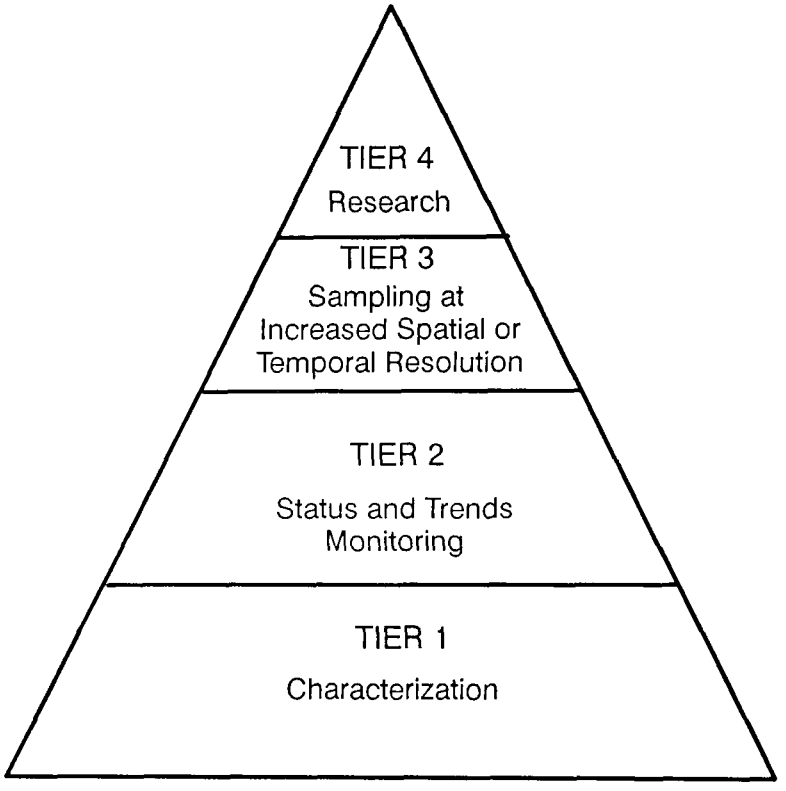



Figure 1-3. Four-tier structure of EMAP and the major activities associated with each of the tiers.

The design is based on dividing the Earth's surface using a truncated icosahedron (i.e., soccer ball) (Figure 1-4). Using a triangular point grid with approximately 27 km between points in all directions, 40 $km^2$ hexagons centered on each point will be characterized by EMAP (Figure 1-5). In the conterminous United States, approximately 12,600 hexagons (Figure 1-6), representing about one-sixteenth of the total area of the United States, will be monitored and evaluated by using remote sensing and existing data. Regional estimates of the areal extent of all extensive ecological and landscape resources and estimates of the number of discrete resources (e.g., lakes, stream reaches, or prairie potholes) will be made from the Tier 1 data (Overton et al., 1990).

Tier 2 will use probability methods to select a subset of the ecological resource units within the 40 $km^2$ hexagons in proportion to their occurrence and importance. Tier 2 activities will rely heavily on the use of specific indicators implemented by each resource group. Tier 2 sampling will involve

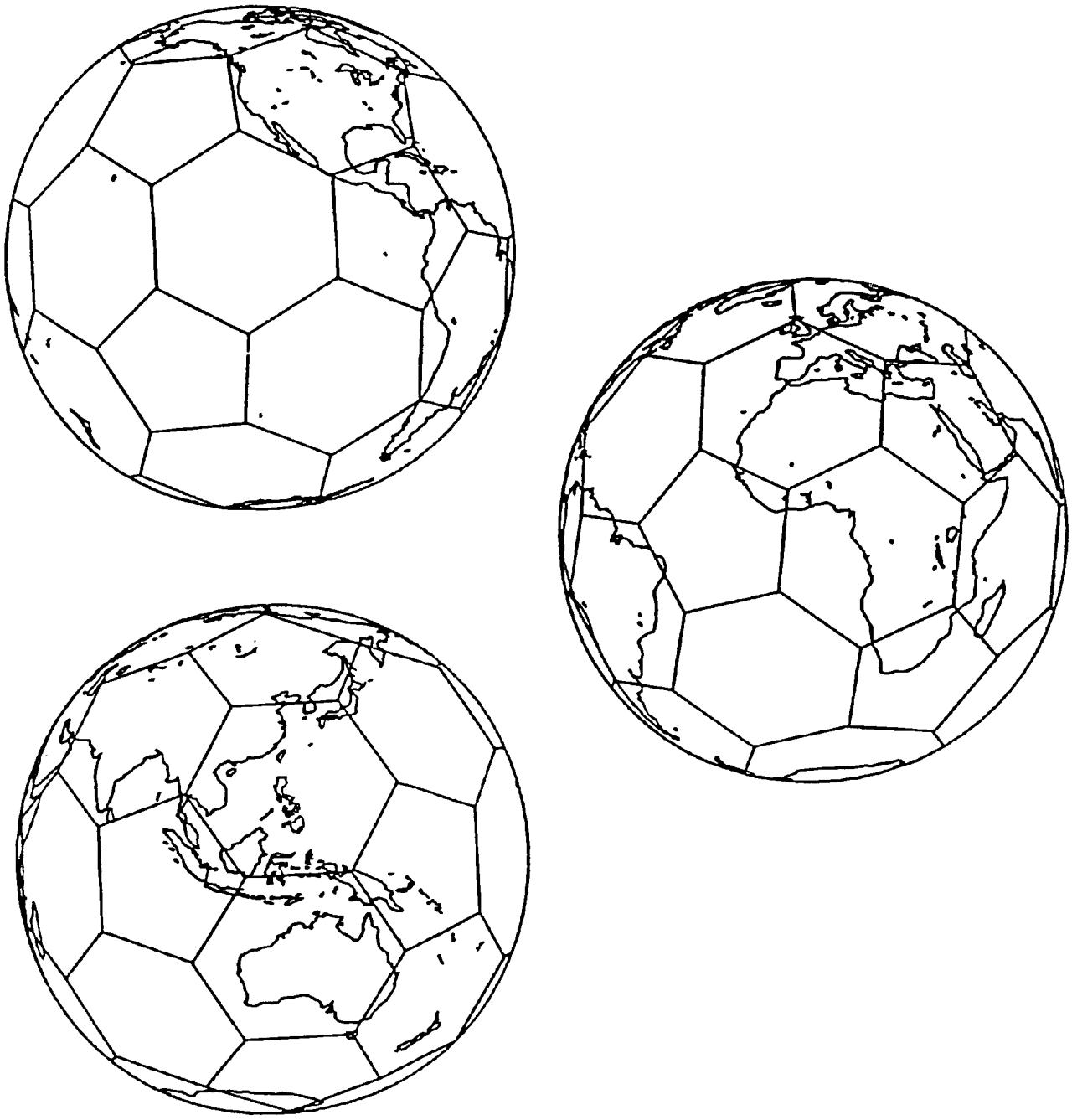


Figure 1-4. The trunicated icosahedron model projects the familiar soccer ball tessellation pattern onto the earth.

periodic visitation to selected points in the nationwide grid to collect samples and data of ecological resource condition. The nominal density of these grid points is one point per 640 km $^2$. This density will be increased or decreased to meet specific needs. Selection of specific sites for monitoring will strongly depend on the location of the ecological resources within the grid. The grid

Figure 1-5. The base grid placed advantageously on the United States.

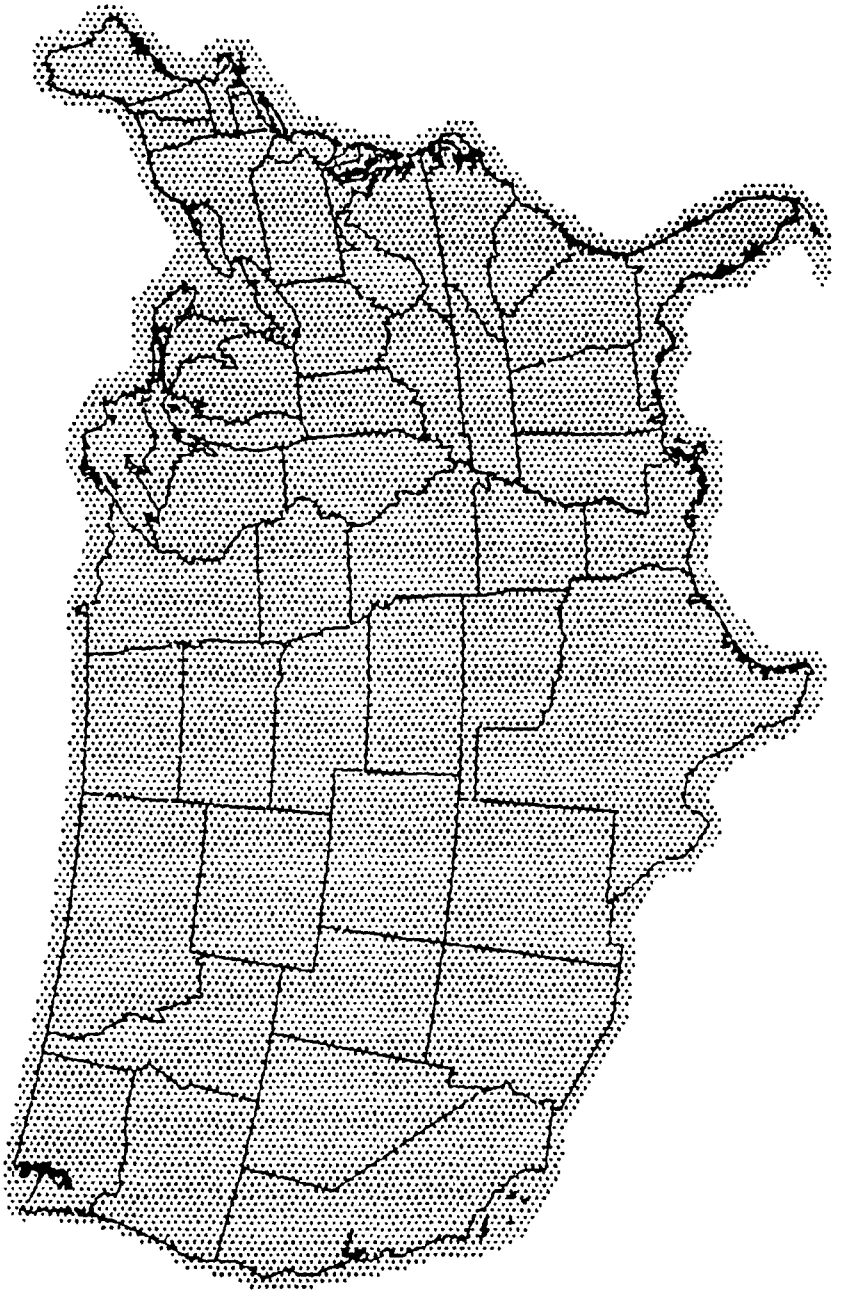


Figure 1-6. Approximately 12,600 points over contiguous United States.

used in Tier 2 can be extended to provide global as well as national coverage or enhanced coverage for state or local resource assessment.

Tier 3 will focus on subpopulations of interest (e.g., redwood forests, saguaro cactus, low alkalinity lakes) or provide additional diagnostic information beyond Tier 2. Sampling intensity will be increased either spatially or temporally to increase confidence in the data relative to status and trends of the subpopulations of interest.

Tier 4 includes process-level research that may be conducted at specific, nonrandomly selected sites. Research at these sites will likely center on the development of new sampling, measurement, or assessment methodologies; center on ecological indicators; or involve pilot or demonstration scale studies incorporating all aspects of EMAP.

The EMAP design has been developed to be adaptive, simple, rigorous, robust, and flexible. Its flexibility is such that data from other agencies and monitoring programs can be directly incorporated into the data base. The EMAP intent is to develop a monitoring network that will fill critical data gaps in order to determine the status and evaluate trends in the condition of the Nation's ecological resources.

## 1.4 EMAP - ARID ECOSYSTEMS

The purpose of this document is to describe a strategy for establishing an integrated environmental monitoring and assessment program for arid ecosystems in the United States. This Strategic Plan is designed to be a "living" document responsive to changes in the state of knowledge concerning arid ecosystems. It represents an initial attempt at developing a strategy for monitoring and assessing the condition of arid ecosystems within a spatial and temporal framework.

The EMAP-Arid Ecosystems Resource Group's (EMAP-Arid) Strategic Plan is being developed in cooperation with key natural resource management agencies (e.g., BLM, USFS, NPS). Economic, scientific, and institutional resources are being combined into an integrated program that will allow environmental issues to be addressed in a cost effective and scientifically defensible manner. Negotiations for formal cooperative agreements (e.g., memoranda of understanding) between EMAP-Arid and appropriate agencies and institutions are currently underway.

# 2.0 RATIONALE AND APPROACH

## 2.1 INTRODUCTION

EMAP is designed to be an interagency, interdisciplinary monitoring and assessment program focused on ecological resources in arid regions of the United States. EMAP-Arid has fully embraced the mission, goals, and objectives of the Environmental Monitoring and Assessment Program as outlined in Chapter 1. EMAP-Arid is not intended to be a compliance monitoring program and will not replace the need for these activities. Products from EMAP-Arid will be used to determine the relative magnitude and geographic location of environmental problems and assist in establishing objective mitigation and research priorities. EMAP-Arid will provide an ongoing monitoring framework within which new variables can be added or regional modifications made, so that the magnitude and extent of effects from newly identified problems can be determined on a more timely basis.

This chapter discusses the rationale, conceptual approach, and implementation strategy for EMAP-Arid. It provides background information on arid ecosystems within the EMAP framework and establishes the basis for a strategic plan.

## 2.2 BACKGROUND FOR ARID ECOSYSTEMS MONITORING AND ASSESSMENT

Arid and semi-arid ecosystems (hereafter referred to simply as arid ecosystems) occur on most continents of the Earth, comprise about one third of the land surface, and support about 20 percent of the human population (approximately 1 billion). In the United States these ecosystems occupy nearly 40 percent of the land surface area (Figure 2-1) and are important commercial, agricultural, mineralogical, and energy resource centers. For example, 80, 60, and 30 percent of the total U.S. production of oil, natural gas, and coal occurs in arid regions of the western U.S. (National Geographic Society, 1982).

Arid ecosystems are characterized by climatic conditions where sparse and erratic rainfall is combined with long, warm summers and a pattern of descending air giving rise to extremely dry conditions. Precipitation is both spatially and temporally highly variable. This high variability is as important as the low quantity in determining the productive potential of arid systems (UCAR, 1990). Nearly all the precipitation falling on arid ecosystems leaves through evaporation or transpiration rather than through surface or ground-water drainage. Soils common in arid systems are deficient in moisture and nitrogen, low in organic matter content and aggregate strength, and often low in permeability. Natural vegetation in arid ecosystems includes grasslands, shrublands, and savanna. Scattered trees are present in the emphemeral drainages and lush riparian forests are present along some water courses.

Historically, overexploitation of the limited resources of arid ecosystems combined with a restricted and unreliable water supply have led to severe land degradation and associated rapid

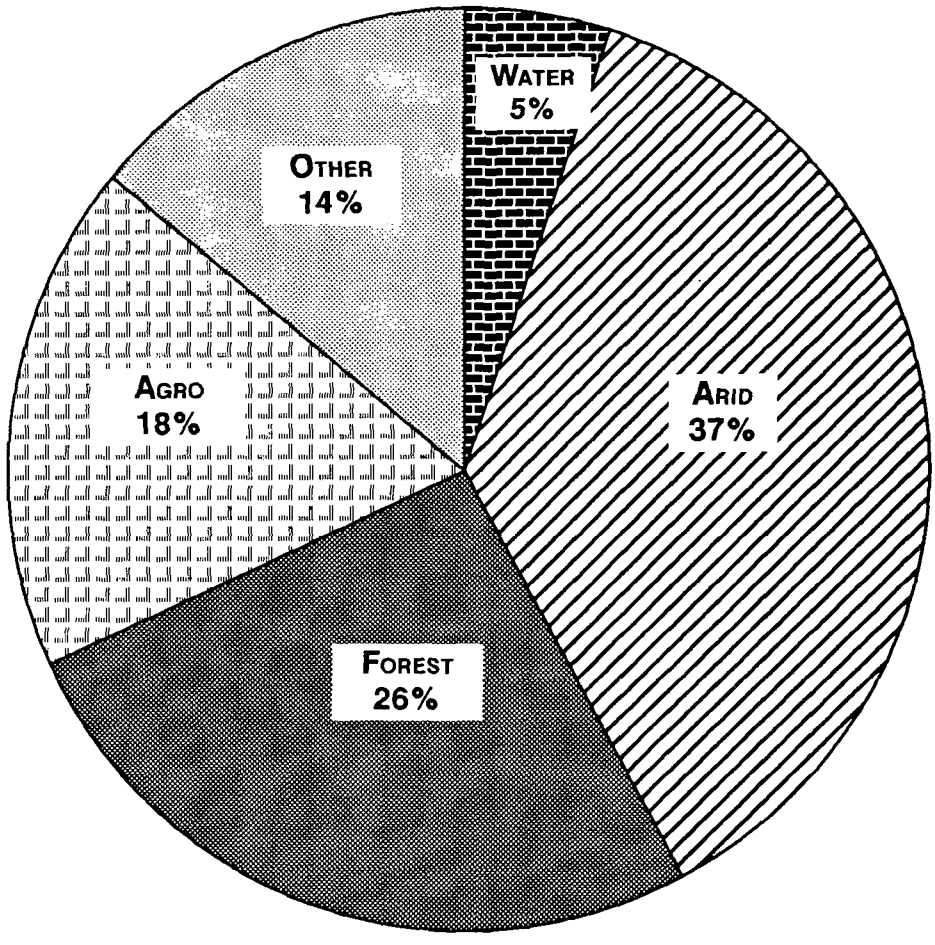



Figure 2-1. U.S. land and census water breakdown by ecosystems.

declines in productivity. Once degraded, arid lands are generally unlikely to return to their preimpacted state without extensive reclamation. Hence, arid ecosystems are often termed "fragile" because they show little resistance or resilience in the face of disturbance (UCAR, 1990).

Existing environmental degradation of arid systems is evident. Complex environmental problems, in part fostered by 19th century policies, programs, and resource management practices, are found across most arid lands in the western United States. The Colorado River is dead at its mouth and normally discharges no water into the Gulf of California because so much of its waters are diverted for irrigation. On the east side of the Sierra Nevada, Owens Lake has been dry for most of this century, Mono Lake and Pyramid Lake have been heavily drawn down, and the survival of the animals that depend on these critical bodies of water has been threatened.

Thousands of abandoned and working mines have discharged poisonous metals into aquifers and streams, including the Clark Fork, the largest hazardous waste site requiring cleanup under the Superfund Amendments and Reauthorization Act in the United States (Wilkinson, 1990). Because of agricultural pollution, Kesterson, Stillwater, and other arid regions wildlife refuges have experienced major bird mortality due to chemical contamination. The Ogallala Aquifer, stretching from Texas to the Dakotas, has been depleted in some areas to the extent that land once irrigated for agriculture is now abandoned due to lack of available water (Wilkinson, 1990).

While the preceding examples are some of the more serious environmental problems of arid lands, other more regionally based environmental issues have and continue to affect these ecosystems. Grazing, biodiversity, desertification, water resource management, air quality, and global climatic change are regional issues important to the health of arid ecosystems. These issues drive and will continue to drive much of the public, scientific, and policy making concern for arid systems.

### 2.2.1 Grazing

Grazing of livestock on public and private arid lands over the entire western region of the United States has been practiced for over 100 years. Current data indicate that over 70 percent of the land in 16 western states is grazed (Duffus, 1988; Jacobs, 1988). The federal government (e.g., Bureau of Land Management and the U.S.Forest Service) controls most of the grazing through allotments on about 268 million acres. Recent reports (Wald and Alberswerth, 1989; Duffus,1988) show that 68.4 percent of BLM rangelands and over 50 percent of all federally controlled rangelands evaluated were in an unsatisfactory condition. These studies also showed that 19 percent of the surveyed allotments were threatened by livestock overgrazing and that about 8 percent were actually declining in quality. Riparian ecosystems associated with rangelands were identified as particularly vulnerable and in poor condition as a result of grazing. These studies sited insufficient monitoring data for management decisions as a principal reason for the unsatisfactory condition of rangelands.

While grazing is an important ecological component of many arid ecosystems, man has greatly increased its frequency, intensity, and extent with the introduction of livestock. Widespread changes in soil and plant species composition have occurred with increased grazing pressure in arid systems. Examples of changes in plant species composition include replacement of grasslands and savannas by shrublands or woodlands dominated by unpalatable species and the degradation of woodlands or perennial grasslands to communities dominated by unpalatable perennials, ephemerals, or bare ground (UCAR, 1990). Grazing impacts on soils result from decreases in plant cover which may cause higher summer soil temperatures, lower winter soil temperatures, increased bare soil evaporation, and increased wind and water erosion. Additionally, infiltration may decrease and runoff may increase due to soil compaction, nutrient turnover increase, and carbon storage decrease, all as a result of grazing. Effects on plants and soils can often be compounded or mitigated by variations in weather or changes in climate. However, it appears that most arid systems have a critical threshold beyond which recovery is very slow and difficult (UCAR, 1990).

### 2.2.2 Biodiversity

Biological diversity has recently been recognized as an important global resource to be indexed, used, and, above all, preserved (Wilson, 1988). The wide variety of genes, species, communities, and ecosystems provide natural resources (e.g., food, medicine, and shelter) for daily subsistence and ecological services (e.g., climate moderation, water and nutrient cycling, and breakdown of wastes) necessary for the survival of life on Earth (Blockstein, 1989). Arid ecosystems in the United States exhibit a tremendous variety of habitats and accommodate a vast array of animal and plant species. Biodiversity (species richness) in these systems, particularly Mediterranean-climate regions, can rival that found in tropical forests (Mooney, 1988). Unfortunately, plant and animal species in arid ecosystems have not escaped the impact of increasing urbanization, agricultural usage, mining, and recreation. Observed declines in species such as the desert tortoise, bighorn sheep, desert pupfish, California condor, and saguaro cactus are attributable to changes in land use, air and water quality, habitat availability, and climate. Continued impacts on biodiversity in arid systems will undoubtedly have long-term global ecological consequences.

### 2.2.3 Desertification

Desertification has been defined as "the decline or destruction of the potential or actual biological productivity of arid and semi-arid lands caused by certain natural and man-made stresses" (Bender, 1982). An extended period of drought, severe mismanagement of land, or evaporation of water, leading to soil salinization, can bring about desertification. The U.N. Environmental Programme estimates that about one third of the world's land surface and the livelihoods of at least 850 million people are threatened by global desertification (Speth, 1988). In the United States over 75 percent of arid and semi-arid lands have been impacted, and 10 percent of these lands are in a state of severe or very severe desertification (Figure 2-2; Dregne, 1977).

Recent studies by Schlesinger et al. (1990) in a semi-arid grassland indicate that changes in arid ecosystem function leading to desertification are the result of increases in the spatial and temporal heterogeneity of water, nitrogen, and other soil resources. For example, increases in heterogeneity from grazing, off-road vehicles, row-crop agriculture, or other perturbations can lead to the invasion of grasslands by shrubs, concentrate soil resources under the shrubs, and increase the removal of soil materials between shrubs by water and wind erosion.

Losses of desert soil by wind erosion may be globally significant. It is estimated, for example, that 40 to 60 percent of the atmospheric nitrate over the North Pacific Ocean is derived from continental aerosols (Schlesinger et al., 1990), presumably from the deserts of China. In the United States, much of the nitrate deposited in eastern forests as dry deposition may be derived from desert soils in the West. Desert soils also are likely to contribute significantly to global cycling of sulfur, phosphorus, calcium, and other elements. Arid ecosystems also contribute to atmospheric concentrations of methane and other hydrocarbons as well as nitrous oxide. Increases in these gases may affect the production of tropospheric ozone but their contribution is poorly understood at this time. With the area of arid lands expected to increase due to desertification and other processes, any change in these resources may have global implications.

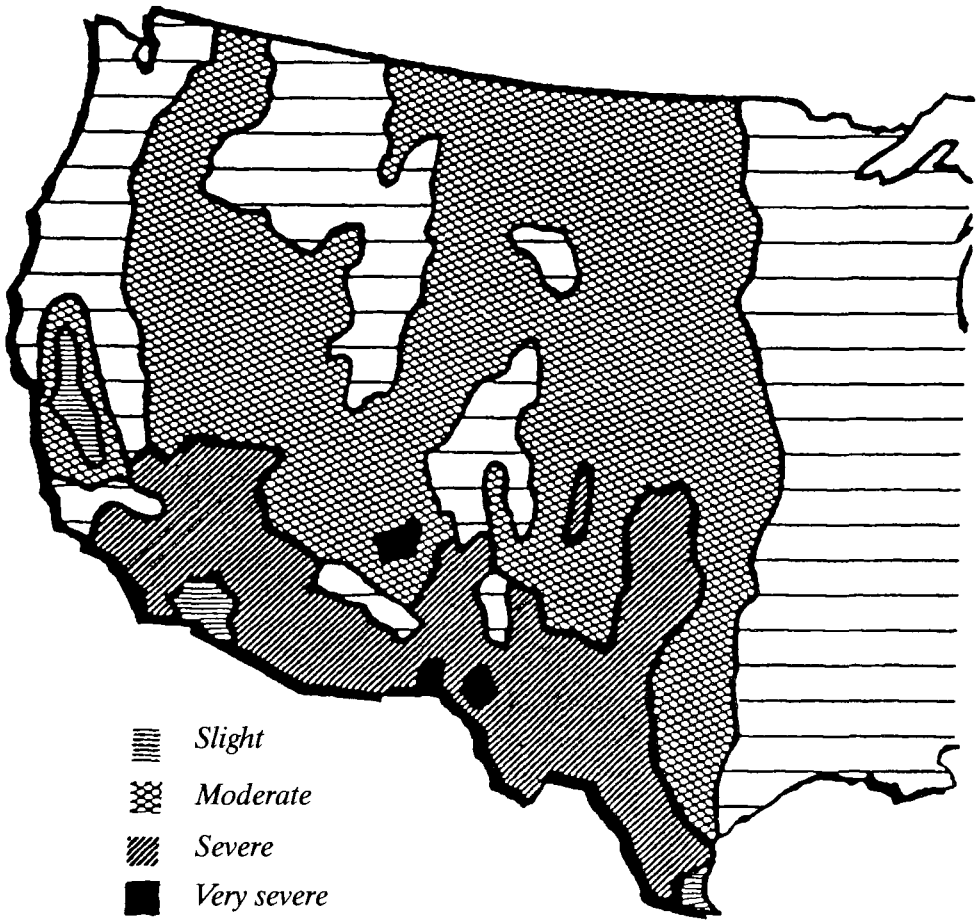



Figure 2-2. The status of desertification in the United States. Source: Dregne, 1977

### 2.2.4 Water Resources

Undoubtedly the most important and most limiting environmental factor in arid ecosystems is water. Species (including man) occupying these systems and living at their ecological limit are dependent upon and adapted to limited but reliable surface and ground-water supplies. Exploitation of these limited water resources, principally to irrigate crops, continues in arid regions worldwide. Crop irrigation accounts for 90 percent of the water use in the western U.S. (Wilkinson, 1990).

Reduction in water availability because of irrigation and domestic importation has had a pronounced affect on arid systems, particularly riparian communities. Today, it is estimated that only 20 to 30 percent of the riparian ecosystems that provide habitat for 40 to 90 percent of all vertebrate wildlife remain in the United States. Of the remaining riparian systems, 80 percent are considered to be in an unsatisfactory condition (Crumpacker, 1984). These estimates have

recently been confirmed by statewide BLM estimates for Idaho and Colorado indicating that 80 and 90 percent, respectively, of the riparian communities along over 17,000 miles of streams were in poor to fair condition (Duffus, 1988).

The conversion of natural or grazed systems to irrigated agriculture has also had a profound effect on arid ecosystems. Agricultural conversion of biologically diverse plant communities results in monocultures with a uniform canopy, declines in soil organic matter, increases in soil bulk density, and decreases in infiltration and may lead to increases in soil salinity (UCAR, 1990). The accumulation of salts is especially significant as soil and shallow ground water can eventually become too saline for plant growth. Increased salinity combined with mobilized toxic trace elements (e.g., selenium) from subsoils or agricultural pesticides and fertilizers may result in the development of a mosaic of vegetation communities composed of exotic species not native to the region. Changes in the vegetation and soil environment can alter surface energy budgets (i.e., albedo, evapotranspiration, and sensible heat flux) (UCAR, 1990). Resultant increases in air temperatures will increase potential evapotranspiration, reduce relative humidity, decrease water availability, and hence, increase aridity. Restoration of arid lands impacted by man is a difficult and expensive proposition.

### 2.2.5 Air Quality

Continued rapid urbanization and industrialization of arid lands in the western U.S. has caused considerable concern about air quality. Concentrations of air pollutants in the West have generally increased over time in association with increases in population. Nitrogen oxide (NOx) emissions , for example, have increased by 50 percent since 1960 (Young et al.,1988). Ozone ($O_3$) concentrations in many arid systems have also increased recently and some of the most extreme values in the Nation are found in the South Coast Air Basin (Los Angeles area). Concentrations of sulfur dioxide ($SO_2$) in the West, however, have decreased by a factor of two since the late 1960s (Young et al., 1988). Wet deposition of chemical anions and cations (i.e., $H^+$, $NH_4^+$, $Ca^{2+}$, $NO_3$, and $SO_4^{2}$) is not problematic but increases across arid systems from west to east (Young et al., 1988).

Much of the recent concern over air quality in arid ecosystems is focused on ozone and visibility. Numerous Class 1 areas (e.g., national parks and wilderness areas) occur in much of the western United States and, hence, regional changes in air quality may have significant impacts. Ozone occurs on a regional scale and is extremely problematic for vegetation due to its high toxicity. Numerous studies have shown that ozone and photochemical smog have affected vegetation in arid ecosystems particularly in California. Recent reviews of the data by Shriner et al. (1990) clearly show the effects of ozone on vegetation. Most of these studies were conducted on forest trees and agricultural crops because desert vegetation was considered to be relatively insensitive. Research by Thompson et al. (1984), however, has shown that certain species of desert annuals are extremely sensitive to ozone at concentrations below current ambient standards.

Concern over visibility is linked to the atmospheric transport of pollutants from urban and industrial sources into national parks, wilderness areas, and other Class 1 airsheds. Amendments

to the Clean Air Act now provide for visibility protection for Federal Class 1 Areas and provide for the conduct of visibility studies, establishment of visibility regions, and formation of regulatory commissions. Continued expansion of man's activities in arid ecosystems is likely to increase problems associated with air quality.

### 2.2.6 Global Change

Of all the issues facing arid ecosystems, global climatic change may be the most significant. Several current models of climatic change predict that lower precipitation and shifts in precipitation seasonality will occur in the interior of large continental areas where arid ecosystems are most commonly located. While these models are somewhat speculative, even small changes in climate in arid zones would greatly intensify the already high natural variability and could lead to permanent degradation. Because vegetation in arid ecosystems is known to be very responsive to even small changes in climate, these systems may be the first to be affected by global environmental change (UCAR, 1990). Even if feedback mechanisms stabilize mean global temperatures at current levels, small changes in circulation, cloudiness, or water vapor transport could significantly change arid ecosystem climate. The sensitivity and vulnerability of the United States has been identified by Maggs (1989) in Figure 2- 3. Clearly arid ecosystems in the western United States are the most vulnerable to global climate change, and the Great Basin Desert appears to be the most sensitive. A recent publication by Wharton et al. (1990) confirms the responsiveness of the Great Basin to climatic change over the last 50,000 years.

Changes in the composition, structure, or function of arid ecosystems are also likely to affect regional and global climate through feedback mechanisms. Changes in the biota of arid lands due to climate change (i.e., increasing aridity) and changes in land use (e.g., conversion to irrigated agriculture or urbanization) may alter mesoscale atmospheric circulation, albedo, soil moisture, and evapotranspiration (UCAR, 1990). Changes in the vegetation of arid ecosystems may also affect wind and water erosion (i.e., transport of aerosols to the atmosphere), trace gas exchange (e.g., ammonia and methane), and fire frequency . The significance of these changes is enhanced in view of the expansive global extent of arid systems over one third of the global land surface area.

There is past evidence to indicate that arid ecosystems have affected and are being affected by climatic change. Extensive deposits of loess in Alaska and dust in Antarctic ice demonstrate that during the last ice age, wind erosion from desert regions was a significant phenomenon and may have greatly influenced planetary albedo. These changes in arid lands also may have accelerated continental deglaciation. Recent data suggest that the climatic warming (increased aridity) of the current interglacial period may be responsible for ecosystems in the southwestern United States shifting from a sink to a large source of atmospheric carbon dioxide (UCAR, 1990).

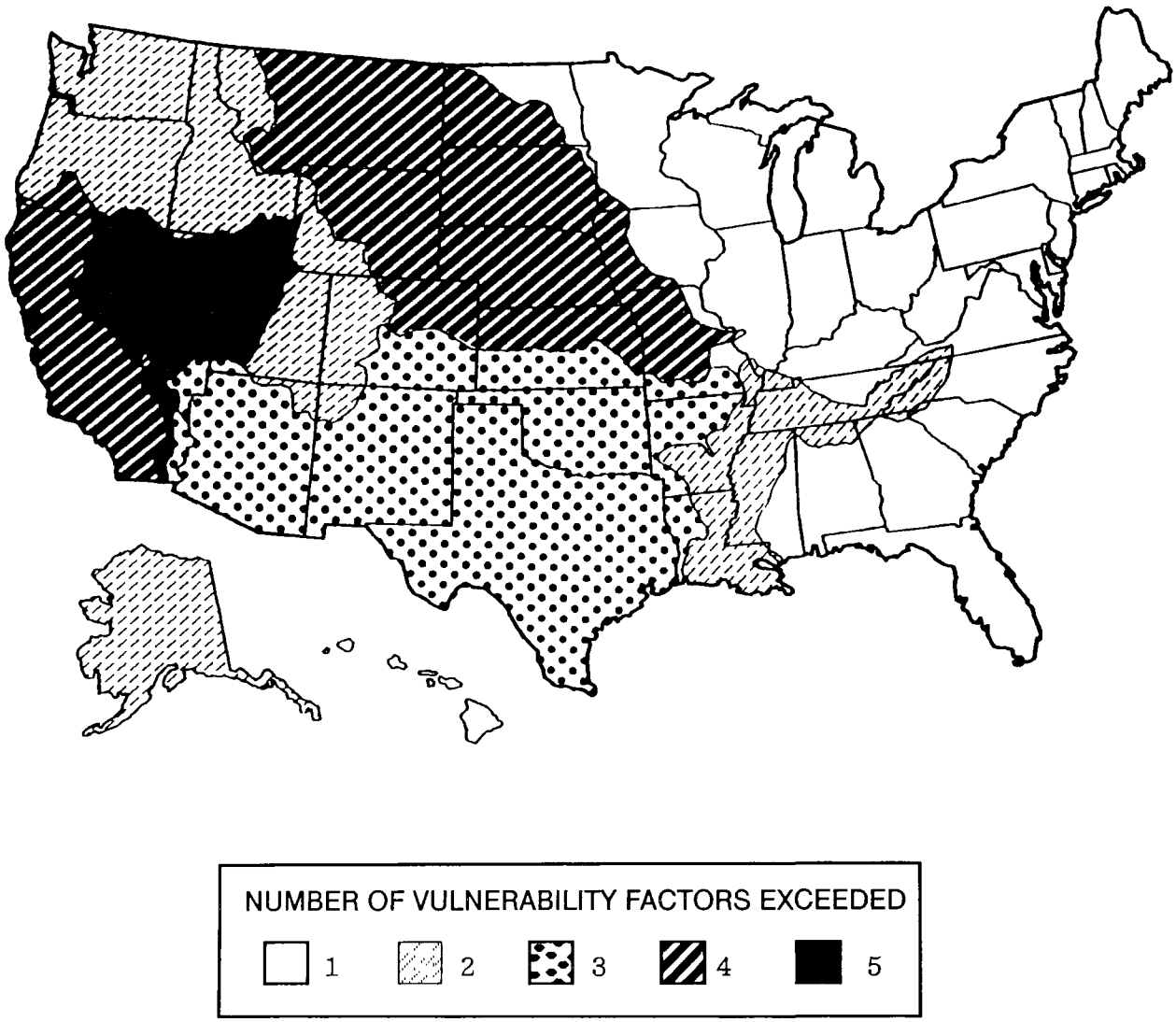



Figure 2-3. Vulnerability to climate change based on availability of water resources. (Maggs, 1989)

### 2.2.7 Summary

In summary, while arid lands have been used throughout history by relatively small numbers of people, recent population explosions in conjunction with development practices has precipitated a rapid degradation of these regions. Slight shifts in climate may lead to further degradation and affect the entire global environment. Arid ecosystems can no longer be considered remote places of little value. They are intricately linked to all other ecosystems and may greatly influence their condition.

## 2.3 ARID ECOSYSTEMS – DEFINITION

The ecosystems considered by the EMAP-Arid resource group may not strictly follow those traditionally considered as arid or semi-arid systems from a biogeographic perspective. The working definition for the Arid Ecosystems Resource Group is given as follows

> *Arid ecosystems are terrestrial systems characterized by a climatic regime where potential evaporation exceeds precipitation, annual precipitation ranges from <5 cm to 60 cm, and daily and seasonal temperatures range from -40 °C to 50 °C. The vegetation in arid ecosystems is dominated by woody perennials or graminoids with a low form physiognomy including drought resistant trees in open canopies. Arid ecosystems also include associated riparian areas occurring within the arid zone. Irrigated lands are not considered part of EMAP arid ecosystems even though they occur in the same climatic region.*

This definition is designed to include the arid ecosystem resource classes considered important to EMAP. It also attempts to take into account boundaries (ecotones) between resource classes that may be important in monitoring environmental change.

## 2.4 CONCEPTUAL APPROACH

The EMAP-Arid resource group is developing and implementing a holistic, ecological resource approach to monitoring and assessment. The overall strategy (Figure 2-4) is to identify issues and endpoints, measure and integrate indicators of ecological condition, and evaluate spatial and temporal variability to determine the status and evaluate trends in the condition of arid ecosystems. A key concept behind the approach is to integrate synoptic (complete landscape coverage), sample-based (e.g., field measurements), and retrospective (historical) indicator data with stressor information in order to evaluate correlative relationships and determine spatial and temporal variability. Integrating the data derived from these types of indicators is essential to defining the status of arid ecosystems and assessing trends in their condition. The main emphasis is on the development of a detection level monitoring program that determines large-scale patterns and trends. This approach will augment and add value to existing long term ecological research sites whose primary aim is to determine cause and effect relationships.

To assist in the logical development of the arid ecosystem monitoring program, EMAP-Arid has adopted guidelines developed by the National Research Council (NRC) for designing and implementing environmental monitoring programs (Figure 2-5). The NRC process provides a formula that leads from defining goals to disseminating information to decision makers. The NRC framework will help ensure the program's effectiveness in addressing its user's needs and promote compatibility across all EMAP resource groups. The EMAP-Arid resource group is currently at Step 2 in the process.

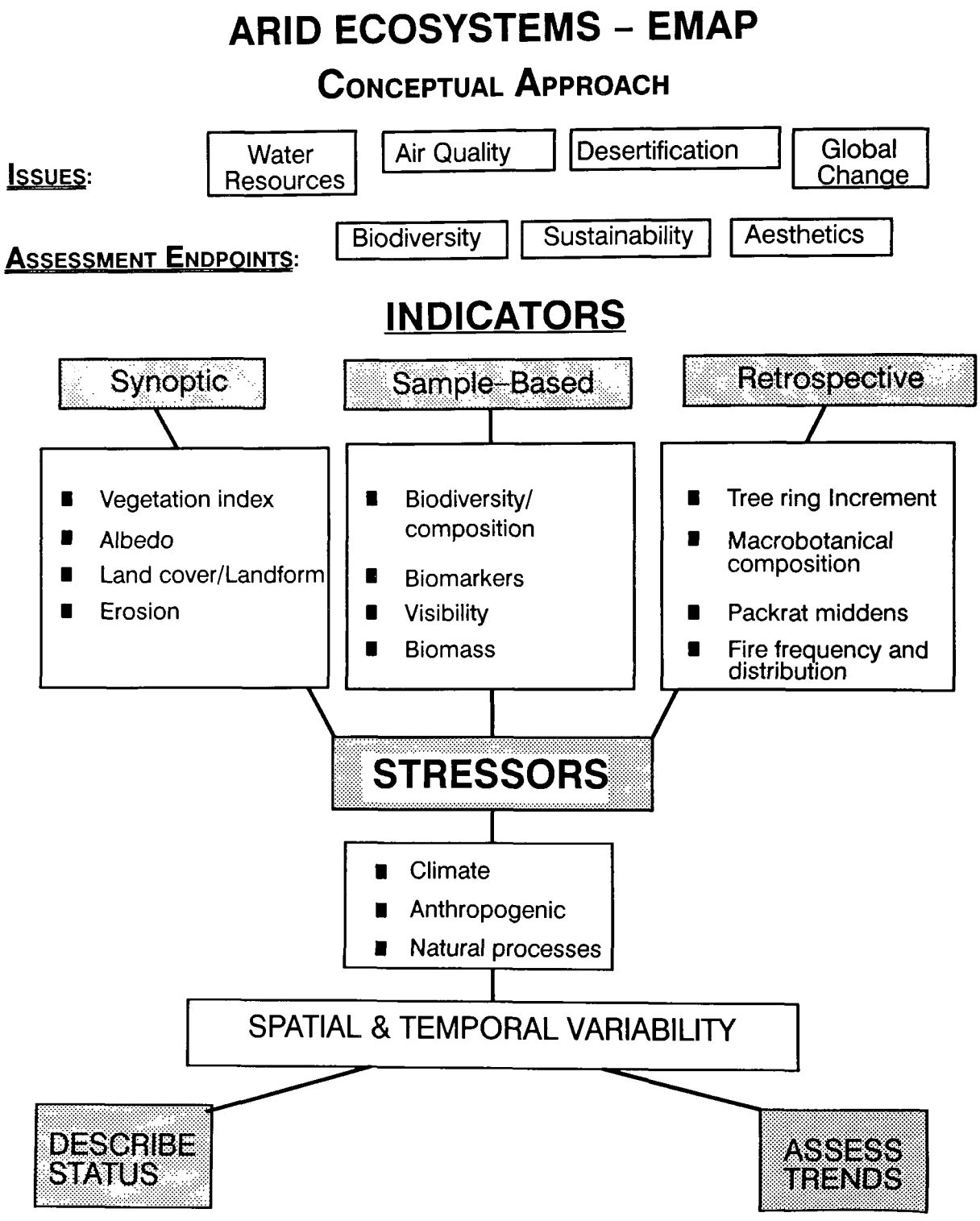
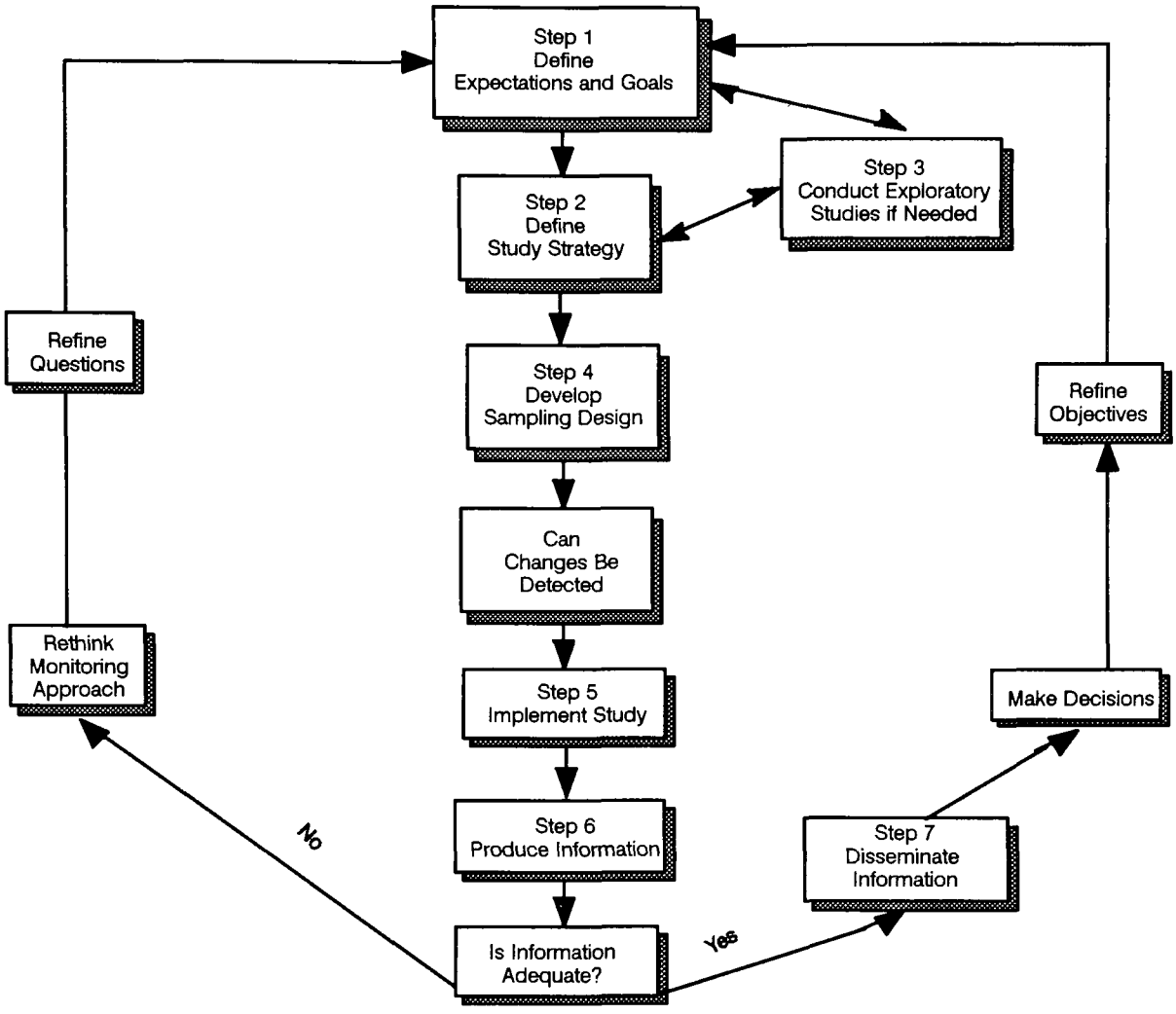



Figure 2-4. Conceptual approach for EMAP-Arid ecosystem.




*(Source: NRC 1990)*

Figure 2-5. The elements of designing and implementing a monitoring program.

## 2.5 DEFINING EXPECTATIONS AND GOALS - STEP 1

The ultimate goal of EMAP is to provide scientifically based information on the condition of the Nation's ecological resources that will enable natural resource managers and decision makers to establish sound environmental policy. EMAP is in a unique position to foster communication between scientists and users of scientific data through the development of interactive partnerships (e.g., memoranda of understanding). The focus and mission of EMAP-Arid are defined as a component of the overall EMAP (Section 1).

To establish a common ground upon which science and policy can interact, an expanded approach to Step 1 (Figure 2-6) has been used by EMAP-Arid. The elements of this approach (Figure 2-6) include: (1) identifying relevant societal and ecological issues; (2) determining ecological endpoints; (3) evaluating pertinent environmental laws and regulations; (4) developing questions of interest; (5) identifyinf and evaluating existing information and data gaps; and (6)

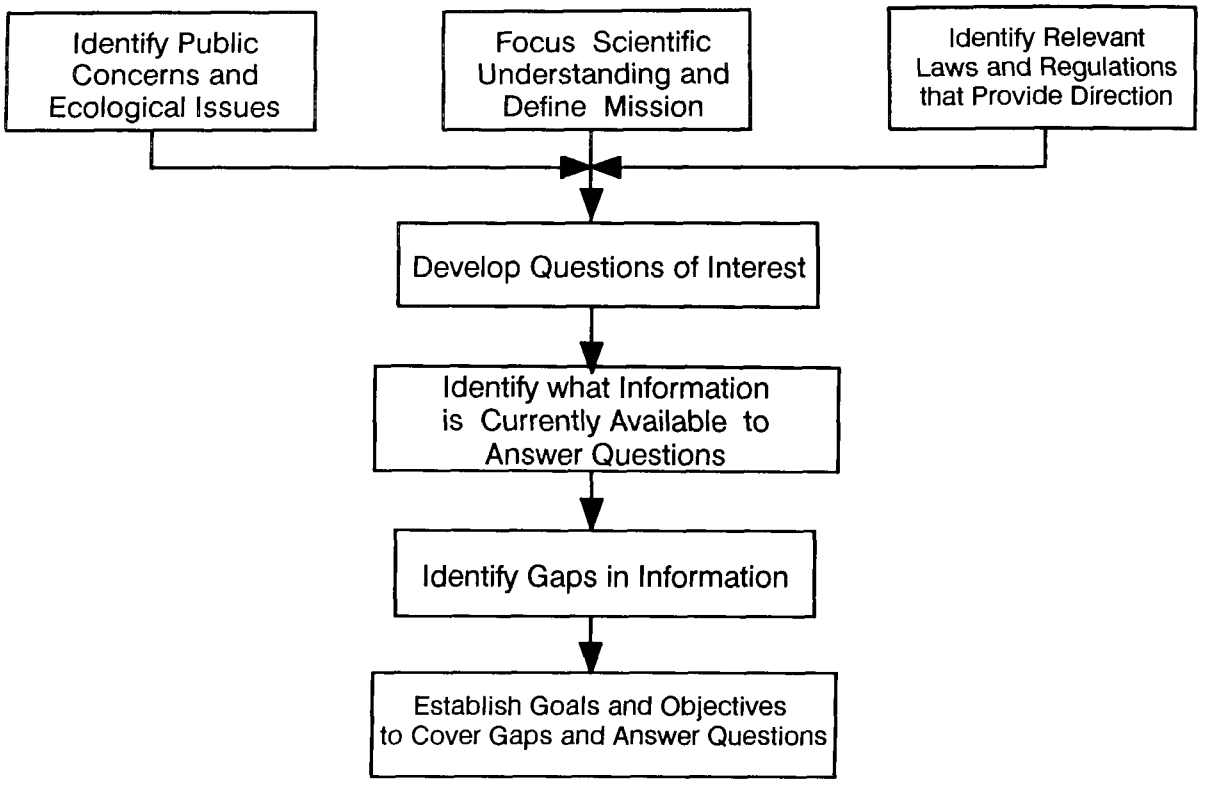



Figure 2-6. Process used by the EMAP arid ecosystems resource group to define expectations, goals, and objectives of a monitoring program.



(Adapted from NRC 1990)

establishing goals and objectives to address the data gaps and answer the questions of interest. The following sections will address these six points.

### 2.5.1 Issues of Public and ScientificConcern

Several major issues for arid ecosystems were discussed in Section 2.2 (i.e., grazing, biodiversity, desertification, water resources, air quality, and global change). Much of the concern over these issues stems from the tremendous increase in man's activity (i.e., population) in arid regions of the United States over the last 40 years. The 1990 census data reveal that in the 11 arid western states the population since 1950 and 1980 has increased 169.85 percent and 22.29 percent, respectively. A large share of this increase is due to a demographic shift to the western United States These population increases can be linked to an observed deterioration in air quality (e.g., ozone, particulates), increasing demands on limited supplies of water, and loss of critical wildlife habitat (from desertification and urbanization). With the prospect of global climatic change, the condition of arid ecosystems may be increasingly threatened because of their sensitivity and responsiveness to climate.

### 2.5.2 Assessment Endpoints

Assessment endpoints for EMAP-Arid are quantitative or quantifiable expressions of environmental values that have both social and biological relevance. They are quantities accessible to prediction and measurement and susceptible to the environmental stressors of concern. Of the three endpoints identified in Figure 2-4, sustainability is generally all-encompassing and may be directly linked to biodiversity and aesthetics.

#### 2.5.2.1 Sustainability

Sustainability is the capacity of a system to maintain its productivity when subject to stress. Sustainability in arid ecosystems depends on the number of people present and the demands they make on the system, the system's physical and biological processes, and the investment society is willing and able to make to overcome constraints in the system (Orians, 1990). Arid ecosystem sustainability involves careful conservation of biological resources, maintenance of material balances into and out of the system, and implementation of resource management programs.

Sustainability in arid ecosystems can only be measured over decades, centuries, and perhaps millenia. Its measurement is critical to interpreting changes in the status and evaluating trends in the condition of arid ecosystems. Changes in air and water quality, land use, climate, and other environmental stresses can lead to increases in erosion, salinization, chemical contamination, and desertification which can directly influence arid ecosystem sustainability.

Sustainability can be measured in numerous ways (i.e., measurement endpoints). Net primary productivity is principal among the possible measures of sustainability and can be derived by evaluating indicators such as vegetation greeness, annual wood increment, standing biomass, and root to shoot biomass ratios. Other indicators which reflect sustainability are associated with energy and water balance, reproduction and regeneration, and species composition, frequency, and distribution.

#### 2.5.2.2 Biodiversity

Biodiversity has recently become a popular environmental issue and is an environmental attribute of concern to the public (Nash, 1989). Changes in global populations of amphibians, historic declines in birds species such as the California condor, and a reduction in observed numbers of saguaro cactus are popular examples of biodiversity losses that have drawn public attention. Biodiversity, however, involves more than just species diversity or endangered species. The issue is focused on biological impoverishment at multiple levels of organization. These levels of organization include: regional landscape, community-ecosystem, population-species, and genetic integrity (Noss, 1990). Biodiversity operates at and across all these levels of organization and is attributable to three components of ecosystems—composition, structure, and function.

Indicators of biodiversity are numerous. Indicators range from perimeter to area ratios, contagion or habitat patchiness, gamma index of connectivity, Patton's diversity index, and fractal dimension at the landscape level to karyotypic analysis, DNA sequencing, and sib analysis at the genetic level. Other indicators at the ecosystem-community and population-species levels include Habitat Layers Index; species density, frequency, and diversity; and retrospective pollen and woodrat midden analyses. These indicators are further discussed in Appendix A.

#### 2.5.2.3 Aesthetics

Past studies of aesthetics have shown that the need to interact with other species is deeply rooted in the human psyche (Orians, 1990). For example, people spend large sums of money to have flowers in their homes, travel to see unusual organisms or environments, and to have views of nature from their windows. The aesthetic value of a resource or experience often depends on the number of people attempting to enjoy it and on the abundance or rarity of the species or habitat. While this endpoint has perhaps more social, than ecological relevance, it is a reflection of ecosystem composition and structure. Therefore, changes in these attributes will affect the public's perception of the condition of the environment. Changes in the aesthetic condition of a resource may alter its use and impact management and environmental policy.

### 2.5.3 Legislative Mandate

In order to determine the scope and rate of ecological degradation or improvement of response to management and conservation programs, an integrated national approach for monitoring ecological condition and anthropogenic stresses is necessary. Presently, the responsibility for protection and management of the Nation's arid ecosystems is shared by numerous agencies including the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service (USFS), National Park Service (NPS) and EPA. These agencies are mandated by public laws to protect the integrity and sustainability of these resources. Broad federal statutes such as the National Environmental Policy Act of 1969, the Federal Land Policy and Management Act of 1976, the Multiple-Use Sustained Yield Act of 1960, and the National Forest Management Act of 1976 provide a sound basis for the management of multiple resources on federal lands.

Numerous pieces of legislation have been enacted to protect specific resource components from degradation and toxic pollution at both the federal and state levels. The Clean Water Act of

1977; the Water Quality Act of 1987; the Comprehensive Environmental Reponse, Compensation and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA) are key federal mandates controlling toxic substances and their effects on fish, wildlife, and recreation. Administered by the EPA, these and other toxic chemical laws including the Federal Insecticide, Fungicide and Rodenticide Act and the Toxic Substances Control Act, may apply to activities conducted under the jurisdiction of other management agencies, for instance BLM or USFS insect control programs. Although primarily administered by the BLM, mining activities may be subject to EPA regulations for hazardous substance handling, disposal and cleanup. The Taylor Grazing Act of 1934 and the Public Rangelands Improvement Act of 1978 are the principal mandates for managing grazing resources on public rangelands. Wildlife management guidelines are provided by the Fish and Wildlife Coordination Act of 1934, Public Rangelands Improvement Act, and the Endangered Species Act of 1973. Recreational and landscape resources for arid lands are protected and managed through statutes such as the Wilderness Act of 1964, the Land and Water Conservation Fund Act of 1965, Wild and Scenic Rivers Act of 1968, and the Soil and Water Resource Conservation Act of 1977. While many public laws, such as the Clean Air Act and Safe Drinking Water Act, address primarily human health issues, they also are designed to protect ecological resources in arid systems.

### 2.5.4 Critical Scientific Questions

Arid ecosystems have probably been the least studied and are likely the most misunderstood of the resource systems (e.g., forests, agroecosystems) under study in EMAP. While numerous studies have been conducted, many scientific questions remain unanswered for arid ecosystems. EMAP-Arid certainly will not address all questions of scientific interest and will not necessarily be able to define cause and effect relationships based on the collected information. Nevertheless, it is important to identify critical scientific questions that need, in the broadest terms, to be addressed and are important to guide EMAP-Arid monitoring and assessment. This list of questions does not encompass all of the scientific issues but is designed to provide a basis for EMAP-Arid planning and development. These questions are as follows:

Desertification – What is the extent and rate of desertification?

- What are the changes in distribution of shrub dominated versus perennial graminoid dominate versus annual graminoid/forb dominated systems, particularly in "tension zones"?
- To what degree is desertification associated with grazing and/or climate change?
- What is the relationship between desertification on: species composition; fire frequency, intensity, distribution, and extent; and water quality?

Sustainability – What is the present biomass and rate of productivity?

- Are vegetation productivity and species composition changing in association with climatic variation, management practices, fire frequency, or other natural or anthropogenic factors?
- Are the dominant vegetation life-forms changing on temporal and spatial scales?

- What is the status and rate of change/replacement of native versusn. exotic species?
- Are soils changing in association with climatic variation, management practices, etc.?
- Is there a change in landscape pattern (distribution, density, or composition)?
- Is the cycling of nutrients and water or the flow of energy through the system being altered?
- Is there a change in forage quality or quantity?

Water – What is the status and what trends are being observed in surface and ground water quality and quantity?

- What role do arid ecosystems play in global water cycling and related energy balance processes?
- To what extent do riparian ecosystems mitigate water quality and quantity?
- What role do current land and water resource management practices play in determining water quality and quantity in arid ecosystems?

Erosion – What is the rate of soil erosion in arid ecosystem watersheds?

- What changes in quantity and quality of soil erosion are occurring in arid ecosystems?
- What are the rates for aeolian, slope, and channel erosion?
- In what ways is resource use and management associated with erosional rates and

Fire – What is the role of fire in arid ecosystems and to what extent is associated with environmental change?

- To what extent is fire associated with weather, vegetation characteristics, arson, and management practices?
- How is the extent, distribution, frequency, and intensity of fires altered with changes in arid ecosystem composition, etc.?
- What is the relationship of fire with arid ecosystem structure and function (e.g., soil carbon and nitrogen, productivity, species composition)?

Air Quality – To what degree are changes in air quality associated with the structure and function of arid ecosystems?

- To what extent are changes in air quality associated with anthropogenic emissions, fire, erosion, etc.?
- What changes are occurring in visibility, atmospheric deposition rates, and chemical cycling that may be associated with arid ecosystems perturbations?
- What is the relationshyip between air quality and recreation, ecosystem productivity, water quality, etc.?

### 2.5.5 Existing Information and Data Gaps

An extensive, but preliminary evaluation of existing data and monitoring programs is provided in Section 6. The use and integration of existing information into EMAP-Arid is a difficult but extremely important task. The EMAP-Arid approach is to use data collected from previous and ongoing studies and monitoring networks to the fullest possible extent. Ecological research sites; Federal, state, local, and private monitoring programs; and scientific studies will be used in all phases of EMAP-Arid. Existing data will assist in formulating ecological research questions, developing ecological indicators, defining historical baselines, and understanding ecological processes. Direct linkages to ongoing monitoring programs will also be made to minimize duplication and enhance interagency cooperation. Many other data bases and networks will be explored over the next few years.

### 2.5.6 Goals and Objectives

The end result of the process outlined in Figure 2-6 is the establishment of goals and objectives. The overall goal of the EMAP-Arid is to:

> *Provide an unbiased estimate with known confidence of the current and changing conditions of ecological resources in arid ecosystems at the regional and national level.*

This goal is in concert with the EMAP goal and represents the focus of EMAP-Arid. Specific objectives for EMAP-Arid that must be met to achieve this goal are:

- Measure the status, evaluate trends, and estimate the extent of arid ecosystems using synoptic, retrospective, and sample-based methodologies.
- Determine the spatial and temporal correlation between stressor(s) (e.g., pollutants) and ecological condition/trends.
- Provide information to decision/policy makers and management, regulatory, and research agencies and institutes that can be utilized for comprehensive regional planning.
- Develop a regional interagency communication and data transfer network.

EMAP-Arid has also established 5– and 10– year goals and objectives. Meeting these goals and objectives will depend on the success of pilot and demonstration studies, development of interagency agreements, program integration, and the availability of funding for monitoring and research activities. The 5– and 10– year goals and associated objectives are:

5 Year Goal

> *Establish baseline conditions, develop a management structure and procedures, secure interagency commitments and assess the ability of EMAP-Arid to integrate information to determine regional ecological condition.*

Objectives

- Identify and review critical issues and scientific questions on a regular basis.
- Characterize and classify arid ecosystems in terms of extent and distribution.
- Develop and select indicators to assess temporal and spatial variability and sensitivity.
- Develop sampling protocols for selected indicators.
- Acquire, assess, and integrate existing databases into EMAP-Arid.
- Develop an information management network with cooperating agencies and research institutions.

10 Year Goal

*Determine regional trends in the condition and extent of selected arid ecosystem resources and develop test scenarios to determine causes of regional alteration, degradation, or enhancement.*

Objectives

- Establish a condition index for arid ecosystems.
- Evaluate trends in selected core indicators.
- Assess effectiveness of EMAP within arid ecosystems.
- Implement an integrated interagency monitoring program.
- Implement a long term strategic research plan.

These goals and objectives undoubtedly will change as EMAP-Arid progresses toward full implementation. They will be periodically (at least annually) reviewed to determine their applicability and appropriateness and will help to guide the program in an orderly and strategic manner.

## 2.6 IMPLEMENTATION

Implementation of EMAP-Arid will generally be accomplished by following the steps outlined in Figure 2-5. Currently EMAP-Arid is at Step 2, Define Study Strategy, which is the scope of this document. Following an extensive review of the strategy, exploratory (i.e., pilot and demonstration) studies will be conducted before a regional sampling design is finalized for full implementation. The sampling design will be evaluated on the basis of its ability to detect change. Following full implementation, the information produced will be assessed for its adequacy and appropriateness for use by decision makers and resource managers. Implementation of EMAP-Arid and the steps leading to full implementation are viewed as a dynamic process which issensitive and flexible to advances in our understanding of monitoring and assessing arid ecosystem conditions.

Several important design, indicator, and logistical issues need to be evaluated, field tested, and resolved before EMAP-Arid is ready for full scale implementation. The following subsections describe the types of efforts that will be made to scientifically and operationally advance the EMAP-Arid group toward national monitoring of all arid ecosystem resources. Within a given region and formation, the proposed tasks will generally be completed in sequence.

### 2.6.1 Analysis of Existing Data, Research, and Monitoring Resources

The synthesis and evaluation of existing data, research sites, and monitoring networks appropriate to each region and formation (see Section 4 for definition of formation) is a critical and cost effective first step required before proceeding to field studies. Evaluation of existing data will provide an up-to-date understanding of arid ecosystems necessary for the development of conceptual models and indicators. Existing research and monitoring sites (e.g., LTERs, BLM Range sites, National Parks) are likely candidates for calibration of synoptic indicators, "canary" sites to address specific issues, and as locations for process-based research in the development of ecological indicators. Integration of ongoing monitoring networks with EMAP-Arid will provide an important mechanism for effectively and efficiently assessing the condition of arid ecosystems. Examples of specific tasks that will be addressed include the following:

- Identify or develop conceptual model(s) using existing data for each formation that will integrate issues and ecological endpoints leading to the selection of specific indicators for implementation.
- Investigate the commonality between the EMAP-Arid design, existing monitoring networks, and long-term research sites in terms of issues, indicators, logistics, data base management, quality assurance, etc.
- Quantify to the extent possible the spatial and temporal variability of candidate indicators.
- Evaluate trends in the condition of arid ecosystems using historical and paleoenvironmental data at sites where information is sufficient.
- Using geographic information systems, initiate an analysis of the relationships between physical, biological, and stressor environmental variables.
- Perform simulations of expected indicator performance and proposed data analysis and interpretation techniques.

### 2.6.2 Workshops and Meetings

Further refinement of indicator selection criteria and core indicators will be done through additional workships and scientific meetings. Recognized aird ecosystem experts will review candidate indicators, conceptual models, and on-going monitoring and research programs in order to develop a list of core indicators for evaluation in pilot studies. Similarly, issues and methodologies concerning sampling design will be reviewed, evaluated, and designs recommended in a series of workshops and meetings.

### 2.6.2 Pilot Studies

Pilot studies are field projects that will be conducted on one arid ecosystem formation (e.g., grassland) generally in more than one region with a limited set of indicators to meet one or more of the following objectives:

- Develop, evaluate, and refine sampling methods and assessthe sensitivity of indicators of arid ecosystem condition, for the specific formation and region of interest.
- Evaluate the ability of the proposed indicators to assess ecosystem condition at sites preselected, using expert judgement, to reflect both nominal and subnominal conditions.
- Quantify the temporal variability within the index sampling period to evaluate and refine proposed sampling protocols.
- Quantify the regional spatial variability for proposed indicators.

Pilot studies will be conducted in all arid land formations and all regions, prior to full-scale implementation.

### 2.6.3 Regional Demonstration Projects

Regional demonstration projects are field studies conducted in a survey mode using the EMAP-Arid frame and the proposed EMAP-Arid sampling protocols. Demonstration projects will be conducted for each formation and region using a limited suite of indicators. The objectives of these regional demonstrations include the following:

- Identify and resolve logistical problems associated with the program design.
- Gather the information necessary to evaluate alternative sampling designs and establish appropriate data quality objectives for the program.
- Evaluate the specificity, sensitivity, reliability, and repeatability of the responses of selected indicators over a broad range of environmental conditions.
- Generate data that can be used as tools to identify sensitive areas and assess the effect of management and policy.

### 2.6.4 National Implementation

The full-scale implementation of EMAP-Arid will involve the monitoring of arid ecosystem condition and extent in all of the proposed EMAP-Arid formations and in all regions of the country, utilizing the full suite of proposed synoptic, sample-based, and retrospective indicators. Following completion of pilot studies, the program will initiate one regional demonstration project, monitoring one formation in one region, and then gradually scale up using the following proposed implementation priorities:

- Monitoring of the arid ecosystem formation in additional regions, adding new regions each year until the formation is monitored nationally;

- Yearly additions of new arid formations, starting in one region and then gradually expanding to other areas; and
- Expansion of the core list of indicators for national monitoring, as additional indicators are developed, tested, and approved.

### 2.6.5 Implementation Priorities and Schedule

EMAP-Arid has established priority classes (formations) and an implementation schedule for each priority class. Formations are ranked and shown in Table 2-1 for each EPA region identified in Figure 2-7. The ranking of each formation is based principally on a review of arid ecosystem issues and their importance to decision makers, resource management agencies, and scientists. Rankings are somewhat arbitrary since formations often cross state and EPA Region boundaries which are not based on ecologically units. In addition, these rankings must be considered preliminary as they may change as progress is made towards implementation.

The implementation schedule for each region and formation is shown in Table 2-2 and Figure 2-8, respectively. The years when pilot studies, demonstration projects, and full implementation are anticipated to begin are subject to progress made in each sequential element and the adequacy of financial resources to complete the required tasks. The proposed schedule is very ambitious but it is important that a long-term monitoring and assessment program be fully implemented as soon as possible in order to address the critical issues facing arid and other ecosystems in the U.S.

## 2.7 PROGRAM PRODUCTS

Proposed EMAP-Arid products for FY91-FY95 are identified in Table 2-3. The proposed products represent the principal outputs of EMAP-Arid and will in many ways drive the program. Details of the specific reports and other EMAP-Arid deliverables are contained in Section 13.

TABLE 2-1. EMAP-ARID LAND RANKED PRIORITY CLASSES.

| | EPA REGIONS | | | | | |
|---|---|---|---|---|---|---|
| Priority | 1-5 | 6 | 7 | 8 | 9 | 10 |
| 1 | Grassland Formation | Riparian Formation | Grassland Formation | Riparian Formation | Riparian Formation | Riparian Formation |
| 2 | | Grassland Formation | Woodland Formation | Desertscrub Formation | Desertscrub Formation | Grassland Formation |
| 3. | | Woodland Formation | Riparian Formation | Grassland Formation | Grassland Formation | Woodland Formation |
| 4. | | Desertscrub Formation | | Woodland Formation | Scrubland Formation | Desertcrub Formation |
| 5. | | Scrubland Formation | | Scrubland Formation | Woodland Formation | Tundra Formation |
| 6. | | | | Tundra Fomration | Tundra Formation | |

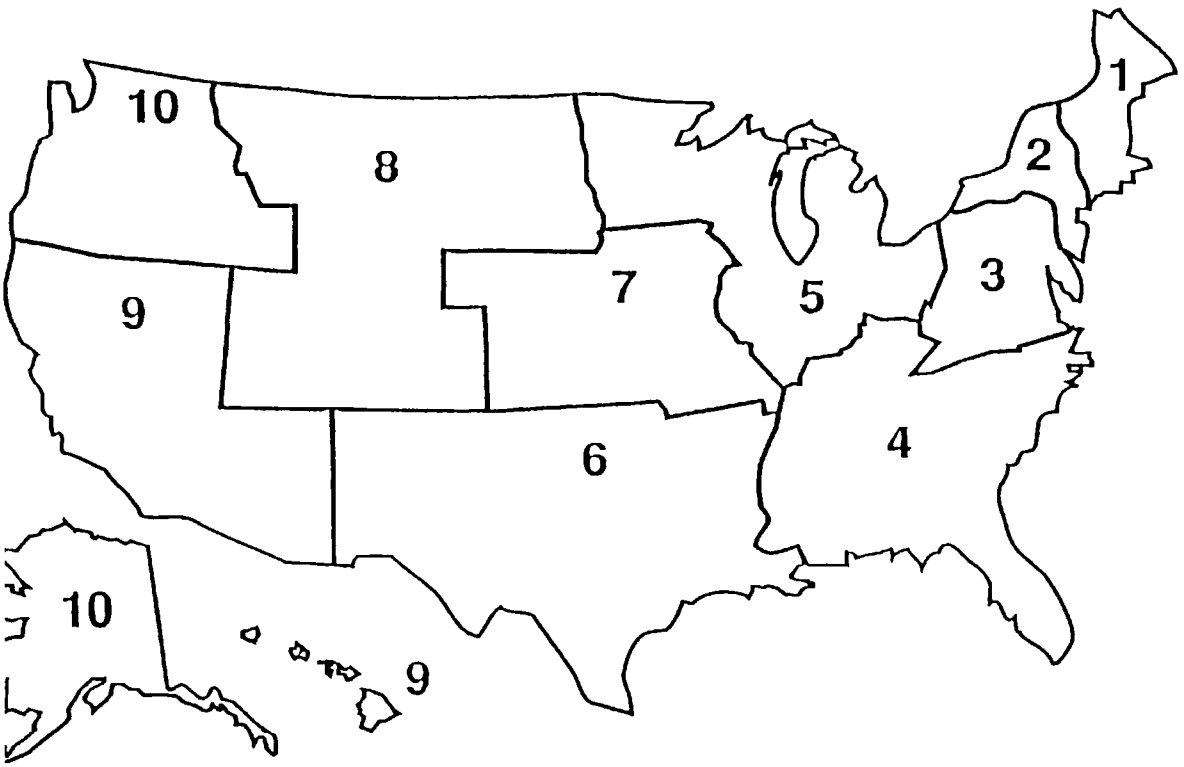



Figure 2-7 EPA Regions

TABLE 2-2. EMAP-ARID IMPLEMENTATION SCHEDULE - BY EPA REGION.

| | FISCAL YEAR | | | | | |
|---|---|---|---|---|---|---|
| Region | 92 | 93 | 94 | 95 | 96 | 97 |
| 6, 9 | Pilot | Demo | Implement | Implement | Implement | Implement |
| 7, 8 | | Pilot | Demo | Implement | Implement | Implement |
| 5, 10 | | | Pilot | Demo | Implement | Implement |
| 1, 2, 3, 4 | | | | Pilot | Demo | Implement |

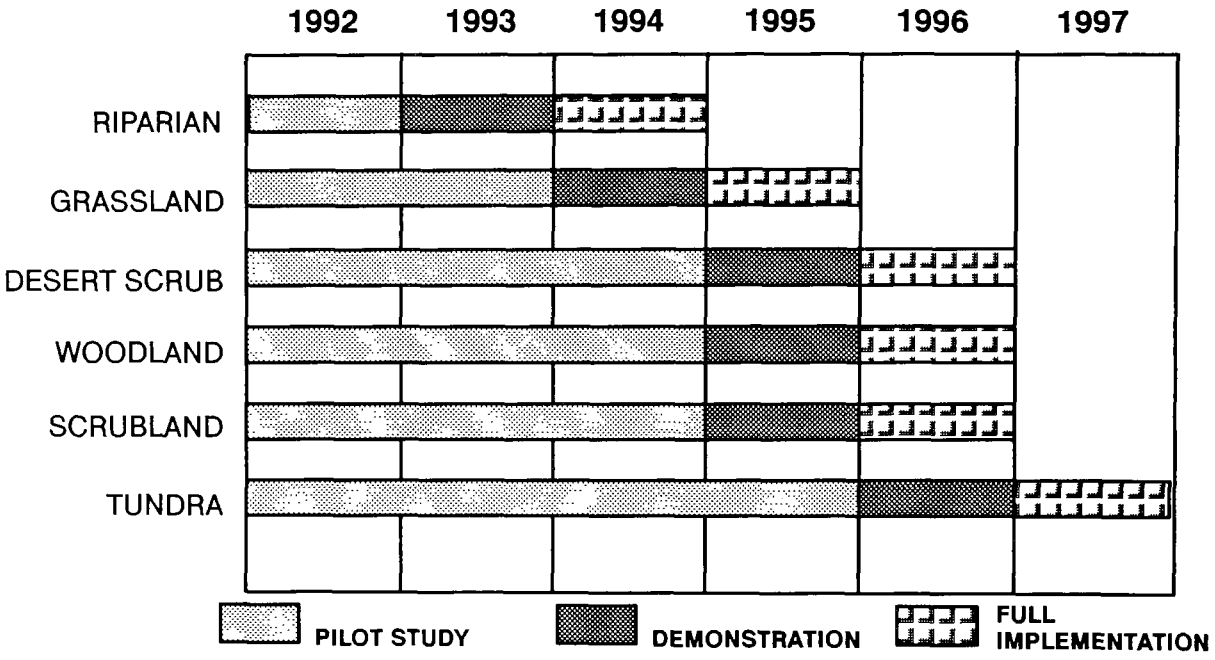



Figure 2-8. EMAP-Arid Implementation Schedule – by Resource Category

TABLE 2-3. PROPOSED STRATEGY FOR PRODUCING EMAP-ARID PRODUCTS.

| PRODUCTS | FISCAL YEAR 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|
| National Monitoring Strategy | ✓ | | | | |
| Integrated Assessment Design | | ✓ | | | |
| Annual Statistical Summaries | | | ✓ | ✓ | ✓ |
| Interpretative Reports | | | | ✓ | ✓ |
| Pilot Studies | ✓ | ✓ | ✓ | ✓ | ✓ |
| Interagency Agreements / MOUs | ✓ | ✓ | ✓ | ✓ | ✓ |
| Demonstration Projects | | | ✓ | ✓ | ✓ |
| Field Methods Manuals | | ✓ | ✓ | | |
| QA / QC Reports | | | ✓ | ✓ | ✓ |
| Implementation Plan / Riparian | ✓ | | | | |
| Implementation Plans | | ✓ | ✓ | ✓ | ✓ |
| Presentations / Publications | 10 | 12 | 12 | 12 | 12 |

# 3.0 MONITORING NETWORK DESIGN STRATEGY

This chapter presents information on the current EMAP-Arid monitoring network design strategy and its relationship to the general EMAP design. Section 3.1 presents a brief overview of the general EMAP monitoring network design. Sections 3.2 and 3.3 present the EMAP-Arid monitoring strategies and designs for the estimation of resource land use and land cover, extent, conditions, and stressors. Three classes of monitoring network designs (Section 3.4), all within the general EMAP design structure, are proposed for handling all of the EMAP-Arid resources of interest, and the EMAP tier structure is generalized to serve the EMAP-Arid requirements. The chapter concludes (Section 3.5) with a brief discussion of some special design issues that need further methodological attention from both the EMAP-Arid team and other EMAP groups.

## 3.I OVERVIEW OF THE GENERAL EMAP DESIGN

The current EMAP strategy is to design and implement a permanent national probability-based sampling network that will satisfy multi purpose customer-oriented needs in the monitoring and assessment of the ecological health of the nation. The monitoring designs are being developed to meet the following objectives as described by (Overton et al.,1989):

1. Provide rigorous and adequate statistical answers regarding any explicit question of status and quality of any resource.
2. Enable an evaluation of the degree of association of status and quality variables with appropriate measures of pollutants and other stressors.
3. Accommodate change in resource definition and classification and correction of errors.
4. Incorporate information from existing environmental monitoring networks and data bases, with immediate implementation with regard to a set of selected monitoring and baseline inventory issues.

The general EMAP design strategy was introduced in Section 1. This design involves four types of activities, or tiers, for accomplishing the ecological monitoring and assessment tasks:

- landscape characterization to determine resource extent and distribution, termed Tier 1,
- regional assessment of the status and trends in resource condition through measurement of ecological indicators, termed Tier 2,
- diagnostic studies of special subpopulations to address the associations between indicators of ecological condition and indicators of exposure and stress, termed Tier 3, and

- joint research studies to aid in the development and understanding of ecological resource conceptual models, termed Tier 4.

These four types of EMAP activities define a hierarchical, or tiered, approach that relates national and regional scale ecological monitoring to site-specific ecological diagnostic and research studies. It also allows feed back from the latter to improve the performance of the former. The greatest spatial coverage occurs for Tier 1 (T1) and Tier 2 (T2) activities, although T2 activities may be conducted on a smaller spatial scale than T1. Tier 3 (T3) activities are expected to focus on specific issues related to condition-stressor associations and undertaken on a regional or subregional basis. Lastly, Tier 4 (T4) activities will rely, where possible, on existing site-specific research programs, e.g., the National Science Foundation's Long-Term Ecological Research program.

### 3.1.1 EMAP Tier 1 Activities: Resource Extent

EMAP provides for two alternative approaches at T1 to landscape characterization of the extent and distribution of resources: a census, or complete coverage, and a sampling based methodology. In some resource classes a remote sensing approach may be able to provide appropriate and cost-effective indicator information on extent and distribution of a resource, and thus the census approach will be possible. However, in other resource situations a remote sensing system will not be able to provide the appropriate extent and distribution information, and hence a probability-based sample of the resource will be selected to estimate the resource extent and distribution.

To provide for the probability-based sampling approach, a hexagon was placed on the North American continent. Grid points established on the basis of the six equilateral triangles that make up the hexagon result in approximately 12,600 grid points in the conterminous United States, which is the grid density for baseline sampling in EMAP. The distance between each of these points is approximately 27 km. Base hexagons, established with these grid points as the center, tessellate the larger hexagon and are about 640 $km^2$.

Arounds a grid point chosen randomly within one of the base hexagons, and then located at the same place within each of the other base hexagons, a standard hexagon of approximately 40 $km^2$ forms standard support area (i.e., arbitary area representing the grid point sampling unit) for the statistical design. Because each of these 40 $km^2$ hexagons is 1/16 of the area of its base hexagon (Figure 3.1), the selected Tier 1 charqacterization sample contains 6.25 percent of the entire land mass of the conterminous United States; a sizable sampling rate for national surveys.

The two sets of hexagons (i.e., the 640-$km^2$ base and the 40-$km^2$ support) are available for landscape description or characterization utilizing a combination of remote sensing systems (e.g., satellite based aerial photography) and other information (e.g., ecological maps, and auxiliary data sets such as NOAA climate data). Some of the resource characterization may be on a census, or complete national coverage basis (e.g., the AVHRR and the Landsat MSS characterization), and some resources will be characterized only for selected subsets of the 40 $km^2$ hexagon sample. The

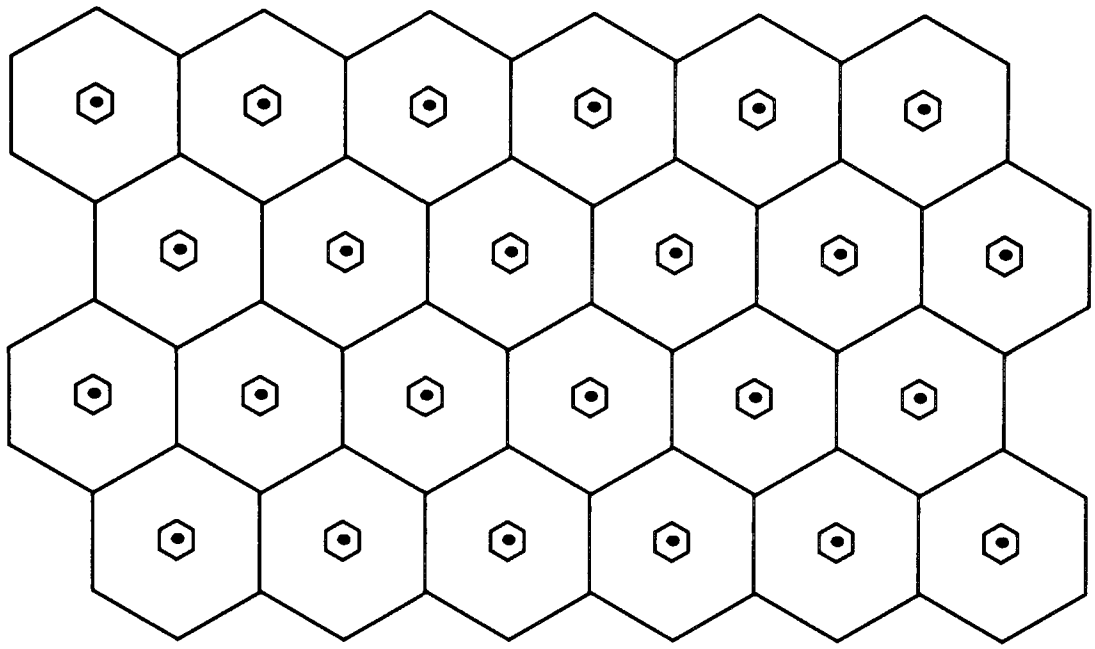


Figure 3-1. The landscape characterization hexagons are 1/16th of the total area and centered on the sampling points. The randomly positioned sampling grid occupies a common but randomly selected position in each of the base tessellation hexagons.

resulting data will be used for a probability-based estimation of the type, extent, and distribution of the various ecological resource populations.

The characterization and other resource information is also expected to be used in a double sampling scheme (e.g., Cochran,1977) for more precise planning of the subsequent T2 investigations of the actual conditions and exposure to stressors of so-called primary T1 resources (i.e., resources that are of particular interest to ecosystem issues and endpoints). Thus, the monitoring network design attempts to guarantee that no "identifiable" ecological resources at the selected level of characterization will be excluded from the sample due to the sampling design, and the double sampling methodology allows for more precise monitoring of the conditions and exposure of primary T1 resources.

Presently plans call for periodic update of the characterization information (e.g., every 5 years for the satellite derived data), and thus new estimates of population resource type, extent, and distribution will be possible. However, because these new estimates will be conditional on the previous sample selection, and they will require some additional qualifications (e.g., no effects of the act of measurement on the results or the so-called "Hawthorne" effect).

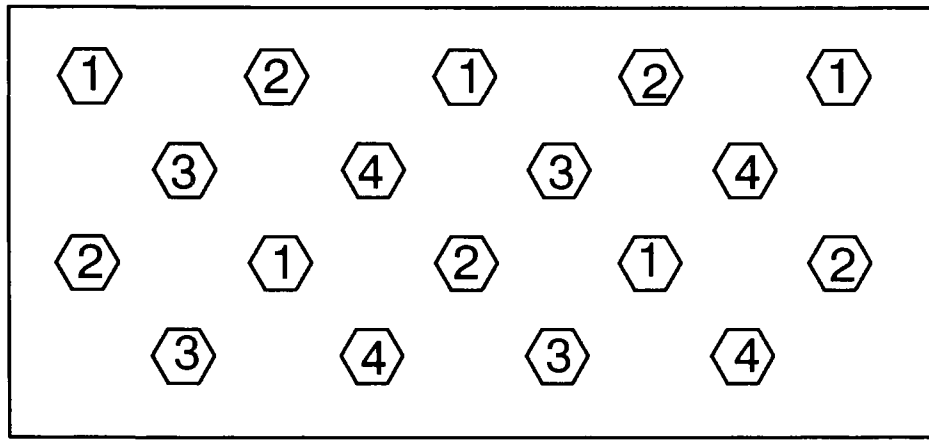
### 3.1.2 EMAP Tier 2 Activities: Resource Condition

Regional assessment of the status and trends of ecological resource conditions is the focus of EMAP tier 2 activities. Ecological condition is assessed by measuring ecological indicators for the resource class of interest. Many ecological indicators will require field sampling to obtain the necessary measurements. The general EMAP design provides for the measurement of these indicators to be made on a subsample of the T1 grid points and their associated hexagons. Other ecological indicators may be measurable through the use of remote sensing, providing complete coverage instead of a subsample of the T1 grid.

In keeping with the double sampling design, the T2 probability-based sample design is based on the T1 grid structure. The T2 design focuses on the collection of condition and stressor information in order to make separate population estimates for primary T1 resources (e.g., Rocky Mountain Alpine tundra). The selected 12,600 grid points, and their associated hexagons, are available for field data collection visits on a rotating basis. One fourth of the total sample (i.e., 3,125) will be available for field visits in each year, and these hexagons will be systematically spaced throughout the United States, (Figure 3-2). However, there is no design requirement that all 3,125 available T1 sample hexagons be visited in a given year, and currently it is not anticipated that any EMAP ecosystem group will visit this number in any year. Rather, an *a priori* systematic spatial proportion of the 3,125 hexagons will be visited each year (the proportion will depend on the particular resource and the variability of the associated indicators). It is this interpenetration (in time and space) of the sample hexagons that has been presented as one of the important characteristics of the overall EMAP design.

The EMAP monitoring design also allows for a decrease or increase in the density of the point grid (i.e., density changes by three-, four-, or sevenfold as well as any multiple), and thus one can change the number and/or "size of area selected for" of both the T1 and the T2 samples, (Figure 3-3). This flexibility allows sampling at time and space densities that are appropriate for the particular resource of interest. It provides a foundation for working with potential EMAP customers on international, national, regional, state, and even local scales.

Spatial Distribution




Time Cycle for Field Subset Visits

| | YEAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 2000 |
| **VISITED SUBSET** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 |

Figure 3-2. Spatial and time distribution for field subset visits.

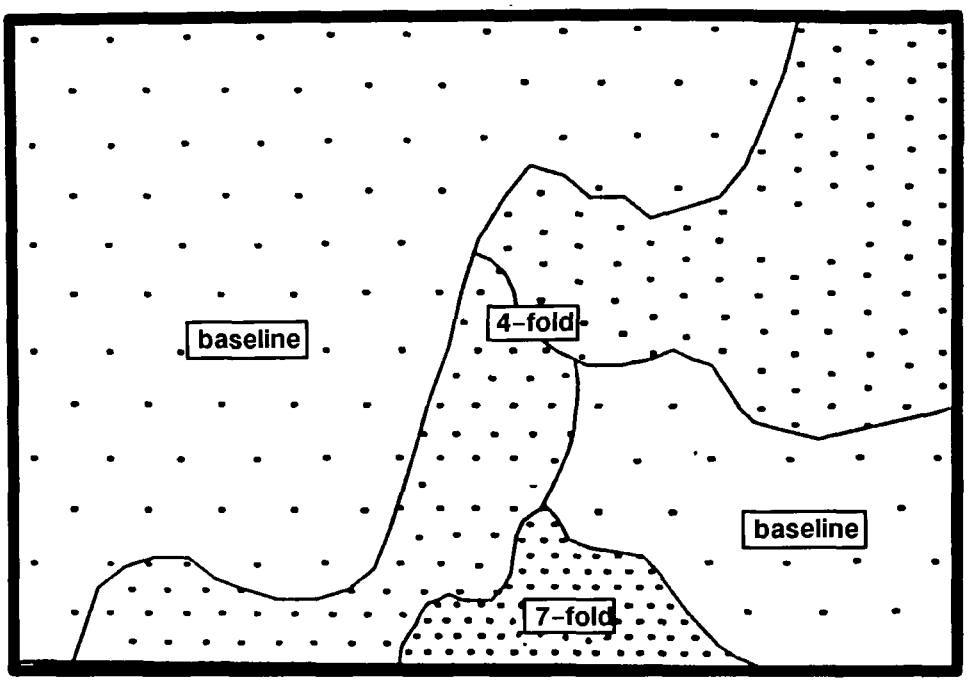



Figure 3-3. Enhancement factor for increasing the base grid density. Enhancement will be made only in the sample grid, not in the base grid.

## 3.2 FEATURES OF THE ARID ECOSYSTEMS MONITORING DESIGNS

The EMAP-Arid monitoring network component of the national EMAP design has the same general objectives as those of the overall monitoring network design and will emphasize some particular features including the following:

- The explicit identification of the major customers (e.g., BLM, and USFW) and users (e.g., EPA managers) of the monitoring results and a clear specification of their present needs.
- A monitoring hierarchy of four ecological levels that EMAP-Arid will use in addressing Tier I through Tier 4 activities.
- The construction of a set of probability-based multipurpose monitoring network designs that will be used with remote sensing and/or field measurement systems to answer specific arid ecosystem resource questions.
- A clear working definition of each general resource population of interest (e.g., Arctic Tundras) and its particular sub populations, (primary resources), of present interest (e.g., Rocky Mountain Alpine and Alaskan Coastal), the resulting identified populations (e.g., the frame or list of the locations of each cluster of Arctic Tundra), and the respective sampling points and their support units.
- A regular triangular point grid design structure that permits both increases or decreases in the grid spacing and the support size in order to be able to focus properly on ecological resources that occur on many scales.
- The ability to use time series data from historical research site(e.g., the yearly "health" of a particular cottonwood-willow community over the past 50 years) both in the design process and possibly in conditional historical estimation or development of resource condition and exposure for similar EMAP sites.

## 3.3 EMAP-ARID DESIGN BACKGROUNDS

The EMAP-Arid component of the EMAP has selected a hierarchy of four ecological monitoring with which to address the general EMAP Tier 1 through Tier 4 activities. These tasks are as follows:

1. Monitor the spatial extent and distribution of resources,
2. Monitor the condition of resources,
3. Perform diagnostic studies of the association between conditions and stressors of resources, and
4. Promote the use of monitoring and other data to aid in the development of resource conceptual models.

Although each of these tasks is important to the overall mission of EMAP, the following set of EMAP-Arid designs will focus only on tasks 1 and 2. Furthermore, each of these tasks may be

approached by collecting remote sensing or field measurement system data. All remote sensing system data will be systematically validated with ground observations. Finally, the following design presentations and discussions should be viewed as preliminary and largely indicative of current strategy.

### 3.3.1 Populations, Subpopulations, and Methodology

One of the first steps in estimating the type, extent, distribution, and condition and stressors of resources in EMAP-Arid is to define the area actually occupied by arid ecosystems; the land area which will be designated as Arid Ecosystems. The Riparian Indicators Workshop began to approach this problem by defining arid ecosystems (see Section 2.3).

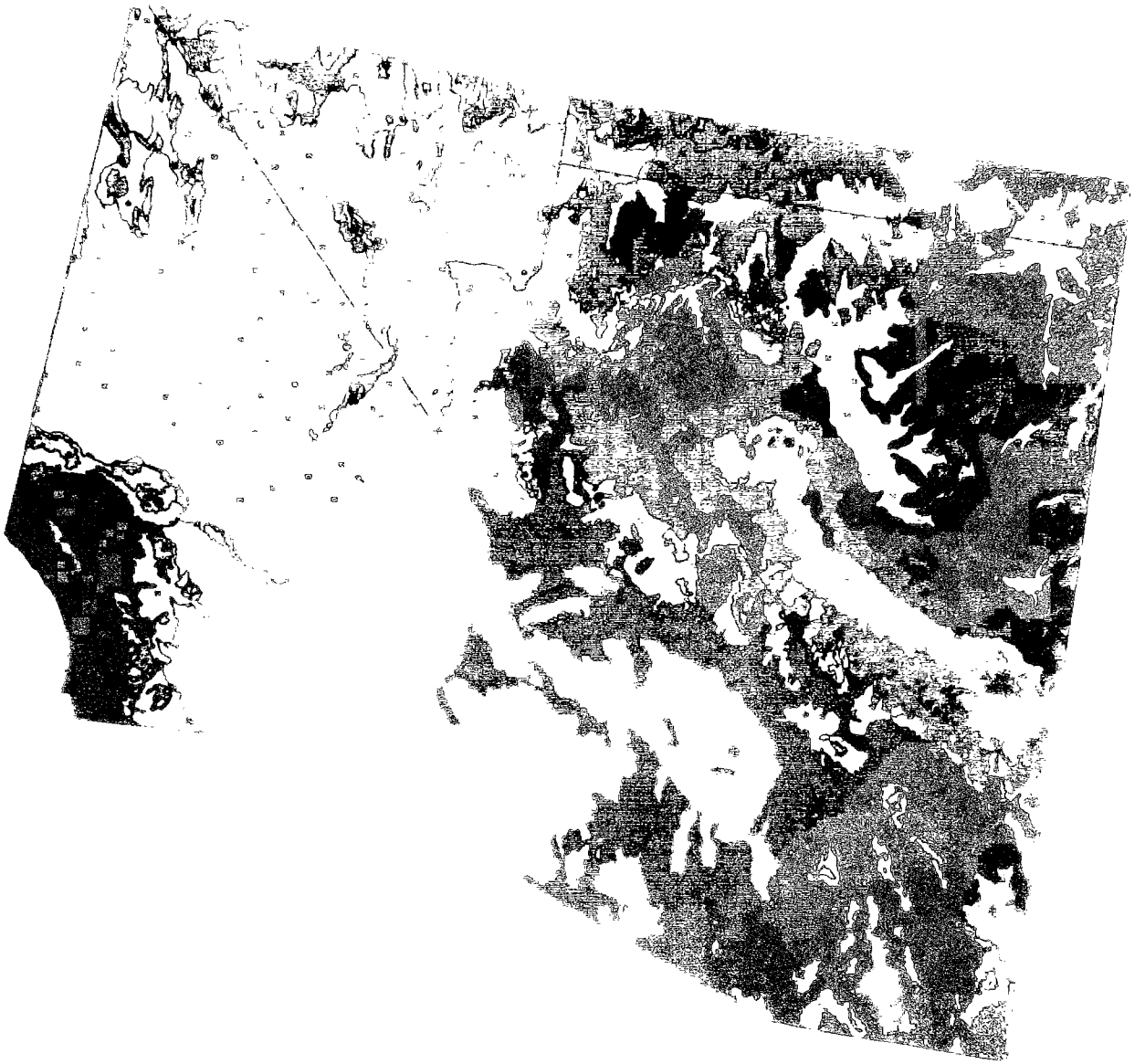
Within this region, we are in the process of more closely defining the actual EMAP-Arid area, and its various resource populations, by utilizing maps of resource categories. Two candidates have been examined (i.e., an Omernik and Gallant map and a Brown and Lowe map), and we have adopted the Brown et al.,1979, classification system and maps (Figure 3-4) because they provide locations of actual biotic communities and are hierarchical. We also are currently considering the possibility of creating a full digitization of the Brown et al. map (portions of Arizona, New Mexico, and parts of other states) have already been digitized and then using a geographic information system to produce maps and lists of populations and subpopulations of interest. However, the Brown et al. (1979) map delineations will not be of fine enough resolution to produce a list frame (potential sample sites) for rare resources such as alpine tundra. Additionally, linear resources (e.g., riparian communities) are not provided for on these maps. EMAP-Arid will, therefore investigate other potential mapping and site sources to identify sampling frames for these types of resource classes.

The ecological populations and subpopulations of interest for EMAP-Arid are described in Section 4. They include a small part of the "wetland" and a large part of the "upland" formations as listed in Brown et al. (1979). The selection of these two general populations, and the specific corresponding subpopulations (e.g., Rocky Mountain Alpine tundra, cottonwood-willow communities) stem from customer and user interests in selected ecological issues and their resulting endpoints (Section 1).

Many of the hierarchical subpopulations can be usefully counted using remote sensing and existing prior information (e.g., AVHRR, Landsat MSS, Brown et al. digitized data). Consequently, for some resources the estimates of type, extent, distribution, and condition may utilize remote sensing data for all questions of interest under the first two ecological tasks. Furthermore, substantial amounts of relevant prior information will be available from the census process for the planning of the second stage of a double sampling design, if such a design is appropriate. In this situation, the second stage will focus on validation and comparisons of the previous hierarchical results.

If we assume we can conduct a census, via remote sensing, the following three riparian resource classes: i.e., cottonwood-willow, mixed broad leaf, and mesquite communities, will be candidates for the primary T1 resources in a double sampling design , will be classified as primary

# BROWN AND LOWE BIOTIC COMMUNITIES AND EMAP HEXAGONS (WESTERN SECTION)



# BROWN AND LOWE BIOTIC COMMUNITIES AND EMAP HEXAGONS (EASTERN SECTION)

# BIOTIC COMMUNITIES

- Subalpine Grassland (141.4)
- Alpine Tundras (111.5)
- Sierran Montane Conifer Forest (122.5)
- Petran Montane Conifer Forest (122.3)
- Petran Subalpine Conifer Forest (121.3)
- Sierran Subalpine Conifer Forest (121.4)
- Great Basin Conifer Woodland (122.4)
- Great Basin Montane Scrub (132.1)
- Californian Coastalscrub (133.2)
- Semidesert Grassland (143.1)
- Californian Valley Grassland (143.2)
- Plains and Great Basin Grassland (142.1)
- Chihuahuan Desertscrub (153.2)
- Mohave Desertscrub (153.1)
- Lower Colorado River Subdivision (154.11)
- Arizona Upland Subdivision (154.12)
- Interior Chaparral (133.3)
- Californian Chaparral (133.1)
- Madrean Evergreen Woodland (123.3)
- Californian Evergreen Woodland (123.4)
- Great Basin Desertscrub (152.1)
- EMAP Hexagons

T1 resources and assigned to individual strata. Assigning each of these primary resources to a separate strata allows us to control their respective sample sizes in an effort to achieve the precision specified by the customers and the resulting data quality objective (DQO). All of the other resources identified by characterization will be termed secondary T1 resources and assigned to the same separate stratum, (Figure 3.5).

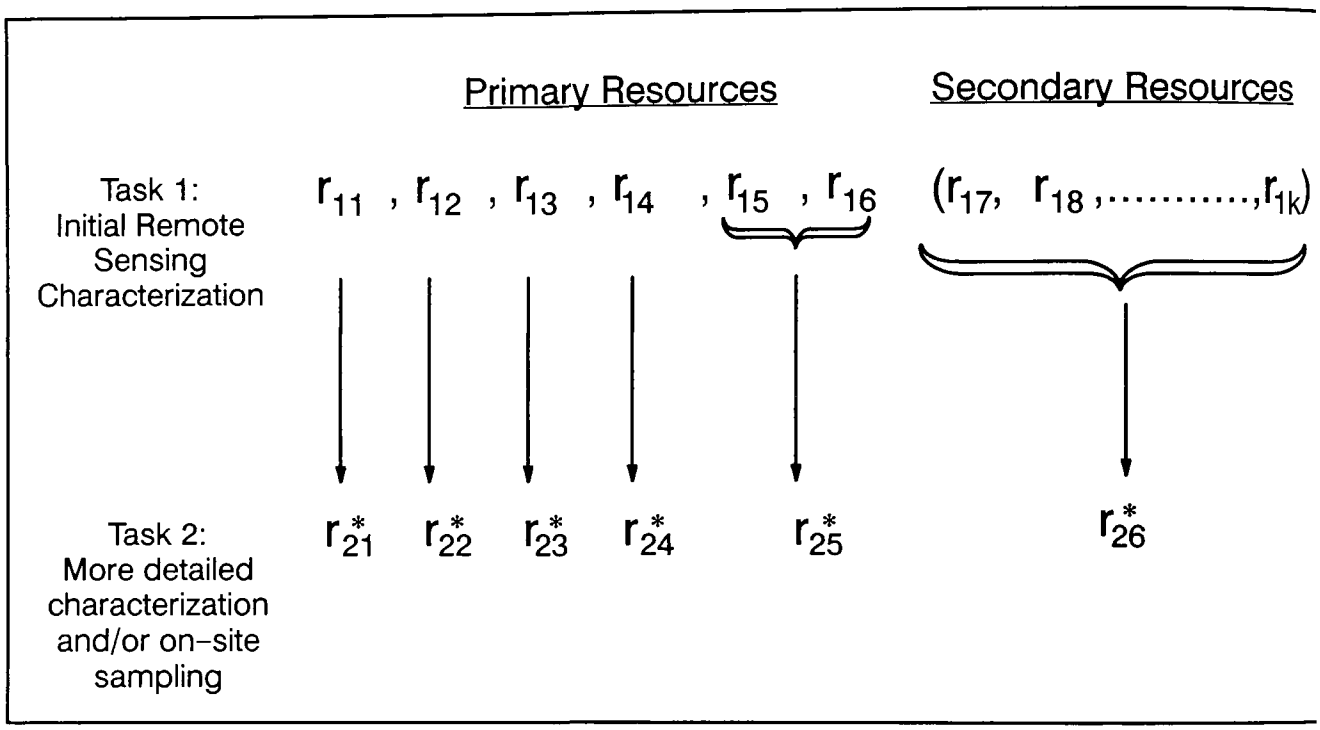



Figure 3-5. Possible double sampling Relationships between tasks 1 and 2 for both primary and secondary resources.

If a secondary T1 resource becomes of special concern, then it can be designated a primary resource, removed from the secondary category, and given a separate T1 stratum in order to control its sample size and the resulting precision of its population estimates. If this situation arises after characterization has been completed, then post-stratification would allow for separate resource estimation but result in loss of control of precision of the estimate. It should be remembered that only the primary resources will be monitored separately in the second stage, or T2, of the monitoring design.

### 3.3.2 The Sample Units

As mentioned earlier, the sample units in the general EMAP statistical design are grid points. However, because a point creates a very small area to sample, there are supports attached to each grid point in the form of a hexagon of some size. Thus, the associated hexagon is the area that the

sample unit will represent at the first level of a double sample design. Hence, the size of the hexagonal support must be carefully examined in order to have it represent an effective ecological unit for the given resource. For the present the standard, or default size, is set at 40 $km^2$ (Overton et al., 1989). Also, a procedure will be needed for handling edge problems (i.e., a sample unit whose support has some portion of its area outside of the boundary of the particular resource class).

### 3.3.3 Frame Development

The two-dimensional regular triangular point grid and its associated hexagons has provided one possible sampling frame (i.e., a sample of the entire population frame). This regular point grid has promoted, but does not guarantee equal spatial coverage across all ecological resources. It also provides for a complete spatial or list frame of the resources of interest within the hexagons selected for sampling. However, cost-benefit analysis is needed to decide if it is better to use a first stage sample to accrue some detailed planning information to provide more focus for the second stage sampling. An alternative frame could be provided by other materials such as maps, state resource inventories, and results of other relevant studies, this kind of frame would use the given resources to collect a larger single-stage sample. Section 3.4 will provide some details on frame construction for the EMAP-Arid situation.

For relatively rare resources of special concern, such as Rocky Mountain Alpine tundra, the regular triangular point grid and its supporting hexagons may not have sufficient resolution to catch any or a sufficient number, of these resource units. Thus, other frame materials EMAP-Arid will investigate alternative frame material source over the next five years will be needed to locate these resources and allow for the construction of a list frame.

### 3.3.4 Sample Selection

At the initial level of the general EMAP design, the set of approximately 12,600 grid points in the conterminous United States has been randomly selected and the supporting standard 40 $km^2$ hexagons have been designated. For the EMAP-Arid study which actual locations and the number are presently under investigation. However, initially it appears that about 4000 grid points fall within areas designated as arid lands, and it would be possible to characterize a yet to be determined systematic proportion of the associated hexagons at an appropriate level of detail.

An alternative to the above sample selection is a census of the entire EMAP-Arid region using a remote sensing system such as AVHRR, Landsat MSS, or other imagery data. There currently appears to be considerable interest in this alternative for a number of reasons. First, some of the potential customers have expressed a strong interest in complete coverage data. Second, it appears that some of the present maps may not be current or accurate enough to correctly delineate the transition zones (ecotones) of various resources; these locations may be the most telling in some ecological issues. Third, this alternative would give us an opportunity to partially evaluate the selected EMAP Tier 1 sample by comparing a census with corresponding sample estimates (e.g., the spatial extent land size distribution for grasslands). Finally, there is some present evidence that the actual cost of such a census may be affordable. This census, or 100 percent sample, strategy is presently being given careful consideration.

## 3.4 THREE CLASSES OF ARID LANDS DESIGNS

Important ecological endpoints for EMAP-Arid region include sustainability, biodiversity, and aesthetics (see Section 2.5.4). For each of these endpoints, critical questions (based on customers needs) already have been or will be identified, and the extent, distribution, conditions, and stressors of the relevant resources will be investigated. Because available existing information and the sampling problems can change from resource to resource, the EMAP Arid resource group investigate the use of several classes of monitoring network designs. This investigation should allow selection of a design appropriate to a given situation.

As a result of the investigation, propose that three classes of monitoring network designs be utilized for EMAP-Arid population estimations (1) a discrete rare resource, (2) an elongated resource, and (3) an extensive resource design class.

### 3.4.1 Discrete and Rare Resource Design

There are some resource populations that clearly are discrete, and often rare (e.g., Rocky Mountain Alpine tundra, riparian communities and playa lakes), and thus special attention is needed to properly sample these resources. Two approaches to this problem are being considered by the EMAP-Arid team.

The first, and presently preferred, approach is to identify each and every discrete cluster or unit of the particular primary resource throughout the EMAP-Arid region. This typically will require substantial existing information (e.g., data drived from remote sensing, maps) of sufficient resolution to identify and accurately locate each unit. Then an ordered (e.g., by elevation) list of the resource units (the list frame) can be constructed, and a systematic sample can be drawn from this list, assuring proper spatial coverage and an appropriate sample size. If the list is relatively short, a systematic sample at interval 1, would achieve a census of the resource units on the list.

The second, more limited approach is to use the EMAP characterization information from a given sample of the hexagons (probably with an enhanced point grid and/or enlarged hexagons) to construct groups (strata) of hexagons based on the likelihood of the existence of the particular resource (e.g., unlikely, possible, very likely). The strata would be sampled with a probability proportional to the likelihood of the existence of the particular resource and a census performed in each of the selected hexagons. This approach would result in more sampling of hexagons which *a priori* had more evidence of the existence of the particular rare resource. The choice between these two alternatives will depend substantially on the quality and quantity of the available information and the relative costs of the two approaches. Finally, if a non-rare discrete resource can be readily listed, then it too can be handled by this type of design. EMAP-Arid plans to evaluate these and other alternatives for discrete and rare resources over the next five years.

### 3.4.2 Elongated Resources Design

In some situations the primary resource of special interest such as cottonwood-willow communities, or the principal area of interest for the resource, such as grassland-desert ecotone,

occurs in linear or elongated forms. In this case, special care must be exercised in order to capture the resource and estimate the resource extent, distribution, condition, and stressors with the desired precision.

The initial problem is to create an ecologically meaningful sample unit for the designated primary resource (e.g., the riparian corridor along a stream reach for measuring the cottonwood-willow communities) and to clearly define the entire desired population of all sample units (e.g., all riparian corridors along all stream reaches.

A second problem is how to identify collection of possible sample units. (Note: the desired population of sample units may differ from the identified set, the frame, in that one may desire to investigate all riparian corridors but be restricted to corridors on "active" steams.) The typical alternatives are map frames, list frames, or conditional population frames constructed from existing information such as the characterization of some of the selected sample hexagons. The latter is the EMAP double sample situation and if it is appropriate, this will be the preferred frame.

As an example, if the remote sensing characterization or other existing information (e.g., the USGS 1:100,000 topographic map) has been able to identify all riparian forest communities, then we can superimpose a set of selected hexagons on this prior information and have the basis for a conditional sample frame for those cottonwood-willow communities. One approach to generating an actual conditional frame would be to construct a within-hexagon list frame of all of the identified possible riparian sample units in all of the EMAP-Arid 40 $km^2$ hexagons using a given membership rule. For example, if the upgradient node of the stream reach resides within the hexagon, then the riparian corridor associated with that reach is a member of that hexagon, Figure 3-6. This list frame then could be used to select the second-stage sample units (e.g., cottonwood-willow communities).

With regard to the sample size question, it has been suggested that typically a total of 50 to 100 sample units over the full four-year cycle are needed to produce adequate population estimates (Linthurst et al.,1986). However, the final desired number of samples should be related to the actual performance of selected indicators and the desired precision of the estimator (these two issues will be addressed in forthcoming EMAP-Arid pilot studies). Finally, if the sample size for a particular resource sample size appears to be inadequate, the grid can be enhanced or the hexagon enlarged or both.

In true double sampling fashion, it is assumed that EMAP-Arid typically will visit only a subset of the selected 40-$km^2$ hexagons for the second stage of the study. Thus, a probability-based rule will be needed for selecting a spatially distributed set of hexagons for each primary resource of interest. It should be noted that a different subset of hexagons may be visited for each resource. However, for a number of reasons (e.g., cost, ecotone estimation, and integrated joint estimation), the EMAP-Arid team believe a "core set" of hexagons in which all primary resources will be measured is preferable.

The above mentioned stream-reach elongated design for riparian resources is very similar to the EMAP Surface Waters stream design (Paulsen et al., 1990). Thus, for riparian resources

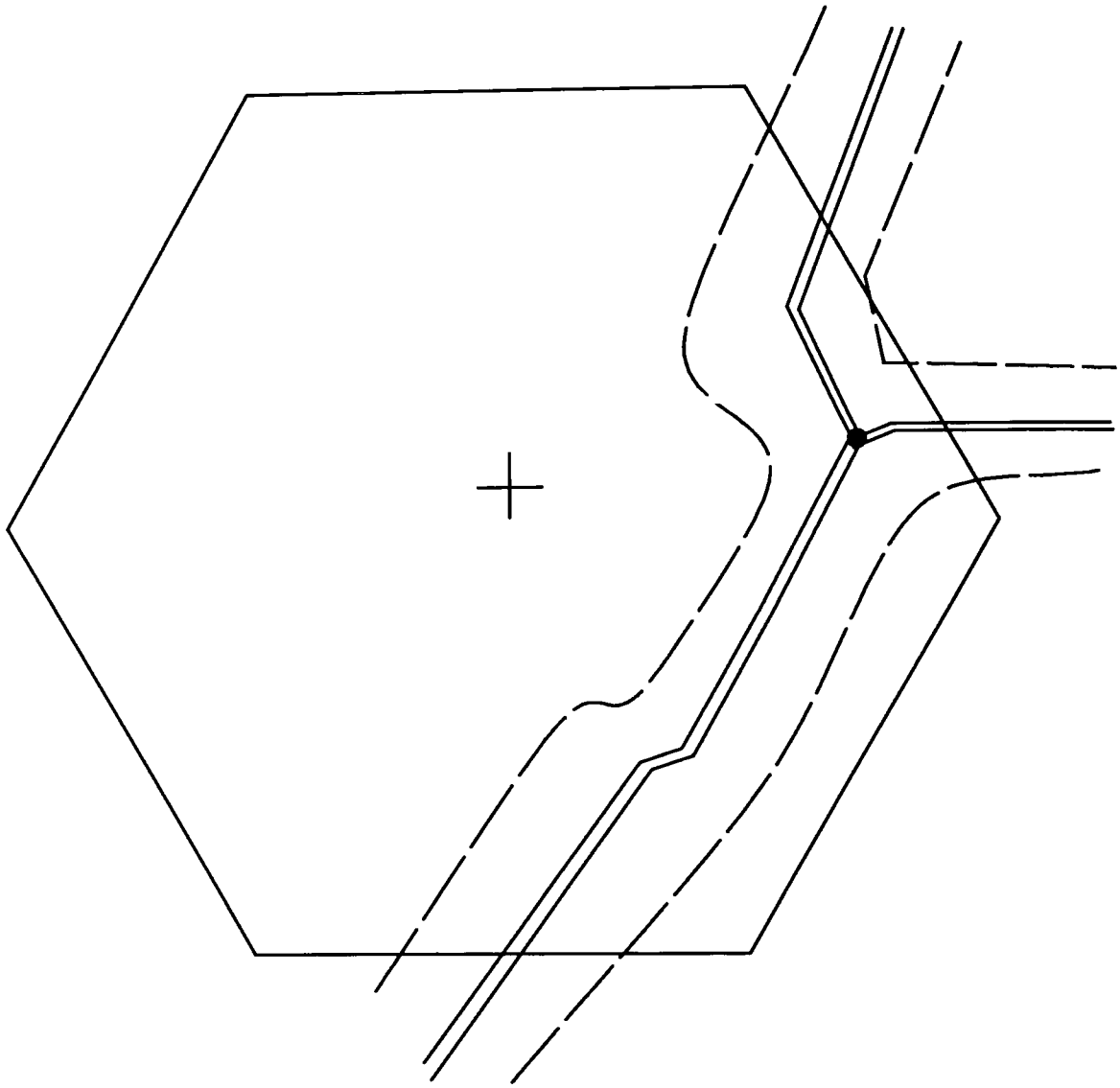


Figure 3-6. A 40-km$^2$ hexagon its stream component, and the riparian corridor.

identified by the EMAP arid resources group, it will be necessary to combine efforts with the Surface Waters group in order to allow for resource sharing and joint estimation of particular resources. Clearly this possibility needs to be further evaluated. EMAP-Arid will be holding workshops over the next few years to develop and evaluate sample designs for elongated resources.

### 3.4.3 Extensive Resource Design

The third situation occurring in the EMAP-Arid ecosystems is the presence of broadly located or extensive resources. Examples include scrubland, grassland, and desertscrub formations. In

this case the selected set of grid points can be used as sample units, and the supporting hexagons (e.g., the standard 40 $km^2$) become the sampling areas. A frame for a particular primary resource can be constructed by using the relevant Brown and Lowe map and overlaying the EMAP point grid and its standard hexagons. Those hexagons that intersect the particular resource become members of the frame. This map frame or an ordered list frame can then be sampled using some type of spatially proper systematic probability rule to select the second stage subsample of hexagons which will be further characterized and visited in the field.

The typical initial primary resource sample size will contain approximately 50 to 100 total hexagons over a complete field cycle (4 years) until detailed information is available on the total variability of the particular indicator which may increase or decrease the number of hexagons. Then, after weighing with the appropriate inclusion probabilities, the empirical frequency and cumulative distribution functions can be calculated for each indicator of the condition of the primary resource (e.g., size of the crown for the scrubland communities).

Lastly, it should be noted that for some primary resources of interest (e.g., creosote bush) the comparison of results from two monitoring designs may be ussful to in assess the condition of the resource. As an example, results from the pinyon-juniper-sagebrush ecotone elongated monitoring design could be compared with the results from the extensive monitoring design to determine the relationship between the two approaches for assessing resource conditions. The ecotone results may prove to be a useful early warning predictor of forthcoming large-scale changes.

## 3.5 OTHER DESIGN ISSUES

A number of statistical and data issues have been directly or indirectly raised by the proposed EMAP-Arid monitoring designs. Some of the more important problems are briefly mentioned and discussed below. Current suggested solutions are also provided in the discussion.

### 3.5.1 Reserve Sample of Grid Point Hexagons

There appears to be a need for a reserve set of hexagons. Two roles presently are planned for this set. First, one needs to assess the "Hawthorne" effect -- does the rancher purposely graze fewer cattle on the land that is within the 40 $km^2$ hexagon than on land outside the hexagon. Consequently, it maybe necessary to monitor pairs of adjacent hexagons and keep one anonymous. Second, we probably need to follow other "rotating panel" type surveys, such as the current population survey, and admit that some percentage of the selected hexagons will become unavailable to us (i.e., access denied) at some point in time. These nonresponse units create both a sample size and an inference problem, particularly if their proportion becomes sizable (e.g., 25 percent). Therefore, the EMAP-Arid group is considering the use of an over-sampling scheme rather than attempting to construct a substitution rule for unavailable hexagons. The latter approach typically is unacceptable if classical statistical inference statements such as confidence interval statements are needed.

### 3.5.2 Plot Designs

The statistical plot design (the spatial sampling design used to select a single sample unit of the resource) should depend on a number of items including the within sample unit variability of the particular resource, the complexity of the indicators being used, and the cost of taking and processing measurements. The possible plot designs include the entire hexagon (a typical characterization situation), a radial design using the three line segments that pass through the center of a hexagon and connect its corners (a balanced spatial design suitable for sampling clustered resources), and a sequence of systematically spaced parallel transects each perpendicular to a single line which passes through the center point of the selected hexagon (a balanced off-grid design possibly suitable for riparian communities). We plan to investigate different plot designs both theoretically and empirically in future studies.

### 3.5.3 Shorter Time and Space Scales

There may be some ecological situations where a resource responds to a stressor on a very short space and time scale (e.g., cottonwood-willows impacted by industrial, mine, or farm effluents). In these cases, it may be important to monitor at least on a yearly basis to detect changes early. Also, an internal or external EMAP-Arid customer may request annual monitoring of the same sites. The EMAP design will accomodate such requests but the costs will likely be incurred by the client.

### 3.5.4 Spatial Association

It is well known that systematic sampling can be viewed as cluster sampling (e.g., Cochran, 1977), and in this case the sampling design handles the intercluster correlation in the population estimation process. In the present context this often is termed spatial association, and the question of enlarging the supporting hexagon versus enhancing the point grid is directly related to this problem). Hence, the EMAP-Arid team expects to consider cluster sampling methodology in planning monitoring designs for both future empirical and simulation studies.

### 3.5.5 Fixed Historical Site Data

Four roles presently are planned for fixed historical site (FHS) data in the EMAP-Arid monitoring network designs. The first use is to aid the designers in the assessment of potential natural variability found in various arid ecosystem indicators over the past decades. The second use is in the identification of new indicators of ecosystem conditions and exposure. The third use is to establish the degree of correspondence between the behavior of the FHS resources and the behavior of the same (other members of a local well-defined population) resources at surrounding sample sites measured on the grid. Hence, we should be able to determine the representtiveness of these historical sites by comparing to measures taken on the EMAP grid. The hope is that FHS data can be used as a proper historical baseline for the evaluation of present resource trends for a local well-defined resource population. Arid the fourth use is to provide information for diagnostic and research efforts, tasks 3 and 4 listed in Section 3.3. It is presumed that some FHSs will become EMAP diagnostic and research sites.

# 4.0 ARID ECOSYSTEMS CLASSIFICATION

Arid regions may be classified according to a number of biotic and abiotic environmental factors, including land use, climate, geology, physiography, and vegetation. While all of these factors are interrelated, vegetation is perhaps the most effective integrator of the environment. Changes in climate, soils, geology, and physiography are all reflected in the vegetation. Vegetation is, therefore, very sensitive to these environmental changes. As such, EMAP-Arid is adopting a classification based on vegetation. This classification can be considered at various levels of detail and spatial resolution for characterization performed by using detailed and intensive ground-based sampling or extensive satellite remote sensing.

Classification systems can be defined as the grouping or clustering of objects based on their resemblance to each other (Ludwig and Reynolds, 1988). Vegetation is heterogeneous, the approaches to its classification numerous, the purposes served by the classifications highly varied, and the personal attitudes of the phytocenologists equally varied (adapted from Kuchler, 1967). There are, therefore, different approaches to an orderly arrangement of vegetation extent and distribution, and each of these may lead to success in certain regions or for certain purposes. The appropriate classification must be selected and developed for the specific purpose.

Vegetation classification (and concomitant mapping) necessarily presupposes that grouping or clustering of similar vegetation species or characteristics exists and that groups of similar species or plant characteristics repeat themselves in a pattern across the landscape. Some ecologists argue (successfully) that the concept of groups or clusters of species represents an arbitrary and anthropogenic view and that, in fact, species distribution follows a continuum across a suite of various environmental parameters. From the landscape ecology view taken by EMAP, however, the importance of characterizing landscape mosaics is of paramount importance; hence the need for a classification system.

Units within a classification system do not imply complete homogeneity of attributes, that is, an equal chance to find a given species or vegetation characteristic throughout the unit, but rather a relative homogeneity of attributes, that is a higher chance of finding one or more species (or vegetation characteristic) within one unit than in another.

A vegetation classification presupposes that a number of vegetation categories can be established. These categories can be arrived at in a number of ways, three of which follow (after Ludwig and Reynolds, 1988):

1. Classifications may be hierarchical or reticulate. In a hierarchical classification, groups at a lower level within the classification are exclusive subgroups of those groups at higher levels. In a reticulate classification, groups are defined separately and are linked together in a web-like network. Nonhierarchical and nonreticulate classifications, or mere listings of types or units, also exist and are common.
2. Classifications may be either divisive or agglomerative. In a divisive classification, the entire collection of sample units (SUs) is divided and

redivided to arrive at the final groupings (i.e., picture an inverted tree). In an agglomerative classification, individual SUs are combined and recombined to form larger groups of SUs (the tree).

3. Classifications may be either monothetic or polythetic. In a monothetic classification, the similarity of any two SUs or groups is based on the value of a single variable, for example, the presence or absence of a single species. In a polythetic classification, the similarity of any two SUs or groups is based on their overall similarity as measured by numerous variables, for example, species abundances.

The EMAP-Arid classification is hierarchical, divisive, and polythetic. For EMAP-Arid, it is highly important that resources be considered in a hierarchical context. This context allows characterization of arid ecosystems at both very coarse or regional levels as well as at finer or local levels. aierarchical system allows for characterization at a multitude of scales and levels of intensity. In addition, it allows for characterization at a finer level of detail if ancillary information or local knowledge is available and use dictates it. This kind of system also allows for characterization at a coarser level should either a lack of available information or demand preclude the need for characterization at the finer level. The following illustrates a general characterization of ecosystems at varying levels within a digital hierarchical classification (Brownet al., 1979):

1,000 = Biogeographic (Continental) Realm
1,100 = Vegetation
1,110 = Formation-type
1,111 = Climatic (thermal) Zone
1,111.1 = Regional Formation (Biome)
1,111.11 = Series (Community of generic dominants)
1,111.111 = Association (Community of specific dominants)
1,111.1111 = Composition-structure-phase

In addition to the hierarchical systems suggested by Brown et al. (1979), the EMAP-Arid examined a number of other classification systems. At the coarsest level, these included systems developed by Omernik, Kuchler, Bailey, which all describe the basic cover types occurring within EMAP-Arid. The basic uses for these systems is for identifying and delineating regional boundaries.

The ecoregion concept developed by Omernik has been used to determine the entire arid ecosystem geographic region of interest that can be defined through broad climatic and physiographic types. Broad boundary identification based upon actual present vegetation may be more useful for EMAP purposes than systems based upon potential vegetation, physiographic types, or broad climatic types. Therefore, an integration of multidate AVHRR imagery with any of these classification systems might be most useful for the delineation of those boundaries. One problem even with the use of a coarse system such as the AVHRR lies with boundary placement. The eastern boundary of EMAP-Arid broadly integrades with wetlands, agroecosystems, and forests, and, therefore, complex decision criteria are required to identify the boundaries.

Small-scale characterization can be extremely useful for identifying changes that may not be perceptible or noticeable at larger scales. An example of such a change might be manifest through

albedo or total surface reflectance. Evidence of a gradual climatic trend toward increased aridity or a tendency toward overgrazing on public lands might be more acceptable if it occurred over very large areas (small scales) than over small areas. In such examples, a high radiometric resolution remote sensing system such as the AVHRR with coarse spatial resolution and with a very short repetitive coverage (twice a day) might be ideal. Coarse classification systems, such as some of those mentioned earlier, or a higher (broader) level within a detailed hierarchical system would be more appropriate for regional characterization.

The EMAP-Arid resource group has adopted the Brown, Lowe, and Pase (1979) classification systems for use at finer levels of landscape characterization. This system allows for landscape characterization for a variety of ecological research and management purposes. The fact that this system is hierarchical adds to its utility for reasons previously mentioned. An example of the Brown, Lowe, and Pase classification, which might be of use in portions of Nevada, is (the first digit has been deleted):

150 Desertscrub Formation
151 Arctic-Boreal Desertlands
151.1 Polar Desertscrub
152 Cold Temperate Desertlands
152.1 Great Basin Desertscrub
152.11 Sagebrush Series
152.111 *Artemisia tridentata* Association
152.112 *Artemisia tridentata*-mixed scrub-grassAssociation
152.113 *Artemisia nova* Association

We have adapted this system to meet the characterization needs envisioned for EMAP-Arid. Using the example of characterization in central Nevada, delineation and identification would begin at the second digit to differentiate a Desertscrub Formation (150) from, for example, a Grassland Formation (130). The third and fourth would identify the locale. At the fifth digit, there would be an attempt to differentiate a sagebrush series (152.11) from, for example, a blackbrush series (152.13). With ground sampling and verification, characterization to the sixth, seventh, or even eighth digit might be possible. Digital remote sensing (Landsat TM or even MSS) might be able to separate units at very fine levels depending upon percent cover, the differentiation of reflectance properties among types, the association of the vegetation types with ancillary information (elevation, parent materials, soils, slope and aspect), and ground verification.

The structure of our classification, then, proceeds from the formation through the series level to progressively finer levels. The EMAP-Arid group plans to investigate flora/fauna classification alternatives. Formation level categories are listed in Table 4-1.

TABLE 4-1. VEGETATION DIVISION, FORMATION AND VEGETATION TYPES INCLUDED IN EMAP-ARID.

| Vegetation Division | Formation | Vegetation Type |
|---|---|---|
| Wetland | Riparian Forest | Cottonwood/Willow<br>Mixed Broadleaf<br>Mesquite |
| | Riparian Scrub | Salt Cedar<br>Mixed Scrub |
| | Wet Tundra | |
| | Strandland | Salt Cedar<br>Mixed Scrub |
| | Other [1] | |
| Upland | Desertscrub | Creosotebush-bursage<br>Sagebrush |
| | Grassland | |
| | Scrubland (or chaparral) | |
| | Woodland | |
| | Tundra<br>Other [2] | Rocky Mtn. Alpine Tundra |

[1] Marshlands, submerged emergents, and similar wetland cateogories are included in EMAP-Wetlands.

[2] Forest lands and agricultural lands are included within separate EMAP resource groups.

# 5.0 INDICATORS

## 5.1 INTRODUCTION

As stated in the EMAP Indicator Development Strategy (ERL, 1990), EMAP success will depend on the ability to characterize environmental condition (or health) and to suggest likely causes of adverse changes. Because concepts such as environmental "condition" or "health" cannot be directly measured, EMAP will monitor a set of environmental indicators that collectively describe the overall condition of an ecosystem. An environmental indicator is defined as an environmental attribute that, when measured, quantifies the magnitude of stress, habitat characteristic, degree of exposure to the stressor, or degree of ecological response to the exposure. Because of the importance of indicators in interpreting ecosystem condition, the selection, development, and evaluation of these indicators for use in a broad-scale regional status and trends program is a major component of EMAP activities.

Indicators will be used within EMAP to assess condition, or health, of ecological resources. Rapport (1989) lists three approaches or criteria commonly used to assess ecosystem health: (1) identification of systematic indicators of ecosystem functional and structural integrity; (2) measurement of ecological sustainability or resiliency, i.e., the ability of the system to handle stress loadings, either natural or anthropogenic; and (3) the absence of detectable symptoms of ecosystem disease or stress. Additionally, an indicator should be (from Noss, 1990):

1. sufficiently sensitive to provide an early warning of change;
2. distributed over a broad geographical area;
3. capable of providing a continuous assessment over a wide range of stress;
4. relatively independent of sample size;
5. easy and cost-effective to measure, collect, assess, and/or calculate;
6. able to differentiate between natural cycles or trends and those induced by anthropogenic stress; and
7. relevant to ecologically significant phenomena.

In more general terms, determination of ecosystem health involves measurement of systemic indicators of ecosystem functional and structural integrity. Measurements of primary productivity, nutrient cycling, species diversity, system stability, prevalence of disease, structure (e.g. distribution of life forms), and the occurrence of contaminants are examples of parameters that can be used to quantify ecosystem condition (Rapport, 1989). These measurements can be made and are applicable to virtually all ecosystems including arid ecosystems. The parameters which are measured are referred to as indicators.

## 5.2 DEVELOPMENT OF INDICATORS FOR ARID ECOSYSTEMS

The overall strategy and process employed to specifically develop indicators of ecological health for arid ecosystems is similar to that identified by Hunsaker and Carpenter (1990). EMAP-Arid has developed a conceptual model linking ecological endpoints and indicators to assess the status and evaluate trends in the condition of arid ecosystems. Hunsaker and Carpenter (1990) divided indicators into three groups: stressor, exposure, and habitat indicators (other investigators might add response). While the EMAP-Arid resource group recognizes the importance of this trichotomy, EMAP-Arid has adopted a further characterization based on how they're measured. This activity retains the process used throughout the EMAP as outlined by Hunsaker and Carpenter (1990), but consists of three measurements categories of indicator types (synoptic, sample-based, and retrospective) that have been identified for arid ecosystems Figure 5.1).

The initial broad list of indicators developed for EMAP-Arid were determined through a series of workshops and interactive meetings involving EMAP-Arid team members and others from the academic community and various resource agencies. Workshops were held in September 1989, January 1990, and September 1990 to develop and discuss candidate indicators. The candidate indicators were compiled by a number of working groups and presented for review to the workshop participants. Selected indicators have been summarized and are presented in Table 5-1. Table 5-2 lists the sample protocols for each indicator. Fact sheets discussing these indicators have been compiled and are summarized in Appendix A.

As mentioned above, we have further classified indicators by the way in which they're measured. Synoptic measurements of indicators provide full landscape coverage and essentially eliminate the need for probability-based field sampling because they measure specific attributes over the entire population. Advancements in remote sensing and image processing technologies now make the use of synoptic indicators as measures of ecosystem health applicable to environmental monitoring. Arid ecosystems are particularly well suited for the application of synoptic indicators because of the numerous near by cloud-free days, the general lack of a closed vegetation canopy, and the availability of imagery over large spatial and temporal frameworks.

Sample-based measurements of indicators are somewhat more traditional in nature and are based on field and laboratory methodologies that estimate population values by sampling selective parts (sites) of the ecosystem. Standard plot-level measurements of species composition, density, cover, and diversity are examples of sample-based data. These types of indicators can also be used to calibrate synoptic indicators to make them applicable for regional assessments. They are good indicators of ecosystem function and process.

Retrospective measurements of indicators are ecological measurements which provide a temporal and spatial framework for environmental monitoring. Because long-term ecological data are very sparse, data derived from proxy historical and paleoenvironmental indicators can be used to place synoptic and sample-based indicator measurements in a long-term (up to 50,000 years) ecological perspective. This capability is particularly critical in order to determine if observed changes are within expected values or are part of a natural long-term cycle. Use of retrospective

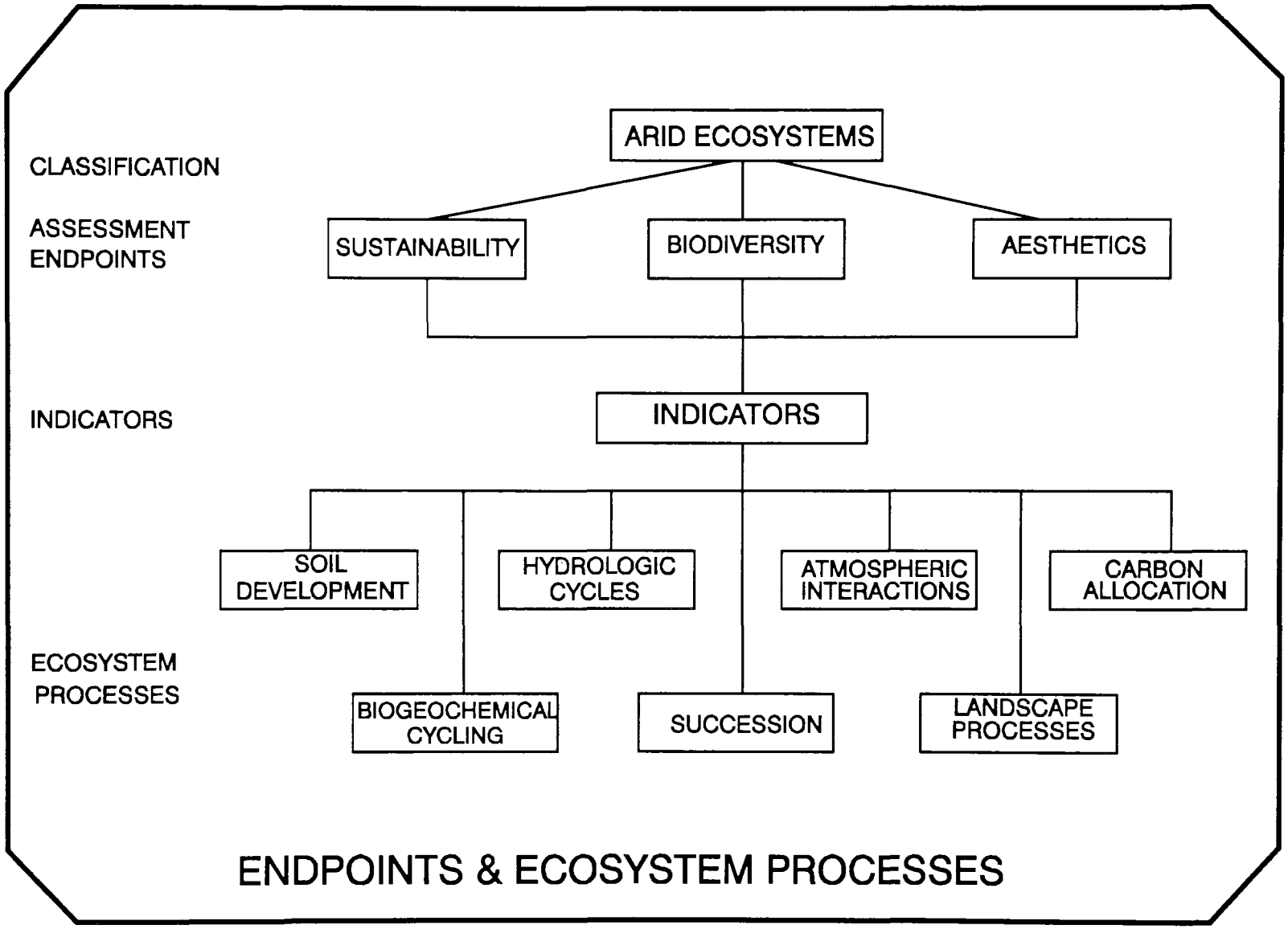



Figure 5–1. The EMAP conceptual model links ecological endpoints and indicators to assess the status and evaluate trends in the condition of arid ecosystems.

TABLE 5-1. CANDIDATE INDICATORS FOR ARID ECOSYSTEMS

| INDICATOR | LINKAGE TYPE | RELEVANT ENDPOINTS* | MEASUREMENTS CATEGORY | PRIORITY |
|---|---|---|---|---|
| **VEGETATION BIOMASS & CONDITION** | | | | |
| Leaf Area Index/ Vegetation Index | Response | S | Synoptic Sample | High |
| Areal Extent | Response Habitat | B, S, A | Synoptic | High |
| Foliar Chemistry | Exposure Habitat | S | Sample | High |
| Exotic Species | Exposure Habitat | B, A | Sample | High |
| **SOIL PRODUCTIVITY & CONDITION** | | | | |
| Life Form | Response Habitat | A, B | Synoptic Sample | High |
| Mechanical Disturbance Soils and Vegetation | Exposure Habitat | B | Synoptic | High |
| Soil Erosion | Response | B, S | Synoptic | High |
| Lichens & Cryptogamic Crusts | Response | B | Sample | Moderate |
| Physicochemical Soil Factors | Exposure | S | Sample | High |
| **WATER BALANCE** | | | | |
| Vegetation | Response | B, S | Sample | High |
| Ground Water | Response Stressor | B, S | Sample | High |
| Stream Flow | Response Habitat/stressor | B,S | Sample Synoptic | High |
| Precipitation | Stressor | B, S | Sample | High |
| Energy Balance | Response | S | Sample Synoptic | High |
| **LANDSCAPE PATTERN & LAND USE** | | | | |
| Patch Size & Connectivity | Exposure | B | Synoptic | High |
| Habitat Proportions | Response Habitat | B | Sample Synoptic | High |
| Linear Classification Vertical Structure | Exposure Habitat | B, S | Sample | High |
| Land Use | Exposure Habitat | B, S | Sample Synoptic | High |
| Abundance & Density Physical Features | Exposure Habitat | B | Synoptic | High |

Table 5-1. (continued)

| INDICATOR | LINKAGE TYPE | RELEVANT ENDPOINTS* | MEASUREMENTS CATEGORY | PRIORITY |
|---|---|---|---|---|
| FIRE | | | | |
| Occurrence and Area | Exposure Habitat | S, B | Synoptic Sample | High |
| RETROSPECTIVE | | | | |
| Charcoal Record | Response | B | Sample | High |
| Dendrochronology | Response | S | Sample | High |
| Pollen Record | Response | B | Sample | High |
| Woodrat Midden | Response | B | Sample | High |
| WILDLIFE/HABITAT | | | | |
| Species Composition and Ecotone Location | response habitat | B, S | Sample Synoptic | High |
| Relative Abundance Animals (Guilds) | response | B, A | Sample | High |
| Demographics for Animals | response | S | Sample | Moderate |
| Morphological asymetry of Animals | response | S, A | Sample | Moderate |
| Biomarkers | exposure habitat | S | Sample | Moderate |
| Chemical Contaminants in Plant Tissues | exposure habitat | S | Sample | Moderate |

* B = biodiversity
S = sustainability
A = aesthetics

TABLE 5-2. SAMPLE PROTOCOLS FOR ARID ECOSYSTEMS' INDICATORS

| INDICATOR | SAMPLING FRAME | SUGGESTED METHODS | OPTIMAL PERIOD |
|---|---|---|---|
| **VEGETATION BIOMASS** | | | |
| Leaf Area Index/ Vegetation Index | Synoptic | Satellite | peak vegetation |
| Areal Extent | Synoptic | Satellite aerial photos | early summer |
| Foliar Chemistry | Hexagon | tissue samples | peak biomass |
| Exotic Species | Hexagon Synoptic | Survey aerial photos | spring/summer |
| **SOIL PRODUCTIVITY & CONDITION** | | | |
| Life Form | Hexagon Synoptic | Survey aerial photos | seaonal |
| Mechanical Disturbance Soils and Vegetation | Synoptic Habitat | Satellite | late summer |
| Soil Erosion | Synoptic Hexagon | survey/aerial satellite | same season |
| Lichens and Cryptogamic Crusts | Hexagon | abundance species | summer/autumn |
| Physicochemical Soil Factors | Hexagon | quant. pits pedon samples | same season |
| **WATER BALANCE** | | | |
| Vegetation | Hexagon | stomatal conductance Isotopes | growing season |
| Ground Water | Hexagon | Wells | Continuous |
| Stream Flow | Linear Synoptic | Weir Satellite | Continuous/spring |
| Precipitation | Hexagon | Gauges | Continuous |
| Energy Balance | Hexagon Synoptic | Radiometer Satellite | Continuous |
| **LANDSCAPE PATTERN** | | | |
| Patch Size & Connectivity | Synoptic | Satellite aerial photos | |
| Habitat Proportions | Hexagon Synoptic | survey/aerial Satellite | growing season |
| Linear Classification Vertical Structure | Hexagon | Survey | |
| Livestock Grazing | Hexagon Synoptic | Survey aerial photos | seasonal record |
| Abundance & Density Physical Features | Synoptic | Satellite aerial photos | late summer |

Table 5-2. (continued)

| INDICATOR | SAMPLING FRAME | SUGGESTED METHODS | OPTIMAL PERIOD |
|---|---|---|---|
| FIRE | | | |
| Occurrence and Area | Hexagon Synoptic | Survey Aerial photos | Autumn |
| RETROSPECTIVE | | | |
| Charcoal Record | Region | Abundance/size | Early winter |
| Dendrochronology | Region | ring width | |
| Pollen Record | Record | abundance/size species | Autumn |
| Woodrat Midden | Region | Plants/seed | |
| WILDLIFE/HABITAT | | | |
| Species Composition and Ecotone Location | Hexagon Synoptic | survey/aerial Satellite | growing season |
| Relative Abundance of Animals (Guilds) | Hexagon | Counts | summer breeding season |
| Demographics for Animals | Hexagon | Keystone | species dependent |
| Morphological asymetry of Animals | Hexagon | Morphology | species dependent |
| Biomarkers | Hexagon | Samples | spring/summer |
| Chemical Contaminants in Plant Tissues | Hexagon | Elements | growing season |

measurements will provide a mechanism for determining trends from present day environmental monitoring without having to wait decades or longer for collection of environmental data. The use and integration of these three indicator measurement categories will determine critical spatial and temporal variability for environmental monitoring. See Appendix A for specifics on measurement techniques associated with these measurement categories.

### 5.2.1 Field Sampling and Sample-based Measurements

Field sampling is performed for a wide variety of purposes. In the context of indicator development and verification, it provides field verification and characterization of aerial and satellite derived patterns and signatures prior to landscape classification and characterization from

those data sources. Sampling also provides information that can be used to assess both the temporal and the spatial variability of the measured indicators. In addition, field sampling provides detailed information to develop and characterize ground-based indicators such as species composition.

The choice of a sampling strategy is clearly based on the needs of the experiment, the types of questions asked, and overall project objectives. A sampling program must be designed to: (1) Obtain appropriate data for statistical analysis; (2) reduce variability so that indicators are sensitive to conditional changes in critical ecological processes and functions; (3) produce status, trends, and associations among indicators There are many variations to this sequence that define a particular study, and these variations usually determine the best sequence of sampling design and statistical analysis (Green, 1979).

Three examples of specific sampled-based measurements of indicators applicable to arid ecosystems are vegetation cover, density, and biomass. These parameters can be measured to determine if a trend toward increasing desertification is present. Vegetation cover can be measured either as basal area (that which is in contact with the ground) or as foliage cover by projecting aerial parts of the vegetation on the ground. Point methods can be used to estimate cover, whether singly, as in the step-point method, or in frames, as in the point-frame method. Line-intercept methods of cover estimation involve laying out a transect and measuring the length of a species intersected. Line-intercept data are more accurate and the data are obtained more rapidly than by the use of quadrats in communities with different-sized individuals of any one plant species. Quadrat methods may involve ocular estimates of percentage cover by species. Ocular estimates often make use of cover classes and the use of midpoint values. These techniques allow for repeatable observations made by different observers.

Most density measures use counts from plots or distance measures. The measurements may make use of plot frames which may range from one meter square to ten meters square, and are frequently nested, that is, the smaller plots are placed inside the larger plots with herbaceous plants counted in the smaller plots and shrubs and trees in the larger. Line (such as a 50′ or 100′ -meter tape) intercepts are also used to measure density.

Vegetation biomass is most often determined from plots of given areas. Vegetation in small plots is clipped and weighed to yield an estimate of biomass. Measurements of cover and frequency have been used successfully to estimate biomass production of some species with correlation coefficients exceeding 90 percent (adapted from Bonham, 1989).

A critical element in estimating population attributes (i.e., sampling) is acquiring an appropriate number of samples. Sample size is the number of observations made on a measured characteristic of vegetation (such as cover or biomass). The general form of the equation for sample adequacy is

$$n = \frac{t^2 s^2}{(k\bar{x})^2} \qquad \text{Eq. 1}$$

where n is the estimated number of observations needed to obtain the estimate within a given probability; the value for t is the critical value of the t distribution, taken from a table; s is the sample standard deviation, k is the proportion or precision that the true difference of the sample mean occurs from the population mean; and $\bar{x}$ is the sample average (Bonham, 1989).

Vegetation sampling for inventory and monitoring of arid ecosystems often makes use of random sampling and the establishment of permanent plots within vegetation types or subtypes. Sampling for monitoring purposes is usually restricted to selected locations within a vegetation type. In monitoring arid ecosystems, a specific effort must be made to measure characteristics which are likely to change over the monitoring period. Species composition, cover, density, and biomass are all direct factors which can be measured to detect change. Field sampling techniques can be augmented by remote sensing techniques for ancillary measurements of the above characteristics as well as provide a synoptic overview of spatial differentiation of those attributes.

### 5.2.2 Synoptic Measurements

Synoptic measurements provide an overview or "single shot" perspective and typically provide information on the status, condition, and trends of resources on large spatial scales. They include various types of vegetation indices, indications of land use and land cover attributes, and other spatially related features. They are especially amenable to discrimination by remote sensing techniques. They are also crosscutting indicators which can serve equally well in all ecosystems.

Synoptic indicators are of critical importance to environmental monitoring programs such as EMAP because they provide spatially related information that can tie together single-point and sample-based measurements to form a picture of how ecosystems are performing spatially. Measurements of synoptic indicators may be made to estimate the quantity of change of environmental phenomena on an areal basis.

In arid systems, for example, remotely sensed information obtained by satellites and aircraft can provide critical measurements of the areal extent and composition of surface phenomena as well as indications of ecosystem vigor and health. Arid ecosystems are known to respond dramatically to short-term climatic fluctuations, such as variations in annual precipitation. The use of systems with high temporal as well as spatial resolution together with other data sets (including meteorological and ground-based) are most amenable to those kinds of studies. While the NOAA (National Oceanic and Atmospheric Administration), Advanced Very High Resolution Radiometer (AVHRR) has very high temporal resolution (daily coverage), its spatial resolution of 1.1 km renders it of little value for most detailed studies. For the purpose of more detailed studies, the landsat multispectral scanner (MSS), thematic mapper (TM) or the French SPOT satellite system provides considerably more spatial and spectral detail. Table 5-3 compares satellite measurements made through the use of AVHRR, Landsat, and SPOT, with three types of land degradation.

Within the context of EMAP, two basic types of remote sensing will be considered: aerial photography and satellite systems. Aerial photography, either current or historic can be used for measurement and assessment of recent change. Color infrared (CIR) aerial photography acquired for EMAP is being used to provide a means of "ground verification" for subsequent satellite measurements and for separate and finer levels of landscape characterization.

TABLE 5-3. REMOTE SENSING REQUIREMENTS FOR ARID ECOSYSTEMS LAND DEGRADATION ISSUES

**REQUIREMENTS**

| SATELLITE MEASUREMENTS | DESERTIFICATION | SALINITY | EROSION |
|---|---|---|---|
| **Satellites** | AVHRR, Landsat, SPOT, (ERS-1) | Landsat, SPOT | Landsat, SPOT, ERS-1 |
| **Map Accuracy** | 1:5,000,000; 1:100,000; 1 :24,000 | 1:100,000; 1:24,000 | 1:100,000; 1:24,000 |
| **Resolution** | Determined by sensors | Determined by sensors | Determined by sensors |
| **Timing** | Spring | Late spring/late summer | Late spring |
| **Frequency** | Annual | Annual | Annual |
| **Algorithms/Models** | Loss of vegetation<br>Seasonal changes<br>Change detection<br>Climate conditions/change | Loss of vegetation<br>Soil brightness (albedo)<br>Irrigated: saline water<br>Water table fluctuation | Decrease of vegetation<br>Universal Soil Loss Eq. USLE<br>Vegetation *vs.* topography |
| **Validate Data (other data)** | Higher resolution imagery with ground observations | Higher resolution imagery with ground observations<br>Soil samples | Higher resolution imagery with ground observations<br>Physical measurements |
| **Ancillary Data** | Climate conditions/changes<br>Population -- human and animal<br>Soil types<br>Wind erosion<br>Overgrazing<br>Cultural practices<br>Historical imagery | Water table depth<br>Soil<br>pH<br>Electrical conductivity<br>Irrigation practices<br>Water quality<br>Historical imagery | Soil<br>Topography<br>Vegetation cover<br>Climate<br>Historical imagery |
| **Current Capability** | Visual observation of loss of vegetation | Brown or patchy<br>Low-quality vegetation | Sediment in rivers and lakes<br>Gullies<br>Slides |
| **Desired Capability** | Automate, quantify the areal extent<br>Determine degree and intensity of desertification<br>Predict and take corrective action | Provide early automated detection so corrective measures can be applied<br>Monitor progress and success of restoration | Identify and assess degree of erosion in annotated procedures<br>Provide maps and statistical data for corrective structures or practices |

Taken from *Linking Remote Sensing Technology and Global Needs: A Strategic Vision.* 1987. A report to NASA by the Applications Working Group.

Satellite systems include the use of Landsat, SPOT, and AVHRR. These systems are not only of critical importance in landscape characterization (with the AVHRR being used for TM or SPOT data selection and acquisition) but also for the assessment and discrimination of synoptic indicators. Those indicators may take the form of spatial differentiation and variation in vegetation composition and areal extent as well as providing information on landscape and vegetation spectral indices.

Hyperspectral (numerous wavelength intervals or bands) experimental remote sensing systems such as the Airborne Visible and Infrared Spectrometer (AVIRIS) and other airborne systems may offer a third category of remote sensing research and applications to EMAP. An example of their use might include the acquisition of precise measurements of foliar chemistry and photosynthesis.

## Albedo and Desertification --

The use of Landsat MSS and TM and, especially, AVHRR, for deriving vegetation indices is of considerable importance in desertification assessment. The albedo (reflectance integrated over the upward hemisphere of directions; sometimes referred to as brightness) of land surfaces is an excellent indication of degradation. Increasing albedos have long been thought to indicate erosion, salinization, overgrazing, and other deleterious land surface effects. In addition it is considered to be an important parameter for climate models (Dickinson et al., 1989). Observations over large areas may be determined through satellite observations. Surface albedo helps determine how much solar energy is absorbed and hence the surface temperature and evapotranspiration. Desertification, frequently related to albedo, has been defined as the dimunition or destruction of the biological potential of the land, and can lead ultimately to desert-like conditions (UNEP, 1988). It is argued that land can not be desertified by natural conditions but rather only by human interactions with the environment (see, for example, Schlesinger et al., 1990). Various investigators (e.g., Justice et al., 1985) have made use of remote sensing for deriving vegetation indices for the purpose of assessing vegetation parameters associated with desertification. One of the most useful indices is the "normalized difference vegetation index" (NDVI) which has been shown to be highly correlated with vegetation parameters such as green-leaf biomass and green-leaf area and hence can be of considerable value when incorporated into a strategy aimed at assessing desertification. NDVI is typically given as:

$$NDVI = (Ch2 - Ch1)/Ch2 + Ch1) \qquad \text{Eq. 2}$$

where Ch1 represents data from a visible channel (AVHRR Channel 1 or TM Channel 3) and Ch2 represents data from a near-infrared channel (AVHRR Channel 2 or TM Channel 4). NDVI has been used in Africa and elsewhere to demonstrate the effects of overgrazing, especially during times of drought (Justice et al., 1985). Attempting to explain the effects of overgrazing upon the environment is difficult and complicated. However, application of AVHRR has provided critical data to identify damage caused directly by livestock and that caused by other management practices.

### 5.2.3 Retrospective Measurements

Retrospective measurements of indicators of stress, exposure, and response can be used to determine the current status, extent, changes, and trends in the condition of ecological resources in arid ecosystems. These measurements are crossingcutting and can be used by most resource groups to assess the status of resources over time. Future observations must be evaluated against baseline conditions to determine changes in the environment, particularly given the increase in complexity, scale, and social importance of environmental issues in today's world. Critical quantitative and scientifically valid assessments are required within a continuous monitoring framework.

Retrospective historical and paleoenvironmental indicator measurements offer an objective, repeatable and quantitative method for determining trends in ecosystem health. Retrospective indicator include instrumental hydrometeorological data, tree-ring series, pollen data, and macrobotanical remains from packrat middens. The primary advantage there is that they allow probabilistic evaluations of observations obtained during the first year or two of monitoring. They are also applicable to and compatible with observations made in other regions. They make use of existing databases, can be scaled up and down with different spatial sampling designs, and can be used to create models to establish their covariance with synoptic and sample-based indicators. Because retrospective measurements offer a lengthy temporal perspective they are also helpful in formulating conceptual models of environmental change.

Assessment of the nation's ecological resources over large spatial areas and lengthy time periods is a difficult task. Extensive geographic sampling designs can be established, but the temporal aspect of evaluating annual to decadal or longer changes requires a wait-and-see approach. Temporal change, by definition, implies a difference from one time to another, and it seems germane and scientifically responsible to place decisions (when possible) about the significance of such changes on a firm foundation, not just a few years of observations. The first year of a monitoring program yields a reference point, but not a baseline indicative of long-term behavior. Deviations from the reference point represent a change, but the change significance is unknown. Furthermore, short-term spatial variability in an indicator is most likely not representative of the long-term temporal variability (e.g., 100s or 1,000s of years) at any one location.

#### 5.2.3.1 Characteristics of Retrospective Measurements

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.

A comparison of a shrub or tree-ring index for the current year (species and location specific), as a response indicator of productivity, with the time series of indices for the previous several hundred years is an example of a direct analysis. Figure 5-2 illustrates a tree ring chronology, using data derived by calculation 20-year averages, for a bristlecone pine in the White Mountains of

California. The value for the current year can be evaluated with respect to long-term central tendency, variability, and persistence, and a probabilistic value can be associated with its interpretation. In the absence of retrospective information on shrub or tree growth, the value for the current year could only be compared spatially to the tree-ring index values for the current year with other species and locations. It would be impossible to state with any degree of confidence what those values represent in terms of temporal behavior. Retrospective information thus allows consideration of temporal and spatial variability.

A statistical transfer function relating tree-ring indices (independent variable) to annual precipitation (dependent variable) during a recent period of temporal overlap can also be established, validated, and then applied to the tree-ring series to reconstruct the past several hundred years of annual precipitation. In this situation, a long-term record of a stressor indicator can be produced, against which future values can be compared. This model-based approach is described more extensively in the following text.

### 5.2.3.2 Present to Past to Future

The establishment of annual ecological monitoring programs at a regional level allows interannual spatial change detection, but only after several years of data have been obtained. On a minimal level it will be several years before results regarding even simple changes are forthcoming. And, followed in the strictest sense, it will take many years to resolve temporal trends and apply time series models with any degree of statistical significance. Even if temporal trends are distinguishable with a few years of data, the problem remainshow to determine if they represent "local" or "global" changes (global is used here in a numerical analysis sense and is not related in any fashion to global climate change).

A simple example illustrates this point. Assume that 10 years of observations exist for variable X at a particular location and that an overall downward trend has been detected. In the absence of a longer time series one might reasonably conclude that conditions were becoming worse or changing from what we might call nominal to marginal to subnominal. This conclusion especially might be made if the same trends were observed in variable X at multiple nearby locations.

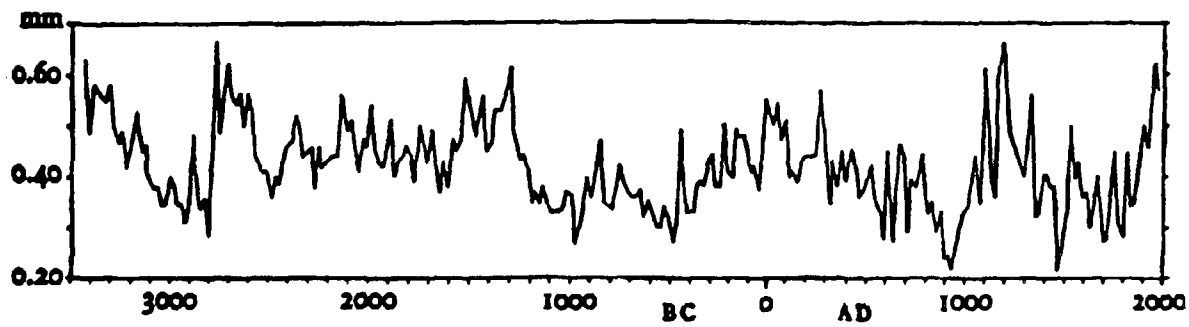



Figure 5-2. Variations of growth (20-year means from 3431 BC) in Bristlecone pine trees near the upper tree line in the White Mountains of California. (Harding 1982).

For purpose of illustration, embed this decadal decline in a longer time series and several feasible interpretations result. The decadal decline could represent a local decrease when conditions are considerably above average, it could represent a local decrease when conditions are considerably below average, or the 10 year period could be centered about the mean level. In the first situation conditions could be described as nominal, in the second they are marginal, and in the third they are subnominal.

The same argument could be made for a decade marked by an overall upward trend. The decadal increase could represent a local increase when conditions are above average, an increase when conditions are considerably below average, or the increase could be centered about the mean level. With long-term data, interpretations would actually be identical to those of the previous example where a downward trend was considered! The objective of this simple exercise is to show that numerous interpretations of the decadal sequence are possible, none of which is correct when examined in the absence of a long-term perspective.

In a third example, the decadal downward trend could actually be embedded in a global downward trend and the conclusion that conditions were worsening would essentially be correct, but unknown, in the absence of additional data. Similarly, the decadal upward trend could be embedded in a global upward trend and the conclusion would also be correct but unknown. Finally the decadal increase and decrease could be embedded in globally decreasing and increasing trends, respectively, and both interpretations would be erroneous.

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, since a tree-ring responds to the integrated effects of temperature and precipitation through its interface with the soil and atmosphere. A time-series plot of the PDSI for the month of July is presented in Figure 5-3. Values near zero indicate normal meteorological conditions, while with increasing distance from zero, positive values indicate increasingly mesic conditions, and negative values indicate increasingly xeric conditions. Note the dust bowl years in the early thirties (Wharton et al., 1990).

#### 5.2.3.3 A Strategy for Using Retrospective Measurements

Temporal calibrations are established when a large set of temporally sequential values of a Retrospective Measurements (RM) have a pairwise correspondence with values of the targeted Stressor Indicator (SI) variable. This is basically a statistical problem in that the set of sample observations must be large enough to allow the creation of a probabilistically valid transfer function. Transfer functions can range from bivariate regression between one retrospective indicator (independent variable) and one synoptic measurement (dependent variable) to equations expressing the covariation between large space-time arrays of RMs and SIs.

The more complicated transfer functions usually require some type of data reduction scheme (e.g., PCA) for the variables involved to minimize problems caused by multicollinearity. This

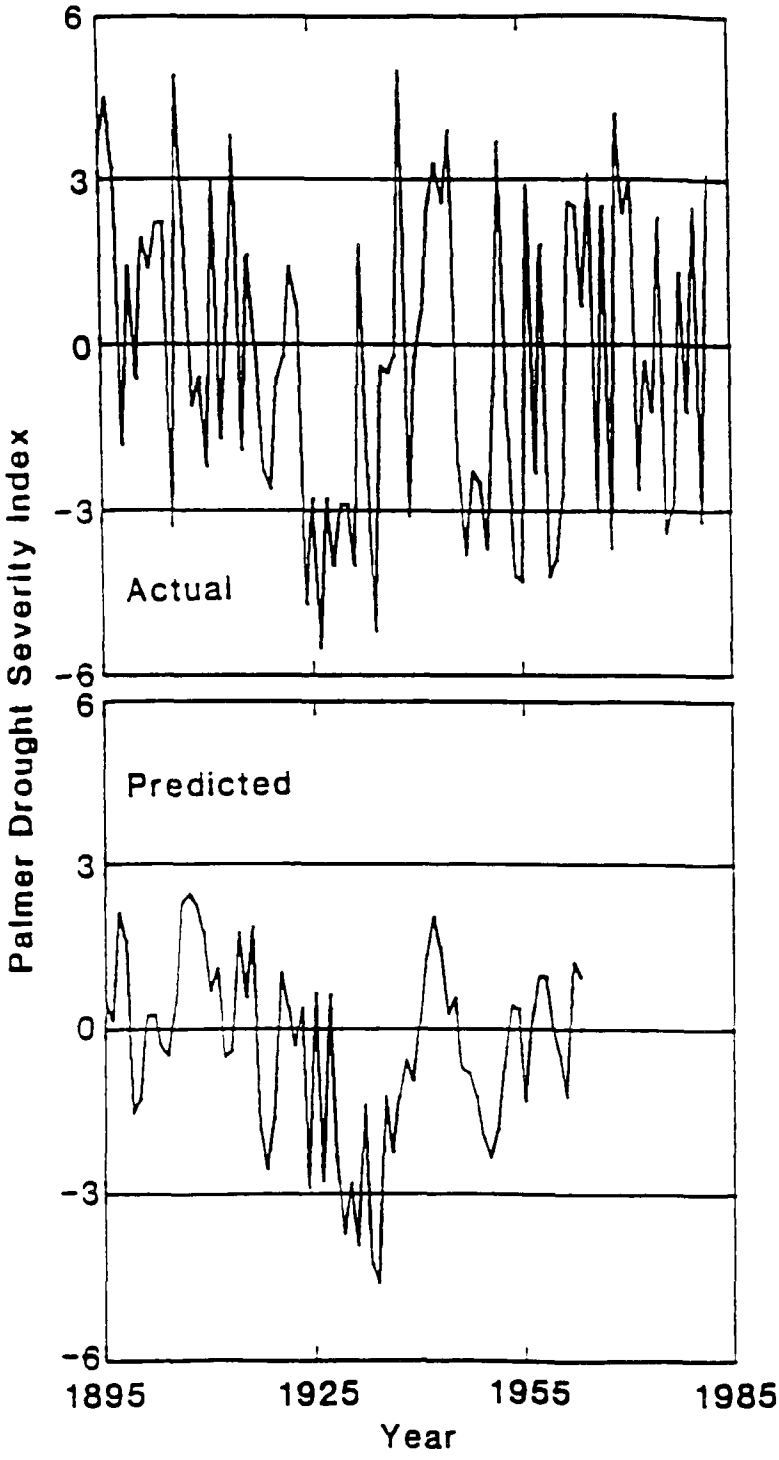



Figure 5-3. (upper) Actual Palmer Drought Severity IIndex for July, Nevada division 1 for the years 1895 to 1983. (lower) Predicted Palmer Drought Severity Index for July, Nevada division 1, 1895 to 1962.

operation usually results in a more parsimonious description of the patterns involved, a desirable feature of most scientific discussion. Also, it normally results in a transfer function based on more degrees of freedom. The sample on which the transfer function is based should encompass the full range of variability expected in the dependent climatic variable(s) during the period of interest.

A spatial calibration is required when the temporal overlap between the retrospective measurements and synoptic measurements is not represented by a large set of observations with a one-to-one time correspondence. In this situation, a transfer function can be established between a large spatial set of observations of SI data (dependent variable) and RM data (independent variable). A transfer function between a remotely sensed AVHRR-based greenness index (dependent variable) and the Palmer Drought Severity Index (independent variable) is an example of a spatial calibration. If a significant transfer function can be established between the two data sets, then its coefficients can be applied to the temporal PDSI series to obtain estimates of past greenness indices.

## 5.3 HIERARCHICAL EXAMINATION OF INDICATORS

While EMAP-Arid has further grouped indicators into sample-based, synoptic, and retrospective measurement groups, it also considers indicators within a hierarchical context, paralleling the hierarchy of the classification scheme (cf. Chapter 4). A hierarchical arrangement of indicators can be illustrated through an example developed by Noss (1990) involving the monitoring of biodiversity. His biodiversity hierarchy concept suggests that biodiversity be monitored at multiple levels of organization and at multiple spatial and temporal scales. The spatial and temporal variations are amenable to consideration through the use of many of the synoptic and retrospective techniques previously discussed. Different levels of resolution are appropriate for different issues. As stated by Noss, if we are interested in the associations between of climate change on biodiversity, we may want to consider (1) climatic factors controlling major vegetation ecotones and patterns of species richness throughout large regions; (2) availability of suitable habitats and landscape linkages for species migration; (3) climatic controls on environmental perturbations at regional and local scales; (4) physiological tolerances, autecological requirements, and dispersal capabilities of individual species; and (5) genetically controlled variation within and between populations of a species in response to climatic variables (Noss, 1990). Again, Noss states that the effects of environmental stresses will be expressed in different ways at different levels of biological organization.

The preceding list can be considered to fall within the following hierarchy: regional landscape (100s to 100,000s of $km^2$); community-ecosystem (a few to 10s of $km^2$); population-species (this is, historically, where most biodiversity monitoring has taken place); and genetic basis. Using this hierarchy, Noss has developed a list of biodiversity indicators. (Table 5-4)

The development of indicators within EMAP-Arid is proceeding through a logical sequence from the identification of candidate indicators through literature review, workshops (as has been discussed), and other techniques, to core indicators for long-term implementation (Hunsaker and Carpenter, 1990). Figure 5-4 illustrates the indicator selection, prioritization, and evaluation approach for EMAP as depicted by Hunsaker and Carpenter (1990). As described earlier

TABLE 5-4. INDICATOR VARIABLES FOR INVENTORYING, MONITORING, AND ASSESSING TERRESTRIAL BIODIVERISTY AT FOUR LEVELS OF ORGANIZATION (adapted from Noss, 1990).

| | CLASSES OF INDICATORS | | | |
|---|---|---|---|---|
| *Level of Organization* | *Composition* | *Structure* | *Function* | *Inventorying and monitoring tools* |
| *REGIONAL LANDSCAPE* | Identify distribution richness and proportions of patch (habitat) types and multipatch landscape types; collective patterns of species distributions (richness, endemism) | Heterogeneity; connectivity; spatial linkage; patchiness; porosity; contrast, grain size; fragmentation; configuration; juxtaposition; patch size frequency distribution; perimeter-area ratio; pattern of habitat layer distribution | Disturbance processes (areal extent, frequency, or return interval, rotation period, predictability, intensity, severity, seasonality); nutrient cycling rates; energy flow rates; patch persistence and turnover rates; rates of erosion and geomorphic and hydrologic processes; human land-use trends | Areal photographs (satellite and conventional aircraft) and other remote sensing data; geographic information systems (GIS) technology; time series analyses; spatial statistics; mathematical indices (of pattern, heterogeneity, connectivity, layering. diversity, edge, morphology, autocorrelation, fractal dimension) |
| *COMMUNITY ECOSYSTEM* | Identity, relative abundance, frequency, richness, evenness, and diversity of species and guilds; proportions of endemic, exotic, threatened and endangered species; dominance-diversity curves; life-form proportions; similarity coefficiency; $C_5$-$C_3$ plant species ratios | Substrate and soil variables; slope and aspect; vegetation biomass and physiognomy; foliage density and layering; horizontal patchiness; canopy openness and gap proportions; abundance, density and distribution of key physical features (e.g., cliffs, outcrops, sinks) and structural elements (snags, down logs): water and resource (e.g., mast availability; snow cover | Biomass and resource productivity; herbivory, parasitism, and predation rates; colonization and local extinction rates; patch dynamics (fine-scale disturbance processes), nutrient cycling rates; human intrusion rates and intensities | Aerial photographs and other remote sensing data; ground-level photo stations; time series analysis; physical habitat measures and resource inventories; habitat suitability indices (HSI, multispecies); observations, censuses and inventories, captures, and other sampling methodologies; mathematical indices (e.g., of diversity, heterogeneity, layering dispersion, biotic integrity) |
| *POPULATION SPECIES* | Absolute or relative abundance; frequency; importance or cover values; biomass, density | Dispersion (microdistribution); range (macrodistribution); population structure (sex ratio, age ratio); habitat vasriables (see community-ecosystem structure, above); within-individual morphological variability | Demographic processes (fertility, recruitment rate, survivorship, mortality); metapopulation dynamics; population genetics (see below); population fluctuations; physiology; life history; phenology; growth rate (of individuals); accumulation; adaptation | Censuses (observations, counts, captures, signs, radio-tracking); remote sensing; habitat suitability index (HSI); species-habitat modeling; population viability analysis |
| *GENETIC* | Allelic diversity; presence or particular rare alleles, deleterious recessives, or karyotypic variants | Census and effective population size; heterozygosity; chromosomal or phenotypic polymorphism; generation overlap heritability | Inbreeding depression; outbreeding rate; rate of genetic drift; gene flow; mutation rate; selection intensity | Electrophoresis; karyotypic analysis; DNA sequencing; offspring-parent regression; sib analysis; morphological analysis |

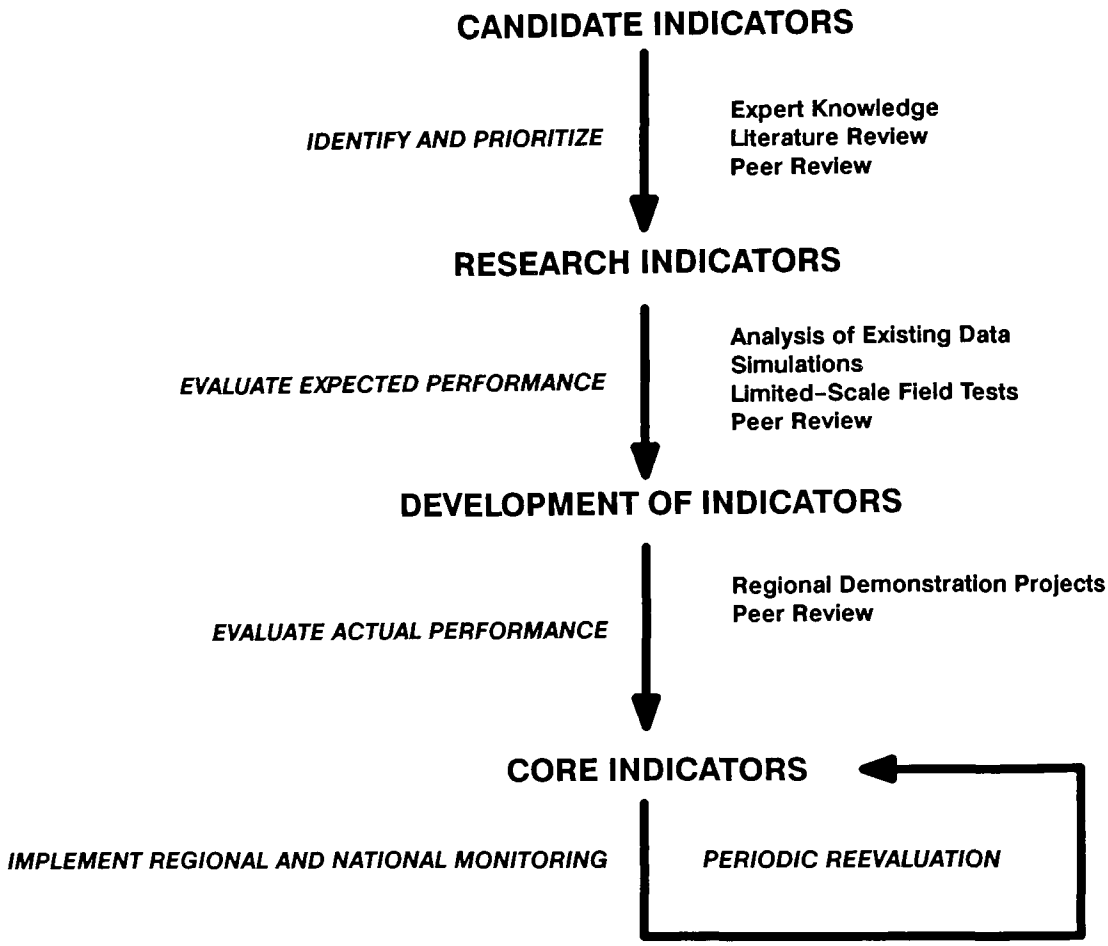



Figure 5-4. Indicator selection, prioritization, and evaluation approach for EMAP (Hunsaker and Carpenter, 1990).

EMAP-Arid will be conducting a series of workshops to further refine indicator selection criteria and reduce the suite of indicators. Pilot projects which address indicators as well as other EMAP issues are of vital significance to the illustrated process.

## 5.4 SUMMARY AND CONCLUSIONS

The three categories of indicator measurements discussed, sample-based, synoptic, and retrospective, are highly useful for characterizing arid and other ecosystem health, condition, and vigor. Each indicator affords a unique perspective on the ecosystem's status and condition. Combined, however, they afford a spatial temporal perspective on reconstructing past climates and conditions. They allow for the addition of vegetation, soils, and other information with which to

characterize past environments. In addition, they provide a wider response function with which to base predictions on future trends. Figure 5-5 illustrates the temporal and spatial resolution of various indicators. When retrospective, climate, synoptic, and sample-based measurements are integrated, a more holistic picture of future environments and climates can be made.

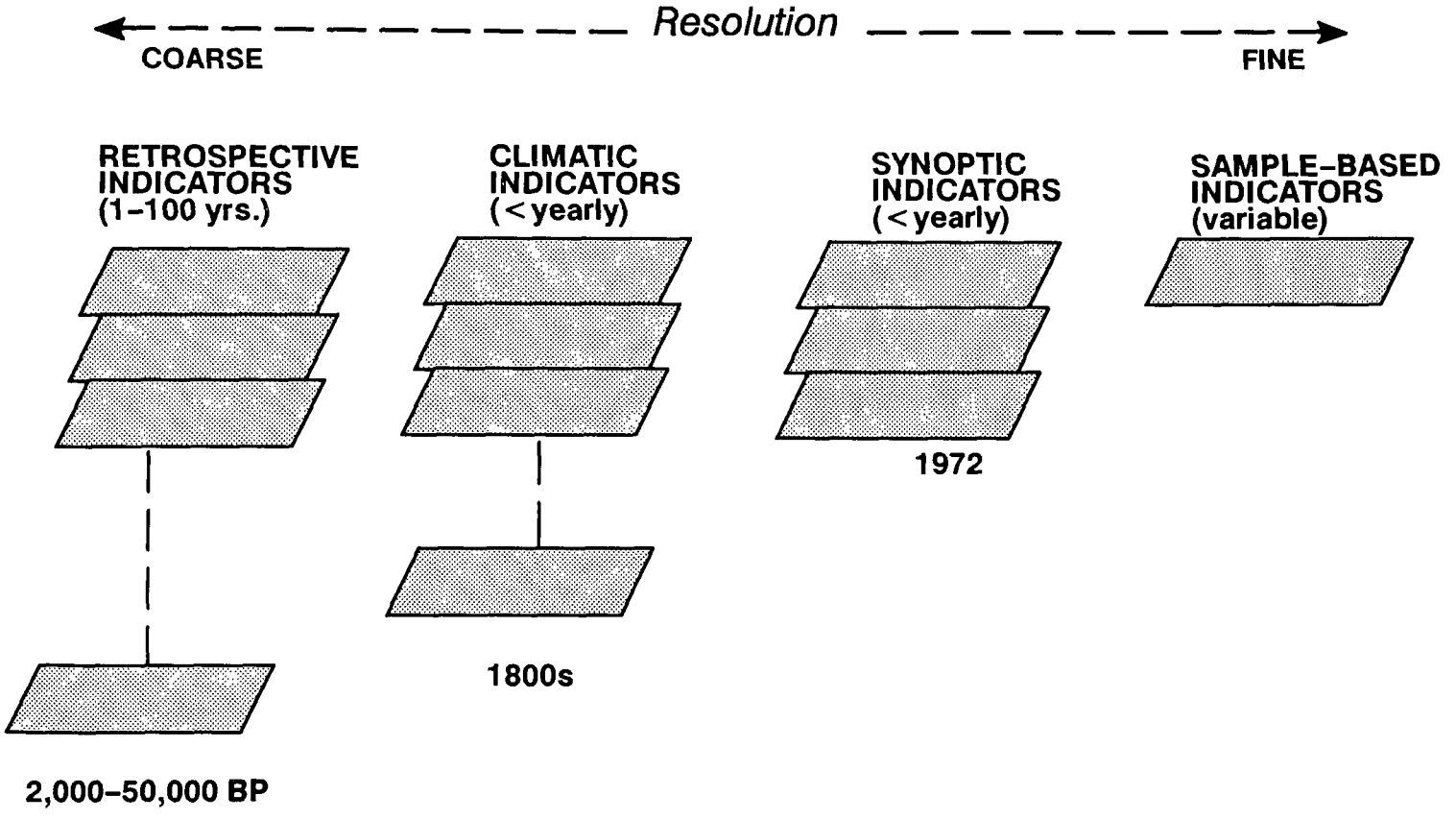



Figure 5–5. Temporal and spatial resolution of various indicators.

# 6.0 ASSESSMENT AND USE OF EXISTING DATA

An important issue to the EMAP-Arid study is the need to identify and summarize existing data sets and monitoring programs and to assess whether they could be used to answer some questions about the condition of arid ecosystems on appropriate temporal and spatial scales. The initial scope of this effort was focused on evaluating existing data sources and sets to determine if they could be used to make large-scale assessments consistent with the goals of EMAP. Applying this approach limited the consideration of many data sources that have long-term data sets because they are site specific (e.g., LTER and many university research stations). Thus, the scope was modified to look at data sources potentially useful to all levels of monitoring in EMAP-Arid

Much of the existing data from research sites should be useful to help formulate ecological research questions, investigate potential indicators, present historical baselines, and provide understanding of how ecosystems function. It is also important to identify established agency networks and sources of expertise to minimize duplication and enhance interagency cooperation.

## 6.1 IDENTIFICATION AND EVALUATION OF EXISTING DATA SOURCES

The principle method used to identify potential sources of arid ecosystems ecological data was an extensive literature search. Over 180 reports and documents were obtained related to desert and rangeland studies conducted by government agencies, universities, and other organizations currently involved in ecological research. In addition, nine directories inventorying agency environmental data sets and databases were reviewed (Zarony, 1987; Yardas et al., 1982; USGS, 1983; Tucker et al., 1980; Olson, 1984; NTIS, 1988; Abramovitz et al., 1990; Olson and Breckenridge, 1990; Multer and Kemp, 1986). Existing research programs, data sets, formal databases, and large scale assessments identified through the literature search were categorized by departments of the Federal Government, agency, or organization and representatives for each source were contacted by telephone.

Because monitoring networks on a large scale are of primary interest, Agency regional offices were contacted to obtain an overview of monitoring activities. A database survey was distributed to 26 contacts who were requested to supply general information and available documentation. These surveys were followed by phone calls to clarify information. Many of the telephone interviews resulted in identifying additional sources that needed investigation.

Documentation from potential databases, data sets, or research and monitoring programs was systematically reviewed and follow-up contacts were made to acquire missing details. Each candidate data source was reviewed for its ability to meet six attributes important in the design of the EMAP: geographical coverage, data quality, temporal coverage, data management, cost, and indicators. A summary of the criteria used for each of these attributes is presented in Table 6-1.

A number of the criteria (e.g., spatial and temporal coverage, and data quality) were selected to identify those data networks that are compatible with the EMAP concept and have

TABLE 6-1. DATABASE EVALUATION CRITERIA.

| ATTRIBUTE | CRITERION | DEFINITION |
|---|---|---|
| GEOGRAPHICAL COVERAGE | Spatial compatibility<br>Statistical design<br>Site location | Regional scale or larger<br>Documented<br>Specified |
| DATA QUALITY | Sample design<br>Collection methods<br>Data preparation<br>Protocols<br>Data summaries<br>Sample size<br>QA program | Documented<br>Documented<br>Methods documented<br>Documented<br>Are produced<br>Documented<br>Documented |
| TEMPORAL COVERAGE | Current<br>Long term | Collected in the past 5 years<br>5 years minimum |
| DATA MANAGEMENT | Computerized<br>Published form<br>Available<br>User friendly<br><br>PC compatible<br>Confidentiality concern<br>Support available<br><br>Manipulations available | Automated<br>Data reported in published form<br>Can be accessed by outside users<br>Easy to use system/minimal training required<br>PC files available<br>Restrictions on data use and access<br>Knowledgeable personnel available to assist users or provide data<br>Universal format files, graphics, statistical packages available |
| COST | Low<br>Medium<br>High | Only phone access and report costs<br>Phone access plus one time use fee<br>Annual access fee and support charges with specific equipment required |
| INDICATORS | Able to indicate (or provide information on):<br>Vegetation biomass and condition<br>Landscape pattern and land use<br>Fire<br>Water balance<br>Retrospective measurements (historical condition)<br>Wildlife/habitat condition | Provide indication for conditions of arid ecosystems |

adequate documentation and data management measures to produce data of known quality (some of the details, such as the statistical bases of the samples, are still to be determined). Obtaining data summaries is important because they allow the use of confidential data that may be restricted for use in EMAP in a raw form.

Existing data sources were also evaluated for their potential to provide data for development of arid ecosystems indicators (Section 5). These were selected following several workshops and input from numerous scientists, and a preliminary discussion of these selections was presented in the EMAP Ecological indicator report (Hunsaker and Carpenter, eds., 1990). This list was revised by the EMAP-Arid group and currently focuses on vegetation changes, landscape pattern, fire, water balance, retrospective analysis, wildlife/habitat, reference/canary sites, and riparian systems.

Table 6-2 summarizes how well each candidate database, data set or related resource assessment program, met five of the six selection criterion. Because indicators (the sixth criteria) are such an important part of the design, a separate section discusses their relationships. In Table 6-2, the letters "Y" or "N" denote whether adequate documentation exists to either meet the criteria ("Y") or not ("N"). If information is inconclusive in terms of using it to evaluate a data source, a question mark (?) was inserted in the table. If information is not available or could not be obtained, the section is left blank.

Failure to meet all criteria does not prevent the data source from being useful to scientists and policymakers. Therefore, information on all relevant databases and data sets is provided so that EMAP has the opportunity to utilize data from existing networks in its design and implementation tasks.

The primary goal of this survey was to evaluate existing programs having extensive temporal and spatial coverage. As a consequence, emphasis was placed on evaluation of those data bases and data sets most likely to meet those criteria. Other sources were identified, but most represent studies of short duration and/or small spatial scale and documentation summarizing these programs is difficult to obtain or non-existent.

Universities are key contributors to the scientific community and independent research conducted at these institutions is of primary importance to EMAP-Arid. For example, researchers at Utah State University, involved in the International Biological Program (IBP), along with personnel from other universities, have developed an extensive bibliography of arid ecosystem studies and data sets generated during that program. In addition, USU is involved in ongoing ecological studies at other arid sites. The University of Arizona's Arid Lands Information System (ALIS) contained current satellite data sets, aerial photography and other information associated with changes in landuse patterns for areas of the southwest. Many state universities and private institutions are involved in federal ecological research programs, for example, universities in Montana, Wyoming, Idaho, California, Utah, and Arizona participate in the Service's cooperative programs for fish and wildlife. University involvement is also important to many longer term projects including the ACOE's Land Condition Trend Analysis (LCTA) program and NSF's Long Term Ecological Research (LTER).

Table 6-2 : Summary of Data Sources with Respect to Evaluation Criteria

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| **DEPT. USDA** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **FOREST SERVICE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Range Forage Database | ? | N | Y | | Y | Y | Y | Y | Y | | Y | Y | | Y | Y | Y | | | N | Y | Y | | X | | |
| RPA Range Database | ? | | | | | | | Y | | | Y | | | Y | Y | Y | N | | | | | | X | | Supports RPA Assessment |
| RPA Wildlife Database | ? | | | | | | | Y | | | Y | | | Y | Y | Y | N | | | | | | X | | Supports RPA Assessment |
| Wildland Fire Statistics | ? | NA | Y | N | N | Y | N | Y | NA | NA | Y | | | Y | Y | Y | | | | | | | | | |
| FRAMIS | N | N | Y | | | Y | | Y | | | | | | Y | Y | Y | | | | | | | | | |
| RUNWILD | ? | | | | | | | | | | Y | Y | | Y | Y | Y | N | | | | | | X | | |
| Resource Planning Act(RPA) Assessment | N | N | R | N | N | Y | N | Y | N | N | Y | I | | N | Y | Y | Y | NA | N | NA | N | X | | | Every 10 years |
| **SOIL CONSERVATION SERVICE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| NRI | N | Y | Y | Y | Y | Y | Y | Y | Y | | Y | I | | Y | Y | Y | N | | Y | Y | Y | | | | Non-federal lands every 5 yrs |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

6-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| AIRS | | | Y | | | | | | | | | | | Y | | Y | N | | | Y | Y | | X | | |
| ADS | | | | | | | | | | | | | | Y | Y | Y | N | | | Y | Y | | X | | NTN, MAP3S; EPRI, others |
| CLEAR | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | | | | Y | | | | | | | | | | | EPA databases index |
| **OTHER USDA** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Agricultural Research Service** | | | | | | | | | | | | | | | | | | | | | | | | | |
| NWWRC | | | Y | | | | | | | | | | | | | | | | | | | | | | |
| Other ARS Watershed Sites | | | | | | | | | | | | | | | | | | | | | | | | | |
| **U.S. DEPARTMENT OF COMMERCE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **NOAA** | | | | | | | | | | | | | | | | | | | | | | | | | |
| National Climate Data Center | | Y | Y | | | | | Y | | | Y | Y | | Y | Y | Y | | | | | N | | X | | |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

Table 6-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| **BUREAU OF LAND MANAGEMENT** | | | | | | | | | | | | | | | | | | | | | | | | | |
| RAIDS | ? | | Y | | Y | Y | Y | Y | | | Y | Y | | Y | | Y | N | Y | N | Y | Y | | | | |
| WORDS | ? | | Y | | Y | Y | Y | Y | | | Y | Y | | Y | | Y | N | Y | N | Y | Y | X | | | |
| TEDS | ? | | Y | | Y | Y | Y | Y | | | Y | Y | | Y | | Y | N | Y | Y | Y | Y | X | | | |
| IDS | ? | | Y | | Y | Y | Y | Y | | | Y | | | Y | | Y | N | Y | | Y | Y | X | | | |
| WMDS | ? | | | | | | | | | | | | | Y | | Y | N | Y | | | | X | | | |
| IHICS | ? | | Y | | Y | Y | Y | Y | | | N | I | | Y | | Y | N | Y | N | Y | Y | X | | | |
| **NATIONAL PARK SERVICE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Visibility Monitoring Network | ? | Y | Y | Y | Y | Y | | Y | | | Y | Y | | Y | | Y | N | | N | Y | Y | | | | |
| Gaseous Pollutant Monitoring Network | ? | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | Y | N | | N | Y | Y | | X | | Data available through EPA AIRS database |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-intermittent

6-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| CPER | | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | | | | | | | | | | USDA-ARS, IBP, Colorado State Univ. |
| Konza | | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | | | | | | | | | | Kansas State Univ., NASA-FIFE |
| **INTERNATIONAL BIOLOGICAL PROGRAM** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Desert Biome | | | Y | Y | Y | Y | Y | | | | N | I | | Y | Y | ? | N | | | | | | | X | 4 desert sites |
| Grassland Biome | | Y | Y | Y | Y | Y | Y | | | | N | Y | | Y | Y | Y | N | | | | | | X | | 11 grassland sites |
| **U.S. DEPARTMENT OF DEFENSE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **CORPS OF ENGINEERS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| LCTA (Proposed) | | | Y | | Y | | Y | | | | Y | Y | | Y | | | | | | | | | | | 14 possible arid sites |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-intermittent

6-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| **NATIONAL AERONAUTICS AND SPACE ADMINISTRATION** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Land Process Program | | | | | | | | | | | | | | | | | | | | | | | | | |
| HAPDEX | | | | | | | | | | | | | | | | | | | | | | | | | |
| **INTERAGENCY** | | | | | | | | | | | | | | | | | | | | | | | | | |
| NAPAP/ADDNET | | | Y | | Y | | Y | | | | Y | Y | | Y | | | | | | | | | | | EPA ADS Info Included |
| NADP/NTN | | | Y | | Y | | Y | | | | Y | Y | | Y | | | | | | | | | | | |
| **NATIONAL SCIENCE FOUNDATION** | | | | | | | | | | | | | | | | | | | | | | | | | |
| LTER | ? | | Y | | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | | | | | | | | | Includes 4 arid sites |
| Jornada | | Y | Y | | Y | | Y | Y | Y | | Y | Y | Y | Y | Y | | | | | | | | | | USDA-ARS, New Mexico State Univ. |
| Sevilleta | | Y | Y | | Y | | Y | Y | Y | | Y | Y | Y | Y | Y | | | | | | | | | | USFWS, Univ. of New Mexico |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

Table G-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| National Range Data System | | | Y | | Y | | | | | | Y | Y | | Y | Y | | N | | | | | | | | Federal and non-federal lands |
| STATSGO | | | Y | | | | | | | | Y | | | Y | | | | | | | | | | | |
| SSURGO | | | Y | | | | | | | | | | | Y | | | | | | | | | | | |
| Wind Erosion Conditions | | | | Y | Y | | | Y | | | Y | Y | | ? | | | | | | | | | | | |
| **U.S. DEPARTMENT OF THE INTERIOR** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **FISH AND WILDLIFE SERVCE** | | | | | | | | | | | | | | | | | | | | | | | | | |
| NWI | ? | Y | Y | Y | Y | Y | Y | Y | | | Y | Y | | Y | Y | Y | N | | | | Y | | X | | |
| NCBP | ? | Y | | Y | Y | Y | | Y | Y | Y | Y | Y | | Y | Y | L | N | N | N | N | N | | X | | Ended 1990 |
| BBS | ? | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | | | | | Y | | | | | |
| GAP Analysis | | | | | | | | | | | | | | | | | | | | | | | | | |
| Refuge System | | | | | | | | | | | | | | | | | | | | | | | | | |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

6-2: Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| **UNITED STATES GEOLOGICAL SURVEY** | | | | | | | | | | | | | | | | | | | | | | | | | |
| WATSTORE | ? | | Y | | | | | | | | Y | Y | | Y | Y | Y | N | | Y | | | | | | |
| NAWDEX | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | | | | Y | | Y | N | | Y | | | | | | Index System for STOREX, WATSTORE |
| NAWQA | ? | | Y | | | | | | | | Y | N | | Y | | Y | N | | Y | | | | | | Water Quality Pilot Program - |
| NASQAN | ? | Y | Y | | | | | Y | | | Y | Y | | Y | Y | Y | N | | Y | | | | | | Water Quality and Flow WATSTORE via NAWDEX |
| ESIS | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | | | | Y | | Y | | | | | | | | | Earth Sciences database repository |
| AWUDS/SWUDS | | | Y | | Y | Y | | | | | Y | ? | | Y | | Y | N | | | Y | Y | | | | Water Use estimates and trends |
| US GEODATA | ? | | | | | | | | | | | | | N | I | Y | N | | | | | | | | 1970 and 1980 Land use-Landcover maps - digitized data |
| **ENVIRONMENTAL PROTECTION AGENCY** | | | | | | | | | | | | | | | | | | | | | | | | | |
| STORET | ? | Y | Y | | | | | Y | | V | | | | Y | Y | Y | N | | | Y | Y | | X | | Water Quality, BIOS |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

Summary of Data Sources with Respect to Evaluation Criteria (continued)

| Database or Data Set Title or Acronym | Geographical Coverage | | | Data Quality (Identified) | | | | | | | Temporal Coverage | | | Data Management | | | | | | | | Cost | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spatial Compatibility | Statistical Design | Site Identification | Sample Design | Data Collection Methods | Data Preparation | Protocols | Data Summaries | Sample Size | QA Standards | Past 5 yrs | Long Term(5 yr min) | < 5 years | Computerized | Published | Available | User Friendly | PC Compatible | Confidentiality Concerns | Support Available | Manipulation Available | Low | Medium | High | |
| **U.S. DEPARTMENT OF ENERGY** | | | | | | | | | | | | | | | | | | | | | | | | | |
| **National Environmental Research Parks, (Networking (ParkNet) underway) (INEL, Los Alamos, Hanford, Nevada Test Site)** | | | | | | | | | | | | | | | | | | | | | | | | | Numerous databases exist for each site, cannot be adequately addressed on this table |
| **STATES** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Natural Heritage Programs | | | Y | | Y | Y | | Y | | | Y | Y | | Y | Y | | | | | | | | | | Some variance from state to state |
| **TNC PRESERVE DATABASE** | | | Y | | Y | Y | | Y | | | Y | Y | | Y | Y | | | | | | | | Y | | |

Yes N No R-Regional N/A-not applicable blank-unknown ?-to be determined L-limited I-Intermittent

Under the administration of various federal and state agencies and universities, research conducted at Experimental Ecological Reserves (EER) and Research Natural Areas ( RNA) has resulted in large collections of ecological data maintained by various institutions. Although most EERs and RNAs in arid regions are of relatively small size, they may be appropriate for use as reference sites. Most studies conducted at these sites address specific questions and are of short duration, however, some may support new research or be of use in other capacities.

Several private organizations also provide access to large data sets, for instance the The Nature Conservancy's State Heritage Program. This program provides large potential for access to data pertinent to threatened and endangered plants and wildlife. However, program format varies somewhat from state to state and each must be reviewed independently. The Audubon Society's Breeding Bird Survey provides annual counts country wide. An summary report is issued yearly and some studies have been conducted to evaluate the statistical validity of the survey. Considerable effort will be required, however, to assess the ability of these and other private sources to meet the rigorous statistical design requirements of the EMAP.

Time constraints prevented extensive review of these and other potential sources during this survey. However, plans exist to examine these databases and data sets using criteria developed for evaluating the applicability of smaller scale and site specific data to the EMAP design.

### 6.1.2 Evaluation of Data Sources Related to Criteria

Only 13 of the candidate indicators presented in Appendix A qualified for use by EMAP-Arid in terms of temporal and geographic coverage and data quality. Maps (where available) identifying the location and coverage of these networks, relative to arid ecosystems, are presented in Appendix B. These databases, representing large-scale monitoring programs conducted by Federal agencies, include:

Storage and Retrieval of Water Quality Data (STORET) Aerometric Information Retrieval System (AIRS), Acid Deposition System (ADS) databases

National Water Data Storage and Retrieval System (WATSTORE), National Water Quality Assessment Program (NAWQA), National Stream Quality Accounting Network (NASQAN)

National Climatic Data Center

National Wetland Inventory (NWI)
National Contaminant Biomonitoring Program (NCBP)

Visibility and Gaseous Pollutant Monitoring Programs

National Resource Inventory (NRI)
National Range Data System (NRDS).

These major repositories house large volumes of hydrological, meteorological, soil, vegetation, and air quality data collected by various federal, state, and local government agencies.

Other sources meeting most of the selection criteria include the Bureau of Land Management's Riparian and Aquatic Information Data System (RAIDS), Wildlife Observation Report Data System (WORDS), Threatened and Endangered Species Data System (TEDS), Integrated Data System (IDS), and Water Data Management System (WDMS); the Forest Service's Range Forage and Resource Planning Assessment (RPA) databases; and the National Science Foundation's Long-Term Ecological Research (LTER) programs. These data sources should be useful in the diagnostics and research activities in EMAP-Arid and we anticipate some joint ventures with these programs.

Although substantial amounts of data are collected by each agency surveyed, many of the databases, data sets, and programs evaluated are site specific and most (with the exception of the LTER program) do not represent long-term monitoring activities. Temporal and/or spatial limitations of these data sources restrict their useful in designing the regional and national aspects of EMAP. However, information on watersheds or range sites can be used to test the interaction and application of indicators. This information will help foster understanding of how well the indicators represent regional ecological conditions. Analysis of the data collected by site specific programs can be used to formulate and help answer basic research questions. For example, vegetation change data from an LTER site could be used as a benchmark for evaluating the efficiency of the ecological system.

Land management agencies, including the NPS, FS and BLM data are usually not integrated in a manner that can be used to effectively assess resources on an appropriate temporal or spatial scale. Reasons cited for this deficiency include patchwork land management, funding problems, and agency mission definitions (USFS 1988, Flather, 1989; Joyce 1989). Many of these coordination possibilities are currently being addressed by the respective agencies and are helping to influence interaction with the EMAP. As long as EMAP-Arid indicators address long range ecological questions, interaction between EMAP and the land management agencies will be necessary.

Every 10 years, the Forest Service conducts a Resource Planning Act Assessment (RPA) intended to evaluate ecological resources on a national scale (Flather, 1989; Joyce, 1989). This assessment combines multipleagency data to estimate the status of rangeland, fish and wildlife, and water resources. The 1989 RPA presents the most current data available in summary form and uses those data to determine the condition of, and forecast demands on, those resources. As part of the report, observations are presented regarding data availability and quality. In general, information about vegetation type and condition is incomplete and data suitable for assessing rangeland characteristics on a regional scale are not available (Joyce, 1989; Flather, 1989). Inventory data for wildlife are inconsistent and inadequate to assess trends on a regional level (Flather, 1989). Information used to assess water resources on a regional and national scale were drawn from large hydrologic data sources such as the EPA STORET and USGS WATSTORE databases.

### 6.1.2.1 Identification of Missing Information for Indicator evaluation

Little information is available to make assessments at the current regional-scale design of the EMAP, but much of the available information may be useful as a knowledge base to support the research needs of EMAP-Arid. Some of the information at a smaller scale such as watersheds, may be useful for the first phase of the double sampling process (Section 3). The EMAP-Arid design would then need to be tested to see how well the watershed information can be aggregated to make regional assessments.

The following discussion summarizes and reviews the agencies or organizations that provide data for the endpoint indicators, discusses the limitations of the data, and identifies missing information for each of those indicators. This information is provided in summary form in Table 6-3. Data source parameters that measure EMAP-Arid endpoint indicators, or other pertinent ecological measurements, are indicated by corresponding numbers as defined in Table 6-4.

#### Vegetation Changes

To more consistently represent available information pertaining to vegetative change, data sources providing measures of composition, stratification, and other measurements of vegetation type and classification are categorized in Table 6-4 as measures of life form (4) under Vegetative Change.

Soils data, vegetation inventories, and site classification data are available from the BLM IDS, RAIDS, and IHICS; the SCS NRI, National Range Data System and the FS Range Forage and RPA databases. However, most of this information was collected for a specific purpose at each site and thus different measures of range condition were used by different agencies (Joyce, 1989). Vegetation composition and productivity data are also collected as part of core research studies for four LTER arid sites. Two of these sites, Jornada and the Central Plains Experimental Range, are former International Biologic Program (IBP) sites where substantial historical data have been collected. Some leaf area and vegetation index measurements also are collected for LTER remote sensing programs and other site specific projects. These data may be useful to validate EMAP measurements that will be obtained on a regional scale via Landsat and other remote sensing techniques. To use these data, a pilot study should evaluate the effort required and the availability of data to compare different collecting methods.

#### Landscape Pattern

Sources such as the National Resources Inventory, National Wetland Inventory, and USGS mapping efforts can contribute general measures of landscape pattern. Remote sensing projects, in conjunction with geographic information system (GIS) developments, such as those at the Jornada and Sevilleta (New Mexico), Konza Prairie (Kansas), and Central Plains Range (Colorado) LTER sites, provide integrated landscape characterization data. However, these

: Summary of Data Sources with Respect to Arid Lands Indicators*

| DATABASE OR DATA SET TITLE OR ACRONYM | Vegetation Change | Landscape Pattern | Fire | Water Balance | Retrospective | Wildlife/ Habitat | Reference Sites | Riparian Systems | Other |
|---|---|---|---|---|---|---|---|---|---|
| **U.S. DEPARTMENT OF AGRICULTURE** | | | | | | | | | |
| **FOREST SERVICE** | | | | | | | | | |
| Range Forage Database | 1 | | | 2,5 | | | 3 | | 1,2,3,4,8 |
| Resource Planning Act Assessment | | | | | | | | | 1 |
| RPA Range Database | 1 | | | | | | | | 1,3,8 |
| RPA Wildlife Database | | | | | | 1,5,6 | | | 8 |
| FRAMIS | 1 | | | | | | | | |
| Wildland Fire Statistics | | | 2,3 | | 5 | | | | |
| RUNWILD | | | | | | 1,5,6 | | | |
| **SOIL CONSERVATION SERVICE** | | | | | | | | | |
| NRI | 1 | 1 | | | | | 1 | 2 | 2 |
| National Range Data System | 1 | | 2,3 | 5 | | | 1,4 | | 1 |
| STATSGO | | | | | | | | | 2 |
| NATSGO | | | | | | | | | 2 |
| SSURGO | | | | | | | | | 2 |
| Wind Erosion Conditions | | | | | | | | | |

*See Key (page 16) for definitions.

6-3: Summary of Data Sources with Respect to Arid Lands Indicators* (continued)

| DATABASE OR DATA SET TITLE OR ACRONYM | Vegetation Change | Landscape Pattern | Fire | Water Balance | Retrospective | Wildlife/ Habitat | Reference Sites | Riparian Systems | Other |
|---|---|---|---|---|---|---|---|---|---|
| **U.S. DEPARTMENT OF THE INTERIOR** | | | | | | | | | |
| **FISH AND WILDLIFE SERVICE** | | | | | | | | | |
| NWI | 1,2 | | | | | | | 1,2 | 2 |
| GAP Analysis | | | | | | | | | |
| Refuge System | | | | | | | | | |
| NCBP | | | | | | | | | 12,14 |
| BBS | | | | | | 1,5,6 | | | |
| **BUREAU OF LAND MANAGEMENT** | | | | | | | | | |
| RAIDS | 1,2,4 | | | | | | | | |
| WORDS | 1 | 1 | | | | | | 1,2,3,4,7 | |
| TEDS | | | | | | 1,5,6 | | | |
| IDS | 1,4 | 1 | | | | 1,5,6 | | | |
| WMDS | | | | | | | | 4,5 | |
| IHICS | | | | | | 1,6 | | | |
| **NATIONAL PARK SERVICE** | | | | | | | | | |
| Visibility Monitoring Network | | | | | | | | | 6,9 |
| Gaseous Pollutant Monitoring Network | | | | | | | | | 6,9,14 |

Key (page 16) for definitions.

6-3: Summary of Data Sources with Respect to Arid Lands Indicators* (continued)

| DATABASE OR DATA SET TITLE OR ACRONYM | Vegetation Change | Landscape Pattern | Fire | Water Balance | Retrospective | Wildlife/ Habitat | Reference Sites | Riparian Systems | Other |
|---|---|---|---|---|---|---|---|---|---|
| **UNITED STATES GEOLOGICAL SURVEY** | | | | | | | | | |
| WATSTORE | | | | 4 | | | | | 5,14 |
| NAWDEX | | | | | | | | | 11 |
| NAWQA | | | | | | | | | |
| NASQAN | | | | | | | | | 5 |
| ESIS | | | | | | | | | |
| AWUDS/SWUDS | | | | 1 | | | | | |
| US GEODATA | 2 | | | | | | 2 | | |
| **ENVIRONMENTAL PROTECTION AGENCY** | | | | | | | | | |
| STORET | | | | 4 | | | | | 5,14 |
| AIRS | | | | | | | | | 9 |
| ADS | | | | | | | | | 6,12 |
| CLEAR | | | | | | | | | 11 |
| **OTHER USDA** | | | | | | | | | |
| **AGRICULTURAL RESEARCH STATIONS** | | | | | | | | | |
| NWWRC | 1,2 | | | 1,2,4,5 | | | 3 | 1 | 5,6 |
| Other ARS Watershed Sites | | | | | | | | | |

See Key (page 16) for definitions.

6-3: Summary of Data Sources with Respect to Arid Lands Indicators* (continued)

| DATABASE OR DATA SET TITLE OR ACRONYM | Vegetation Change | Landscape Pattern | Fire | Water Balance | Retrospective | Wildlife/ Habitat | Reference Sites | Riparian Systems | Other |
|---|---|---|---|---|---|---|---|---|---|
| **U.S. DEPARTMENT OF COMMERCE** | | | | | | | | | |
| **NOAA** | | | | | | | | | |
| National Climate Data Center | | | | 5 | | | | | 6,9 |
| **NATIONAL AERONAUTICS AND SPACE ADMINISTRATION** | | | | | | | | | |
| Land Process Program | 1 | | | 1 | | | | | 5,9 |
| HAPDEX | | | | 1 | | | | | 2 |
| **INTERAGENCY PROGRAMS** | | | | | | | | | |
| NAPAP/ADDNET | | | | | | | | | 5,9,12 |
| NADP/NTN | | | | | | | 4 | | 12 |
| **NATIONAL SCIENCE FOUNDATION** | | | | | | | | | |
| **LTER** | | | | | | | | | |
| Jornada | 1,2,3,4 | 1,2,3,6 | 1,2,3 | 2,5 | 5 | 1,5,6 | 4 | | 2,6,10 |
| Sevilleta | 1,4 | 1,3 | 1 | | 4 | 5,6 | | | 2,6,10 |
| CPR | 1,4 | 1,3 | 1 | 2,5 | | | | | 2,6,10 |
| Konza | | | 1,2,3 | | | | | | |
| **INTERNATIONAL BIOLOGICAL PROGRAM** | | | | | | | | | |
| Desert Biome | 1,2,4 | 1 | | 2,5 | | 1,5,6 | 1,2,3,4 | | 2,3,6,7,10 |

Key (page 16) for definitions.

6-3: Summary of Data Sources with Respect to Arid Lands Indicators* (continued)

| DATABASE OR DATA SET TITLE OR ACRONYM | Vegetation Change | Landscape Pattern | Fire | Water Balance | Retrospective | Wildlife/ Habitat | Reference Sites | Riparian Systems | Other |
|---|---|---|---|---|---|---|---|---|---|
| Grassland Biome | 1,2,4 | 1 | 1,2,3 | 2,5 | 5 | 1,5,6 | 2,3 | | 2,3,6,7,10 |
| **U.S. DEPARTMENT OF DEFENSE** | | | | | | | | | |
| **CORPS OF ENGINEERS** | | | | | | | | | 6,7,10 |
| ICTA (proposed) | 1,2,4 | 1 | | | | | | | 6,7,10 |
| **U.S. DEPARTMENT OF ENERGY** | | | | | | | | | |
| **National Environmental Research Parks** | | | | | | | | | |
| INEL | 1 | | | | | 6 | | 4 | 6,2 |
| Los Alamos | 1 | | | | | 6 | | 4 | 6,2 |
| Hanford | 1 | | | | | 6 | | 4 | 6,2 |
| **STATES** | | | | | | 1 | | | |
| Natural Heritage Programs | 1,4 | | | | | 1,5,6 | | | 13 |
| **PRIVATE** | | | | | | | | | |
| TNC Preserve Database | | | | | | | | | 11,8,13 |

See Key (page 16) for definitions

TABLE 6-4. DEFINES KEY TO CODED VALUES APPEARING UNDER INDICATOR HEADINGS IN TABLE 6-3

**VEGETATION CHANGE**

1-General
2-Areal Extent
3-Leaf Area/Vegetation Index
4-Life Form

**LANDSCAPE PATTERN**

1-General
2-Patch Size
3-Composition
4-Connectivity
6-Vertical Stratification
6-Ecotone Location

**FIRE**

1-General
2-Occurrence
3-Area

**WATER BALANCE**

1-General
2-Evapotranspiration
3-Radiometer
4-Stream Flow
6-Precipitation

**RETROSPECTIVE**

1-General
2-Dendrochronology
3-Pollen
4-Woodrat Middens
6-Fire History

**WILDLIFE HABITAT**

1-General
2-Biomarkers
3-Guilds
4-Assymetry
6-Demographics
6-Species Composition

**REFERENCE SITES**

1-General
2-Foliar Chemistry
3-Erosion
4-Cryptogamic Crusts

**RIPARIAN SYSTEMS**

1-General
2-Areal Extent
3-Species Composition
4-Instream Flow
6-Water Table Flux
6-Water/Soil Conductivity
7-Channel Morphology

**OTHER**

1-Biomass
2-Soils
3-Grazing
4-Range Condition Index
5-Water Quality
6-Meteorological/Weather/Climate
7-Organic Matter Accumulation
8-Management and Use
9-Air Quality
10-Nutrients
11-Support/Ancillary
12-Stress
13-Threatened and Endangered Species
14-Contaminants

small-scale efforts will be of limited value to EMAP. Consistent, nationwide classifications of landcover and landuse patterns are being developed and are scheduled to be implemented by the EMAP Landscape Characterization. Thus, EMAP can provide a good forum to encourage interagency collaboration in development of compatible characterization schemes for planned BLM, NPS, and USFS GIS and remote sensing programs.

### Fire

Nationwide wildland fire data for public and private lands are collected at the Boise Interagency Fire Center. These data (acreage, origin, trends) are compiled yearly and published in statistical form by the U.S. Forest Service Fire and Aviation management staff (Abramovitz et al., 1990). Historical fire data collected as part of SCS Range inventories are maintained in the National Range Data System (SCS, 1976). Numerous fire-related studies are being conducted at arid research sites. For example, experimental burn treatment plots are maintained at the Konza Prairie Research Natural Area and fire disturbance studies are being conducted at the Jornada, Sevilleta, and Central Plains LTER sites. These data, in conjunction with retrospective fire data (Section 6), maybe useful for investigating the ecological site-specific effects of fire on arid ecosystems.

### Water Balance

Streamflow data (collected and stored by the USGS) and precipitation measurements (collected by NOAA and other monitoring programs) represent the largest sources of organized data for evaluating ecosystem water balance. As discussed in Section 6, WATSTORE, STORET, and the National Climate Data Center provide access to these nationwide hydrologic and precipitation data. Some site-specific evapotranspiration measurements are available for LTER and IBP arid and grassland sites, and the USFS Range Forage Database includes both precipitation zone and potential evapotranspiration zone data for range sites in 20 states, including the West. In general, flow and precipitation data are well documented, automated, and readily available. However, good sources of representative data measuring evapotranspiration are not available and no large-scale radiometric data were located.

### Retrospective

Limited fire history data are available for several arid sites associated with the IBP, including Jornada and the Central Plains Experimental Range. Research involving fire scars and tree growth chronology for areas of the Southwest is currently being conducted at the University of Arizona Laboratory of Tree Ring Research (Swetnam and Betancourt, 1990). Historical occurrence and coverage data are available from the National Archives (Swetnam and Betancourt, 1990) and recent information is compiled by the Forest Service Fire and Aviation management staff.

Most available fire data are associated with forest ecosystems and more research is required to identify data specific to arid ecosystems. No sources were located for pollen record, and research conducted at the Sevilleta LTER site is the only identified source of

woodrat midden data. These data can be used to provide historical information on vegetative coverage for an area. The data will be assessed to determine how useful it can be for developing a baseline for making regional assessments.

An extensive data base of tree-ring information is available from the NOAA National Geophysical Data Center (NGDC) in Boulder, Colorado. After a hiatus of 5 years, the International Tree Ring Data Bank reopened and moved its physical operations to the NGDC facility from the Laboratory of Tree-Ring Research at the University of Arizona, Tucson.

Over 1000 Chronologies and ringwidth (or density) measurements from over 600 sites worldwide are now available. Seven hundred twelve of these chronologies are from North America, and several hundred are from the western United States. Additionally, there are chronologies from Europe (252), Australia/New Zealand (76), South America (35), Asia (14), and Africa (1).

An American Pollen Database, coordinated by Eric Grimm at the Illinois State Museum, is under development. The database will be a relational PC-based system, with exportable database tables. The database will include, insofar as possible, original pollen counts, site locations and descriptions, radiocarbon and other chronological data, and bibliographic information. The goal is to incorporate all North American pollen data, both stratigraphic and surface-sample data.

Wildlife Habitat

Most BLM and USFS inventory and monitoring activities assess wildlife habitat. Composition and population data are collected by both agencies, but primarily involve big game, and threatened and endangered (T/E) species. Data representing nongame wildlife is generally not available in state or federal inventories (Flather, 1989). The Christmas bird survey from the National Audubon Society, State Natural Heritage Programs, and the FWS Breeding Bird Survey and migratory bird and nesting counts represent the largest collections of organized wildlife data. The contaminants data collected by the FWS involve migratory waterfowl and starlings for local scale issues and fish for regional scale issues (watershed assessments). These data have been used primarily to assess concentrations of pesticides and metals in tissue. They have proven useful to identify regions of the country that have received insult from organochloride pesticides. Although banned in the U.S., they still are used in Mexico and show up along the border. Numerous smaller scale or site specific programs exist, for instance the BLM's raptor monitoring at the Snake River Birds of Prey Area in Idaho (Steenhof ed., 1989), small mammal studies at LTER sites, and private efforts such as HAWKWATCH in Nevada and Utah (Western Foundation for Raptor Conservation, Inc., 1990).

The Idaho Cooperative Fish and Wildlife Unit headed by Michael Scott, is conducting a study called Gap Analysis to provide a rapid assessment of the distribution of biodiversity. The process uses geographic information systems (GIS) (ARCINFO software) to develop a multifaceted assessment of habitat and wildlife. Presently a vegetation map at a scale of 1:500,000 has been developed and compared to data collected in the field. The next step

converts available information on vertebrate and invertebrate distributions to digitized format. Land-ownership information is then added to generate a map depicting species richness. This information can be combined with maps on species of special interest to identify minimum and optimum areas required for protection of predetermined levels of statewide species richness. The original assessment was done for the State of Idaho. Similar assessments are now being conducted in Washington, Oregon, California, Utah, and Nevada. This process has the potential to provide useful information to aid EMAP-Arid in assessing wildlife and habitat conditions.

Very limited biomarkers, guilds, or asymmetry data were identified. Lack of these data, as well as limited demographic and composition data, represents a significant deficiency for evaluation of the wildlife/habitat indicator.

### Reference/Canary Sites

Designation of a data collection site as a reference or canary site implies that the effects of a single parameter may be observed without being confounded by other influences; for instance a reference site being used to study the effects of fire on erosion should not be subjected to another disturbance such as grazing. Without in-depth study of the sites represented in this assessment, identification of sites appropriate for use as reference sites is not possible. Consequently, all sources for which erosion, foliar chemistry, and cryptogamic crust (i.e. soil crusts formed by algae) data are available have been included whether or not they qualify as reference sites. These are provided so that further evaluations can be made of these data.

Foliar chemistry data are collected as part of site specific studies for the LTER and IBP arid sites. The soils and vegetation data collected by the SCS, BLM, and USFS, include rough estimates of percent coverage for cryptogamic crusts. Data collected as part of the National Acid Deposition Program evaluate conditionally the effects of acidic deposition on cryptogams for selected sites.

Erosion data for range sites in the Western states are gathered by the USFS and SCS. In addition, the SCS collects and summarizes yearly wind erosion data. Watershed erosion data are available from numerous USDA Agricultural Research Service Watershed Research Units and are important since the coverage may better represent the regional level concept of the EMAP. These data do not provide sufficient coverage to be used to assess erosion in arid regions. However, they provide useful baselines.

### Riparian

With the exception of stream flow and other pertinent data contained in large, centralized water databases, information of sufficient quality for riparian assessment is limited. Many agencies have riparian programs to inventory and monitor riparian areas on a site specific or watershed specific basis, but, with the exception of the BLM RAIDS database, few are computerized and none are aggregated to provide a regional assessment (Mussallem, 1990).

The National Soil-Range Team is currently developing a computerized system to characterize riparian areas (National Soil-Range Team, 1988). This system will characterize a site using soil and vegetation data to assess current conditions as well as evaluate site potential.

The FWS National Wetlands Inventory (NWI) is primarily concerned with mapping wetlands and surface waters for migratory waterfowl. The Inventory consists of ata for wildlife refuges and wetlands within arid regions are provided, but the coverage of riparian systems is limited. Riparian systems, as defined by the EMAP-Arid group, might be delineated using some of the NWI data, but a pilot study is required to evaluate this situation.

### 6.1.3 Relationship of Data Sources to Arid Ecosystem Questions and Issues

Hydrological, meteorological, air quality, and pollution information is crucial in assessing status and evaluating trends in conditions across all ecosystems. The large air and water databases are of particular importance due to the currently increased interest in interagency cooperation. Data are collected, contributed, and used by various agencies. For example, NPS Gaseous Pollutants data are available through the EPA AIRS database. The fact that the information is collected, organized, and made available through a sophisticated, well-supported data management network makes these databases potentially important to EMAP-Arid scientists. Further work is needed to interpret these data, to identify missing pieces, and to see how the collected data can be used in assessing the stressors of arid ecosystems.

Two major databases, WATSTORE and STORET, contain the bulk of available hydrologic information. These database systems store water data collected by numerous networks. NASQAN, NAWQA, and the Hydrologic Benchmark Network (HBN) are subsets of WATSTORE and contain nationwide water data from the USGS. The HBN may be particularly useful for establishing reference sites because the streams and basins monitored for water quality are those that have not been altered by man (Abramovitz et al., 1989). Other subsets contain data pertaining to aquatic species, stream flow, water demand, snowpack, and other information that may be used to assess hydrologic aspects of arid ecosystems. The baseline, historical, and chemical information may be of use to EMAP-Arid planning and indicator development work. There are about 150 real-time collection sites (USGS data collection platforms transmitting data to Geostationary Operational Environmental Satellites [USGS, 1986]) and numerous other collection sites in areas currently considered by the arid ecosystems group.

Maps and data generated by the FWS's NWI provide information for determining the extent and the increase and loss in wetland systems. These data are primarily useful to the EMAP Surface Waters and Wetland resource groups in establishing ecosystem function and to EMAP-Arid resource group in characterizing wetland system status. Although this system does not currently specifically map riparian systems, the maps are generally available and could be used to delineate riparian areas for locations previously mapped. Data from these sources can be used to help define historical site-specific status and trends in surface and ground-water quality and quantity and to identify degradation in water resources and riparian habitats. However, there will be limitations because definitions of natural systems for the data sources

may be different than those being used in EMAP; thus, some transitional definitions must be developed if the data are to be used.

Two major sources for air quality and pollutant monitoring include the EPA ADS and AIRS databases. Included within these large systems are data collected from networks such as the National Atmospheric Deposition Program/National Trends Network, NPS Visibility and Gaseous Pollutant Monitoring, and others. Like the water-related databases, these systems provide organized access to air quality and acid deposition data collected through a number of networks nationwide. These databases also provide criteria pollutant data suitable for use in establishing baseline conditions for all EMAP ecosystems. Wet and dry deposition data contained in the ADS database, and pesticide monitoring data collected by the FWS National Contaminant Biomonitoring Program (NCBP), could be used to assess anthropogenic input of selected chemicals to terrestrial systems. These data sources might be used by EMAP-Arid to conditionally address the issue of urban population expansion and determine how increased anthropogenic pressures and pollutants may affect the structure and function of arid ecosystems at the research level.

The National Climatic Data Center is another important source of air quality measurements. In addition, current and historical weather data available through the Center's computerized system, together with climate data collected by other programs (air and water quality monitoring programs and many ecological research programs collect site-specific climate information), may be useful in exploring the link between pollution, climate change, and arid ecosystem functions. An example would be the conditional evaluation (i.e., nonprobability) of the issue of desertification (including increased salinity) by looking at rainfall patterns, stream hydrographs and water quality data and attempting to relate these to distribution of vegetation and wildlife communities. Data are available to do this type of assessment for some fairly large watersheds, but the issue of the usefulness of this effort on a regional scale presently is unresolved.

Several large, automated data management systems contain useful soil and vegetation information. The SCS characterizes soil and vegetation in the NRI, the National Cooperative Soil Survey (NCSS) and the National Range Data System (NRDS). This information is entered in a data base, maintained, and updated on a periodic basis. The SCS also generates maps for the State Soil Geographic Databases (STATSGO), National Soil Geographic Database (NATSGO), and the Soil Survey Geographic Database (SSURGO). The SCS maps and inventories can provide useful prior information for design and indicator development.

The Bureau of Land Management maintains the following databases, which represent an effort to integrate inventory and monitoring data:

WORDS - Wildlife Observation Report Data System

TEDS - Threatened and Endangered Data System

RAIDS - Riparian and Aquatic Information Data System

WDMS - Water Data Management System

IDS - Integrated Data System

These five databases employ a common software system, and the elements for all are standardized to a BLM data element dictionary. This provides common definitions, codes, and cross references from one database to another. In addition, BLM data collection methods and forms are standardized and documented (BLM, 1981). Field data collection forms are used as input records and most western states contribute information to these centrally maintained databases (Ballantyne, 1990). The information collected is project oriented (site specific) and although the data represent long-term inventory records, not all sites are characterized on a yearly basis. However, numerous sites over a large geographic region are characterized. These data sources may be useful in establishing baseline data for specific vegetation and soils relationships.

### 6.1.4 Research Needs to Address EMAP-Arid Questions

A wealth of information exists that can be used to address questions about the conditions of site-specific arid ecosystems. However, the problem is that there are major inconsistencies in the design for data collection and in how the data were collected, analyzed, and reported. Ground and surface water, air quality, and climate data are in large supply and currently are used by several agencies to assess status and trends and make predictions regarding resource demands (e.g., USGS,1986). For large centralized databases such as WATSTORE, STORET, and AIRS, however, the sampling design and QA plan for each contributing agency or organization needs to be further evaluated for compatibility with the EMAP framework. Little additional research is needed to support the data on surface and ground-water quality and quantity currently collected by the USGS. These data probably can be accessed through interagency cooperation. However, research is needed to determine how accurately data collected at a site or on a watershed basis reflect the hydrologic regime of the region. The data supplied by USGS needs to be evaluated to determine what, if any, techniques can be used to extrapolate site-specific information to a larger scale population.

Data sets addressing land use issues such as rangeland condition, degradation of riparian habitat, desertification, mining impacts, and urban encroachment are collected and summarized by several agencies (BLM Public Land Statistics, for example), but much effort is needed to gather, interpret, and integrate information. Some collected data may be of use for prior information even though not currently available in an integrated form. For example, soils data collected by the BLM closely follows the SCS methodology (BLM handbook), and most BLM protocols and forms are standardized. For states and regions where large tracts are managed by a single agency (Nevada for instance is nearly all BLM-managed land) the inventory and monitoring data collected from district to district may be similar. Soil and water parameters collected from FS districts are also similar; however it is less likely that the same data collection methods are employed from station to station (USFS, 1988). GIS projects under development by state and Federal agencies should provide help in integrating existing information. Studies are required to evaluate the compatibility of methods of various agencies.

In conducting these evaluations, emphasis should be placed on quality assurance and quality control (QA/QC) checks. Under current circumstances, much of the data collected by the various agencies is not comparable.

Although some large-scale databases or programs meet most selection criteria, several of these sources may be only slightly useful for EMAP-Arid. For example, the NRI soils data retained by the SCS represent only non-federal lands, and, although useful for other portions of EMAP, they may be of limited value for EMAP-Arid because of the extensive tracts of federal lands in the Southwest. To address this concern, EMAP-Arid will need to work with the BLM and SCS to develop RAIDS and IDS to produce data useful to EMAP. Both of these programs are at a stage in their development suitable for coordination with EMAP. Over the next several years they could help identify and collect the appropriate data to make assessments on the conditions of much of the federal arid ecosystems.

The NWI, conducted by the FWS, is of primary value to EMAP Wetlands. The mapping data for wetland areas lying within arid regions are not classified in a manner to address riparian questions and issues. Future effort is needed to work with the NWI to determine the suitability of using existing aerial photography and remote sensing data to delineate riparian systems. This effort needs to identify the type of analyses required to ensure that adequate ground verification is conducted to assess the quality of data on vegetation species, composition, and distribution.

Future effort is needed to better develop indicators to represent the condition of ecosystems over a large area. Information is generally available for site-specific assessments, but methods are not adequate to integrate these into regional assessments that reflect the condition of ecosystem processes. Good examples of this problem are the LTER and IBP programs that have large collections of historical data on both deserts and grassland ecosystems. These programs have data on selected EMAP indicators, but they have not been evaluated to see if site-specific ecological relationships will generalize to any other location.

### 6.1.5 Using Existing Data

The EMAP-Arid assessment is embarking on a new mission to make large-scale evaluations on the status and trends of arid ecosystems. However, this is not an uncharted course. There are numerous researchers who are working to answer parts of the large question. The challenge to EMAP-Arid will be to see how much of the existing data is useful to answer the EMAP questions. In the case of arid ecosystem assessment, considerable information is available. However, the effort required to incorporate this information into EMAP is substantial because of problems in representation, quality, and full documentation. The effort needed to secure and evaluate this existing data for EMAP purposes continues to be sizable.

# 7.0 LOGISTICS

## 7.1 LOGISTICS IMPLEMENTATION COMPONENTS

The EMAP-Arid resource group proposes to collect ecological information on an annual basis from sampling sites throughout the entire United States where arid ecosystems are present; these sites will be primarily in the western United States. Implementation of this large-scale program will require detailed, comprehensive logistics planning. Logistic considerations include coordination and oversight of all implementation support activities (e.g., access permission and procurement) in addition to actual data collection activities.

A pilot program will help to define the logistical considerations that must be taken into account for future field-based activities. Field activities for a pilot project are scheduled for 1992. One goal of the pilot program is to conduct a monitoring and assessment program which exemplifies future monitoring and assessment activities across the arid ecosystem. Arid zone ecosystems are extremely different structurally and in terms of diversity and exhibit greater system complexity than most other ecosystems. The pilot program will uncover a broad assortment of logistics concerns. During the pilot program, a preliminary logistics plan will be evaluated and developed in more detail. Modifications and improvements to the logistics plan will be determined during the pilot, and the formal EMAP-Arid Logistics Plan will be developed prior to implementing further field activities. This Plan will be implemented in subsequent years and will be appended and updated annually or as needed to incorporate new knowledge and experience or to accommodate unique sampling strategies or conditions.

## 7.2 SUMMARY OF EMAP LOGISTICS ELEMENTS

The EMAP-Arid Logistics Plan will address each of the elements presented in "Guidelines for Preparing Logistics Plans" (EPA, 1990). These elements are summarized below. The major logistic issues and those that are specific or unique to the EMAP-Arid Program are discussed in more detail in Sections 7.3 through 7.6.

ELEMENT 1. Overview of Logistics Activities--Summarize the types of activities required to complete the project. Maintain a timeline or Gantt chart showing all critical path milestones (e.g., project design, indicator selection, site selection, access permission, reconnaissance, procurement, methods selection, development of standard operating procedures, and resolution of specific quality assurance issues). Show required deliverable products such as plans, manuals, and reports. Also provide logistics budget summaries.

ELEMENT 2. Staffing and Personnel Requirements--Describe the number of personnel and the organizational structure necessary to accomplish project objectives. Define who is responsible for staffing and interagency and teaming mechanisms. Consider work schedules to determine whether extra positions should be created or whether existing personnel should work overtime. Create a contingency plan for replacing staff members when necessary. Identify key personnel and provide plans for retaining them.

ELEMENT 3. Communications--Address communications among field crews, laboratory crews, and supervisory personnel and between EMAP participants and any local organizations who should be informed of EMAP field activities. Also include plans for tracking samples, data, crews, and equipment and supplies. Discuss how field crews should interact with the public or with the media. Explain how approved changes in standard operating procedures will be documented and communicated for implementation.

ELEMENT 4. Sampling Schedule--Based on project, indicator, and statistical design or other program requirements, devise an efficient schedule for field activities. Consider geographical sampling windows within geographical areas and other factors such as climate and site access constraints.

ELEMENT 5. Site Access--Address issues related to gaining access to sampling sites including scientific collection permits, if required. Develop a list of local contacts to discern property ownership, jurisdiction, and the best site access methods. Address plans to obtain appropriate access permission and applicable collection permits. Consider how to coordinate activities of more than one resource task group in the same area. Discuss ways to arrange long-term access rights, track changes in ownership of private sites and management of public sites, notification of owners and managers before revisiting the sites for future monitoring, and provide contingency plans in case of future failure to obtain reaccess permission.

ELEMENT 6. Reconnaissance--Define criteria for selecting base operation sites (take into consideration personnel and technical support requirements), geographical location with respect to sampling sites, and time constraints imposed by sampling design or climate. Sampling sites identified as having potentially difficult physical or legal access should be visited during field reconnaissance. Additional resources needed for sampling should be identified if the access problem is due to physical conditions. If the access problem is legal, one last attempt should be made to obtain permission to sample.

ELEMENT 7. Waste Disposal Plan--Explain how chemical and biological wastes will be stored, transported, and disposed of safely and legally. Address what permits will be needed for storage, transport, and disposal of wastes.

ELEMENT 8. Safety Plan--Discuss how emergency situations will be evaluated and handled. Determine emergency contact personnel and what emergency services will be available in the field. Explain what procedures will be used to initiate search and rescue operations. List the training or other preventive measures required to conduct field operations safely. Indicate how this field safety plan will be developed in conjunction with laboratory, processing, and materials handling safety plans.

ELEMENT 9. Procurement and Inventory Control--Identify equipment, supply, inventory control and resupply, and services requirements of the field program and the processes by which they will be acquired and maintained. Determine where back-up equipment will be stored and how sites will be resupplied. Consider shipping regulations, especially for chemical and biological materials. Determine what analytical or other services will be needed and the best mechanisms for acquiring them. A procurement schedule should be provided for all items.

ELEMENT 10. Training Program--Describe who will prepare, review, and revise the field training and operations manual and the procedures for field measurements, sampling, sample handling, shipment, data recording, quality control, safety, waste disposal, and communications. Outline a schedule for the completion of these items. Describe training needs and identify who will conduct and review training. Address how personnel will be evaluated to ensure competency.

ELEMENT 11. Field Operations--Indicate the organizations that will perform each of the daily field activities. Describe how and when the daily field activities will be performed. Discuss and schedule the major events within field operations (i.e., mobilization, demobilization, and phase changes in sampling activities). Consider contingencies such as back-up personnel in the event of sickness. Require real-time evaluation to identify and resolve problems.

ELEMENT 12. Laboratory Operations--Indicate what organizations will be responsible for each type of sample preparation or analysis and for formulating each laboratory operations manual. If EPA conducts the activities directly, provide a development plan for providing appropriate laboratory facilities.

ELEMENT 13. Information Management--Describe any data management activities that might be affected directly by field operations. Establish guidelines for the timely and responsive transferral of information from field personnel to data managers. Indicate the groups that will be responsible for preparing and reviewing field data forms; provide a schedule for the completion of these forms. Develop a schedule for completion of the information management plan by the information management group.

ELEMENT 14. Quality Assurance--Describe who will provide input to the QA plan on field sampling, sample handling and preparation, sample shipment, sample disposition, and data management. A schedule for completing the QA plan will be developed and included in the logistics plan. The QA activities should be coordinated with other resource groups using similar methods. This effort should identify common methods and standards when possible.

ELEMENT 15. Logistics Review and Recommendations--For each year of study, summarize logistic activities. Discuss how personnel will be debriefed to identify and resolve problems. Discuss pilot studies and associated methods evaluation experiments; present logistics data summaries within the full-scale annual ecosystem report.

## 7.3 ORGANIZATIONAL STRUCTURE

Standardization of EMAP-Arid field activities across a nearly nationwide network of field teams is a critical aspect of the logistics process and requires a "Logistics Center." The overall purpose of the Logistics Center will be to provide guidance, training, and ultimately, uniformity in data collection. This uniformity is perceived as a factor critical to EMAP, since much of the data collected during the program will be used to detect trends. If data is collected nonuniformly, comparative analyses will be hampered.

The location and structure of the Logistics Center has not been defined at this time. However, a possible mechanism for instituting the Center would be through regional or district offices of

cooperating Federal resource management agencies. Good candidates for placement of logistics centers would be locally-based BLM offices. Other possibilities include SCS or EPA regional offices. Training and coordination through the Logistics Center would be implemented through a consortium of Federal, state, and private cooperators, each of which could provide various levels of scientific and administrative expertise. Cooperative interactions between EPA, state, and other Federal resource management agencies, as well as the private sector are envisioned as a critical component of the EMAP program.

EMAP-Arid is one of the seven EMAP resource groups that will be conducting annual field operations. There may be overlap between the field objectives of EMAP-Arid and one or more of the other resource groups (i.e., Wetlands, Great Lakes, Near Coastal, Agro, Forest, and Surface Waters). Logistics efforts will be integrated to the extent possible. Sharing facilities such as the Logistics Center or warehouse facilities may be ways of integrating efforts.

As mentioned previously, the long-term success of EMAP is dependent on the development of an interagency program with common goals for the monitoring of the ecological condition of the environment. Arid ecosystems monitoring alone could involve numerous agencies within the Department of the Interior (e.g., BLM, USFWS, NPS, USBR), the Department of Agriculture (e.g., USFS, SCS), the DOD, and the DOE. State game management agencies and natural heritage programs may also support cooperative relationships. As EMAP evolves into an interagency program, agreements between agencies will be established to define responsibilities. These agencies have locally based, experienced field personnel, and it is anticipated that personnel from these agencies will participate in both field and logistics center activities.

The Boise Interagency Fire Center may serve as a model for an EMAP Logistics Center. The Boise Interagency Fire Center is the national logistical support center responsible for coordinating and dispatching the closest suitable manpower, equipment, and aircraft for wildfires which exceed the capabilities of local and regional resources of land management agencies. This center was established in 1984 with an interagency agreement between the BLM, the U.S. Bureau of Indian Affairs, the NPS, and the USFWS. The objectives of this agreement are:

1. Development of interagency programs and services through coordination and cooperation;
2. Effective use of interagency programs and services by cooperating agencies; and
3. Equitable cost sharing of interagency programs and services.

Similar objectives will be established for interagency EMAP logistics centers.

## 7.4 LOGISTICS ISSUES

The complexity of EMAP poses a number of logistics issues. Overlooking or ignoring apparently minor issues or details may eventually jeopardize the success of the Program. These issues will be fully addressed in the EMAP-Arid Logistics Plan. The following discussion provides an overview of major issues for the EMAP-Arid Program.

### 7.4.1 Staffing

Various types of field data must be collected for indicator evaluation; therefore, field crews with varied research experience and expertise will be needed over the life of the program. At a minimum, individuals with knowledge in ecological field sampling methods, soil sampling, ground-water and surface water hydrology, and meteorological measurement will be required on each field crew.

Collection of field data in arid ecosystems is envisioned as a multiteam effort, which will eventually be conducted concurrently across each region by locally based field teams. All field personnel will be required to undergo an intensive training program to insure that protocols are understood and strictly adhered to and to provide consistency across the arid ecosystems program. The overall costs associated with training may be reduced over the long term by retaining field crews for long periods of time. The EMAP-Arid will use and train qualified personnel selected from the permanent staff of the BLM, USFS, NPS, EPA or other Federal agencies; the state resource management agencies, or from universities. Long-term agreements with these agencies and institutions will be negotiated in order to maintain long-term monitoring programs by qualified staff.

The use of personnel from local agencies rather than from short-term or seasonal hiring is advantageous for three reasons: (1) an agreement between EMAP-Arid and other entities will foster cooperative relationships which may lead to a more responsive and integrated sense of commitment by all resource management agencies; (2) use of locally based, permanent resource management personnel will result in greater efficiency because of the familiarity these individuals have of the local environment; for example, these personnel will be familiar with the geography, terrain, and field conditions of the local regions in general, and possibly site specific conditions in particular; and (3) if permanent personnel are used, it is assumed that they will participate yearly, and thus, new field crews will not have to be trained as frequently. The benefits of permanent field crews will eventually be realized both in cost savings and greater accuracy.

To accomplish these types of cooperative agreements, EMAP-Arid will need to demonstrate its utility to the states and other agencies by providing additional data and information addressing their research problems. A concerted effort will be undertaken to inform these agencies of the goals and objectives of EMAP, and to allow these agencies to become involved in the early planning phases of the programs. A cooperative agreement with the BLM has been initiated, and similar agreements will be sought with other resource management agencies, including SCS, USFWS, NPS, USFS, and state management agencies.

### 7.4.2 Access

Obtaining access information and permission to visit sampling sites will be difficult under some circumstances. Strategies for obtaining access permission are not yet fully developed. If land is publicly owned and open to the public, approval may be obtained from the appropriate authority; however, permission may be conditional (e.g., upon the use of nonmotorized transport). Contingency plans for these types of conditions will be developed. Federal lands not open to the

public (e.g., DOE and DOD facilities) may be accessible through Memoranda of Agreement; however, access may be completely denied depending on the types of activities conducted at those facilities. If land is owned privately, each landowner will be contacted and written access permission obtained.

Sample collection permits may be required by the state resource management agencies for collection of flora and fauna. Permits will be obtained from the state resource management agencies regardless of land ownership. State collection permits are usually very specific relative to site location, numbers and kinds of specimens, and identification of field personnel.

Gaining access permission and knowledge of access routes will require reconnaissance. The amount of time required to sample a site is dependent upon the physical access conditions. Some sites may be accessible only by foot, while others may require access by helicopter. Access constraints will be determined prior to the field season with topographic maps and through communication with local resource management agencies or other knowledgeable individuals. Determinations can then be made on how sampling crews and gear will be transported to the sampling site and how samples can be transported adequately.

Since the field sites will not be visited prior to the field season, in some cases the field crew may determine that the site is not suitable for sampling (e.g., because of unanticipated disturbance to the area or logistical sampling problems related to the area). Alternative sites or a strategy for determining an alternative site will be developed and provided to the field crew in advance so a decision can be made to relocate if necessary.

### 7.4.3 Data Confidentiality

Data confidentiality is an issue of particular concern to EMAP. Many landowners may be reluctant to permit access to sites from their property because they fear regulatory and enforcement actions. Access is potentially a design constraint, and denials by landowners could affect the design of the program. Cooperating agencies within the Department of Agriculture often conduct field programs under an agreement of confidentiality with landowners. EMAP data may be aggregated in such a way that individuals cannot be identified to assure landowners and cooperating agencies that site-specific data will not be used against their interests. Agreeing to withhold certain information, however, is in direct conflict with the Freedom of Information Act and the EPA policy on data confidentiality. This issue will be resolved in the near future. The EPA Office of General Counsel is currently being consulted on this matter.

## 7.5 FIELD OPERATION SCENARIO

Arid ecosystems field data collection will be conducted by a team of field scientists and overseen by a field supervisor who is directly responsible for successful completion of all data collection activities. A primary function of the supervisor is to coordinate with the Logistics Center on type, frequency, and specific procedures of data collection. This will require annual training and information sessions led by Logistics Center personnel for all field supervisors prior to the commencement of the field season. The organizational, supervisory, administrative, scientific, and

technical skills of the field supervisor are a key factor controlling successful data collection activities.

The field crew will consist of diverse personnel such as plant ecologists, plant physiologists, wildlife biologists, soil scientists, and other trained personnel, as needed. Each individual will be responsible for the collection of field data in their respective disciplines. It is imperative that each individual be trained in their own field methodology, data management, and quality assurance activities. The Logistics Center will provide a mechanism for ensuring that data is collected accurately and uniformly across the network of field crews.

A variety of information will be collected in the field, including such diverse parameters as soil chemistry, vegetation ecological parameters, plant physiological response, wildlife populations, and meteorological conditions. The level of complexity associated with the equipment involved in these operations necessitates that a field engineer skilled in instrumentation maintenance and repair be present on each team. Although this individual may also be involved in specific aspects of the data collection, a primary responsibility of the field engineer is to ensure that all equipment is in sound working order. This individual will also act as the assistant field supervisor, and provide back-up assistance where needed to all field crew members. The importance of this crew member cannot be underestimated inasmuch as any downtime related to field equipment may jeopardize opportunities for complete data collection.

Prior to the planned date for data collection, the field supervisor will be provided with information on field site locations and alternative sites. Problems with access or data collection will be worked out prior to sending the entire field crew out to collect data. Problems related to access or data collection logistics that are discovered during the first year of data collection will be resolved prior to returning to the field in subsequent years.

Prior to conducting data collection for the first time in any given year, the field personnel, assisted by the field engineer, will perform laboratory and field checks of all field equipment to ensure that all instruments are in good working order. Standard field equipment will include all necessary spare parts (in triplicate) (including batteries or other power supplies), a fully equipped tool box, and first-aid kit. Mechanisms will be developed to properly harness the field equipment to the field vehicle to eliminate the potential for damage enroute to the sites. The field engineer will ensure that the equipment is in good working order at all times.

Unanticipated problems such as climatic conditions or equipment failures may require personnel to remain in the field longer than was originally anticipated in order to accomplish all required data collection. Therefore, all trips and field personnel will be scheduled for approximately 50 percent more time than theoretically will be needed.

## 7.6 DAILY ACTIVITIES SCENARIO

Prior to leaving base camp every morning, individual field crew members will be responsible for consolidating and checking their field equipment. The field supervisor and field engineer will be ultimately responsible for ensuring that all field supplies, including field instrumentation,

equipment, forms, emergency and safety equipment, is stowed in the field vehicle prior to entering the field.

Scheduled field activities will be preplanned; thus each field crew member will have specific duties to perform on any given day. The field personnel will collect data, overseen and assisted by the field supervisor. The field engineer will provide technical support for instrumentation and field sampling as needed and time permits.

Field data collection will be automated to the extent possible. Other EMAP resource groups have demonstrated the efficiency of the Paravant RHC44 portable data recorder (PDR) for many types of field data collection. This computer-based data recorder is fully portable and has proven to be relatively indestructible. These recorders will be fully programmed prior to the field season, requiring little programming or maintenance while in the field. A major advantage to automated data recording is that the information transfer step from hard copy to computer is eliminated, thereby reducing the potential for error. Data input error is also reduced because the PDR can be programmed to reject entries out of an acceptable range of values. Because automated data collection may not always be practical, other procedures will be available as needed.

Upon return to the base camp at the end of each field day, the field crew will download any data loggers or recorders to a portable computer, prepare, pack, and store or ship all samples collected during the day; restock field supplies for the next day; and recalibrate their equipment. The field engineer will clean, maintain, and assist in the calibration of all field equipment. The field supervisor will immediately debrief the crew to determine progress made during the day and prepare a schedule for the following day. Daily or at some other interval, samples will be shipped or data will be transferred to the Logistics Center via modem. The field supervisor will oversee these periodic operations, as well as keep complete records of all collection activities, data transfers, or sample shipments. Figure 7-1 illustrates a flow chart of EMAP-Arid field activities.

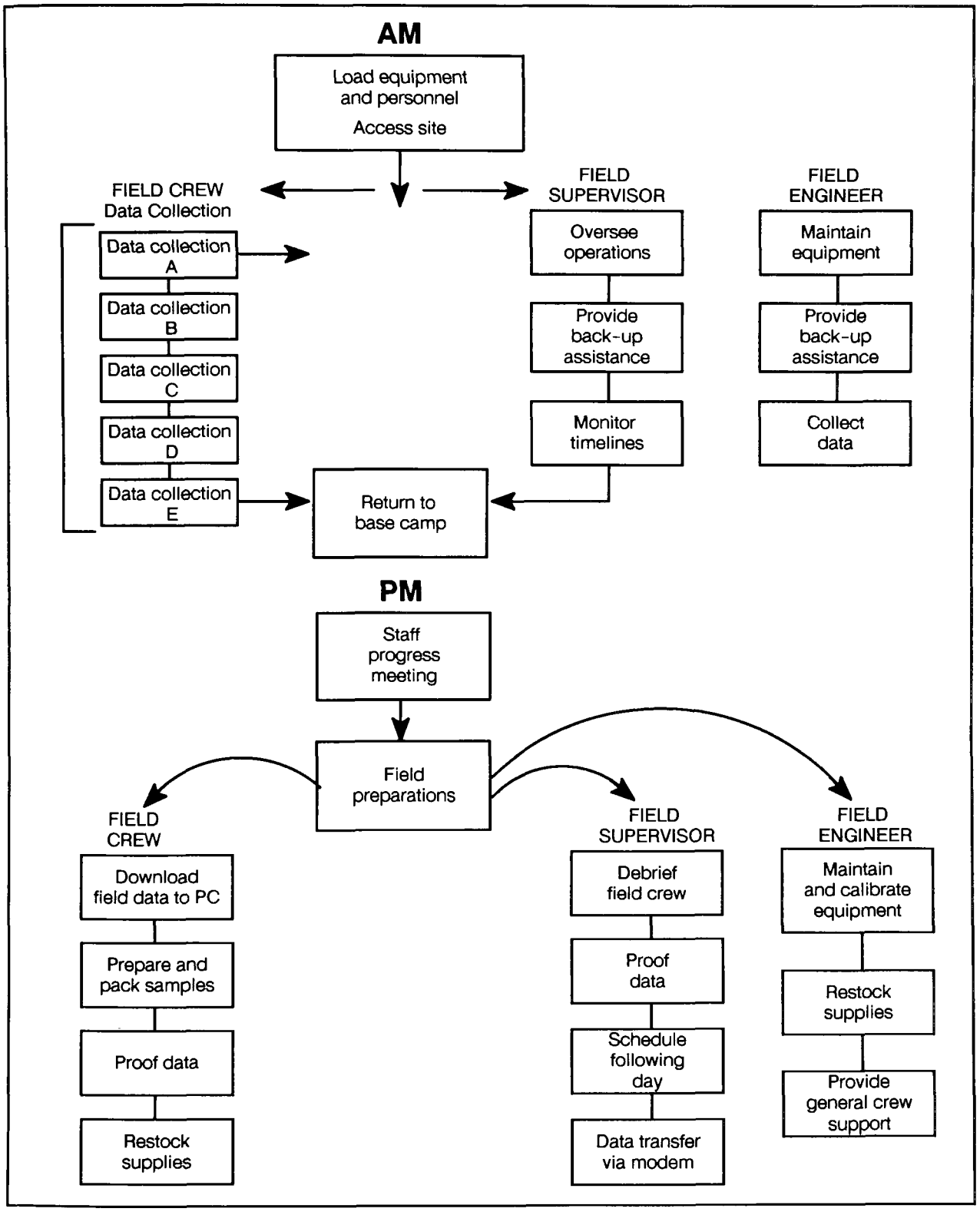



Figure 7-1. Flow chart of EMAP arid ecosystems daily field activities.

# 8.0 ANALYTICAL CONSIDERATIONS AND MEASUREMENT TECHNIQUES

This section addresses the analytical considerations associated with three aspects of the EMAP-Arid data collection and analysis: field data collection, laboratory analysis, and synoptic (remote sensing) analysis. These factors are important considerations in total quality management, which requires the application of qualified personnel, equipment, and techniques under the scrutiny of rigorous process quality control to achieve results of measurable quality as set by data quality objectives. Quality control is discussed in greater detail in Section 9.

## 8.1 METHODS

Methods for measuring habitat attributes in terrestrial and aquatic environments and evaluating biotic condition are described in numerous places (e.g., Cox, 1976; Brower and Zar, 1977; Mikol, 1980; Call, 1981; Hays et al., 1981; Platts et al., 1983; Cooperrider et al., 1986; Graves and Dittberner, 1986; and Platts et al., 1987). The contribution of attributes to an ecosystem may vary due to site-specific characteristics. Identification of limiting or enhancing environmental factors is an important component process of defining the resource condition. Standardization of measurement techniques will make it possible to compare monitoring information and evaluate study results in a uniform manner. Factors to be considered during the planning of field sampling include timing of sample collection, site selection, sample collection, subjective measurement, and training.

### 8.1.1 Sample Timing

Sample timing will minimize the variability of the data yet permit objectives to be met. The best time to collect a sample, the index period, is an important issue in the collection of remote or ground verification data. The index period may change with time of year or day and is a critical value to assess when considering data variability. Some QA concerns can be allayed by considering the following issues:

1. Seasonal influence and multiple measurements over the year—there are numerous instances when time of the year is critical to the objectives of the project. Vegetation assessments, for example, are probably best made in the spring or summer. Multiple measurements taken throughout the year may be required to determine the seasonal variability for some parameters. Sample timing for soil samples, however, may be less important in some cases since fluctuations in soil properties are more stable .
2. Time of day—certain parameters, such as photosynthetic processes and animal activity are influenced by time of day; thus diurnal sampling constraints must be considered in the design.
3. Meteorologic activity—several meteorologic parameters influence the amount of variability in monitoring results. Although field situations do not

necessarily allow for the minimization of such variability, significant sources of variance should be recorded.

4. Ecosystem cycles – measurement of certain ecosystem parameters, e.g., phenological status, or brood success in birds, must be conducted at the appropriate time of year.

### 8.1.2 Site Selection

Selection criteria should be carefully chosen to ensure comparability between sites. For example, if the terrestrial area to be monitored is a remote site, factors such as influence from global and local pollution sources should be assessed and kept to a minimum, the area should be located where a minimum level of economic development is expected in the coming decades, the area should not be subject to intervention, and baseline data should be available for the site with particular emphasis on long-term (30 to 50 years) meteorological records (Wiersma, 1983).

Site selection criteria will depend on a number of factors, including the scale of the program or project. For monitoring a landscape or watershed vegetation type, slope, aspect, drainage class, and soil type should be taken into consideration during selection. For monitoring regional or national representation, geology, physiography, vegetation, precipitation, and temperature regimes should be considered. Ideally, site selection criteria must be concise enough that two independent researchers would choose similar locations. The criteria must minimize the amount of subjectivity that enters into the site selection process.

### 8.1.3 Sample Collection

Natural sample variability may be reduced through various sampling methods. The most common way to reduce sample variability is to composite samples. For example, soil or vegetation samples are frequently composited to obtain an average. Another way to reduce variability is to take a sufficiently large homogeneous sample from which to draw a smaller subsample. These methods work well for small-scale or site-specific assessments; when, for example, the whole site can be gridded.

### 8.1.4 Subjective Measurement and Training

Subjective measurements include those that rely on subjective estimates. Ecosystem studies rely on subjective measurements for estimating such factors as vegetation cover percentages and species composition (Barbour et al., 1987). One problem with subjective measurement can be the high degree of variability between samplers.

One way to reduce the subjectivity from field estimates is by using standardized field forms that provide multiple-choice type answers in addition to spaces for other data. For example, the soil description forms used by the USDA allows individuals with little training to produce fairly accurate soil descriptions by providing choices on all relevant information such as structure, texture, soil color, and horizon depth. Standard methods for reporting properties such as the size, strength, and shape of the soil bed are all described in the soil structure section. An individual

making a soil profile description without a soil description form is much more likely to omit pertinent information than the individual using the form. Similar forms could be developed for all ecosystem studies that require documentation of data from the sampler.

Training is vital to the success of subjective measurement systems. The USFS, for example, is addressing this concern now and working on standardizing data collection so that data can be used in geographic information systems (GIS). For EMAP to be successful, all employees involved in monitoring must receive the same level of training and their activities must be checked by qualified field auditors.

## 8.2 LABORATORY ANALYSES

Analytical laboratories will generally assume that all samples were properly handled and labeled prior to receipt, unless gross problems such as shipping delays are evident. Therefore, it is the responsibility of all field personnel to properly collect, contain, label, preserve, document, and transport their samples via standardized protocol to the analytical laboratories.

The quality of a measurement may be assured if the measurement technique is performed in a technically competent manner by qualified personnel using appropriate methods and equipment. The precision and accuracy of the measurement techniques are monitored to ensure consistency. Acceptable quality may vary by analyte, matrix, or analysis technique. The quality of contracted services is assured by contracting with reputable consulting groups, research institutes, and laboratories that have demonstrated their competence in performing field measurements or laboratory analyses and by monitoring their performance throughout the life of the contract through a variety of quality assurance procedures. The following information will be required within the report process for deliverables under all contractual agreements:

1. A description of the methods or techniques used.
2. The quantitative results.
3. The results of any quality control samples analyzed or measured in conjunction with the report results.
4. Limits of detection for each analyte.
5. A description of any problems encountered in laboratory analysis or field measurement.

Additionally, general quality assurance can be also be assessed via round-robin and crosscheck analysis procedures between consulting groups and contract laboratories. A preselected percentage, e.g., 5 percent, of all results could be selected for this purpose. A quality assurance report will be prepared which evaluates the results provided by the contractor. This report will discuss the quality control data, report any constraints such as detection limits or sample size, and provide an estimate of the precision (as $\pm$95 percent confidence interval) and accuracy (as percent recovery of spiked analyte or reference material) of the analytical results.

### 8.2.1 Analytical Precision and Accuracy

The precision of the method for each analyte is estimated by using a range ratio control chart to calculate an estimate of the 95 percent confidence interval for the method. The precision of the results of duplicate analyses reported in each submitted sample set are compared to precision that is expected, based on the chart. If the precision of the duplicate analyses in a single report is within the 95 percent confidence interval for the estimate of the laboratory precision, based on the control chart, the precision of the analyses is acceptable. The precision of the laboratory is expected to be within the standards established for each type of analysis (Table 8-1).

TABLE 8-1. EXAMPLES OF ACCEPTABLE PRECISION REQUIRED FOR LABORATORY ANALYSES

| METHOD | ±95% CONFIDENCE INTERVAL | |
|---|---|---|
| | REGION OF DETECTION[1] | REGION OF QUANTITATION[2] |
| ICP Scan[3] | 30% | 15% |
| Atomic Absorption (AA) | 20% | 10% |
| Organochlorine Scan | 30% | 15% |
| Petroleum Hydrocarbon Scan | 70% | 35% |

[1] Duplicate analyses fall within the region of detection when their average concentration is between two and ten times the limit of detection. If the average of the duplicate analyses is less than two times the limit of detection, no evaluation of the precision is made. The confidence interval is defined by ±2 times the limit of detection.

[2] Duplicate analyses fall within the region of quantitation when their average concentration is greater than ten times the limit of detection.

[3] ICP = inductively coupled plasma spectroscopy.

The accuracy of the analysis is assessed using percent recovery of spiked analytes. The accuracy of the laboratory is expected to be within the standards established for each type of analysis (Table 8-2). Mean spike recovery and the standard deviation of the mean recovery are determined for each analyte. The recoveries reported with a single sample set are compared to the average recovery for the analyte. If the reported recoveries are within the 95 percent confidence

interval for the mean recovery, the accuracy of the analysis is considered acceptable. In addition to spike recoveries, standard reference materials are frequently analyzed in conjunction with metal analyses. Results from these determinations are compared to both the laboratory average and the certified value. Procedural blanks are also utilized to assure quality and are analyzed to confirm that no analyte is added during the processing of the samples. These data are expected to be below the limit of detection and results are included in the quality assurance report.

TABLE 8-2. ACCEPTABLE AVERAGE SPIKE RECOVERIES FOR ASSESSING ACCURACY OF THE ANALYSIS

| ANALYTE | ACCEPTABLE RECOVERY RANGE |
|---|---|
| Metals (ICP) | 80-120% |
| Metals (AA) | 85-115% |
| Organochlorine Pesticides | 80-120% |
| Petroleum Hydrocarbons | 60-140% |

### 8.2.2 Detection Limits and Required Sample Size

The tables provided in Appendix C summarize information for organic and inorganic analytical capabilities that are typically requested (Tables C1 and C2), lower limits of detection per analyte and minimum and optimal sample weights or volumes required by each method (Tables C3 through C7). Detection limits are directly affected by sample size and vary among laboratories due to differences in methodology and instrumentation.

## 8.3 SYNOPTIC SUPPORT REQUIREMENTS

Synoptically based data collection, integration, and analysis is an integral part of the EMAP-Arid research agenda, and there are many inherent analytical considerations that must be considered for this aspect of the program. Developing a relationship between data derived from remote sensing and the GIS will require that attention be given to the integration of the data sets. Remote sensing and GIS error associated with data acquisition, processing analysis, conversion, and final product presentation could have a significant impact on the confidence of decisions made using the data. The error sources and issues present within this process are discussed in Lunetta et al. (1991). This section highlights basic considerations in synoptic data analytical techniques.

### 8.3.1 Aerial Photography

Acquisition and interpretation of aerial photographs are important features of the synoptic data program. An orientation and training program that is task and function specific will be implemented to ensure technical competence, compliance with standard operating procedures, and maintain continuity and depth of expertise in the event of personnel turnover. CIR photography will be used to the extent possible, and new photography will be obtained if baseline photography is not available. All film will be labelled and provided with a data tracking form upon receipt, and visual inspections will be immediately implemented to check for damage or flaws. The film will also be analyzed to ensure adequate coverage, to determine scale, and to identify the hexagon center. Film quality will be maintained through proper handling procedures.

In the data preparation stage, photographs and hexagons will be registered and mylar composite maps will be generated. The analysis will delineate polygons and assign attribute codes in accordance with a classification system. Comprehensive quality control and quality assurance reviews are to be performed on this product to ensure consistency in applying the classification system and accompanying user conventions and as a check for any inaccuracies in boundary delineations or classifications.

### 8.3.2 Multispectral Data Quality Control

Analytical procedures included in the multispectral data analysis will include raw data examination and evaluation, documentation of analytical procedures and data tracking, routine data backups, audits of documentation and technical personnel, and corrective actions.

The raw data will be evaluated to ensure proper areal coverage and an absence of scanner striping, clouds, or haze. An Analysis and Data Tracking Form will document the digital characterization process and will cover all procedures that are applied to the data. Procedures will also be developed for classification and raster-to-vector data conversion to ensure that the data products are accurate.

### 8.3.3 GIS Data File Development

The transfer of information from aerial photographs or multispectral data to the GIS will require that measures are imposed to ensure data integrity and map consistency. A Hexagon Production Record sheet will provide record-keeping methods for ensuring that all operational processes are completed. During GIS development, standard checks will be made to ensure that all polygons are closed and coded and that all codes are valid and to check map registration. Hexagon tracking forms will trace the development of each hexagon from the photo acquisition stage through data base development.

# 9.0 A STRATEGY FOR QUALITY ASSURANCE

## 9.1 INTRODUCTION

The arid ecosystem component of the EMAP will be collecting each year a sizable quantity of data, in a sequence of locations, with numerous measurement systems, by a variety of field personnel, and at a considerable cost. These data will be further checked, edited, and processed at various laboratories and assembled, through a distributed information management system, into regional and national data bases. Subsequently, population estimates of various ecological parameters (e.g., extent and condition) will be made and the results will be utilized by EMAP customers in many ways including the assessment of the effectiveness of present regulations and policies in protecting the health of arid ecosystems. Clearly, the EMAP-Arid data will be a valuable resource to many users, and thus it needs to be properly focused, identified, collected, processed, assembled, documented, and preserved in order to provide these users with results of known quality. The strategy used to assure the proper performance of these steps is the focus of quality assurance (QA) plans and activities.

The origin of QA within the EPA stems from regulatory and compliance activities which traditionally have differed considerably from the proposed EMAP activities. Hence, the EMAP-Arid project will take a new approach to environmental QA, and it will emphasize the philosophy and strategy of total quality (e.g., Snee, 1990) in its efforts to achieve excellence in design, implementation, analysis, and reporting. Thus, particular attention will be placed on the:

1. Description of the EMAP-Arid information products.
2. Identification of the relevant customers, their potential decisions, and the resulting data quality needs.
3. Building in quality, or excellence, in the design stage.
4. Training for, and standardization of, the implementation of the monitoring design.
5. Early detection of problems and the use of "improvement teams" to diagnose, recommend, and implement corrective action.
6. Need to recognize and reward individuals and teams for outstanding performances.

Finally, all EMAP-Arid participants will be expected to pursue the philosophy of continual improvement in all EMAP-Arid activities.

## 9.2 DATA QUALITY OBJECTIVES

The EPA has a policy that all data collections conducted under its sponsorship must be properly planned and implemented so that the resulting data are of known and documented quality

and meet the specifications of the users (Stanley and Verner, 1985). This policy was officially stated in U.S. EPA Order 5360.1, "Policy and Program Requirements to Implement the Quality Assurance Program" (EPA, 1984), and, in a memorandum accompanying the issuance of the Order, Deputy Administrator Alm indicated two steps that are needed to accomplish the data quality assurance task:

> *".... the user must first specify the quality of data he needs; then the degree of quality control necessary to assure that the resultant data satisfy his specifications must be determined."*

These two steps presently are addressed by the data quality objectives (DQOs) process and the corresponding quality assurance project plan (QAPP) required in EPA-sponsored projects. The development of the DQO process stemmed from the EPA need for data that clearly would be defendable in regulatory and judicial situations. The process should involve four steps: (1) the user indicates the types of decisions to be made and the desired data quality; (2) these statements then are translated into quality assurance requirements; (3) a sampling design is created in response to the requirements; and (4) comparisons are made between what is desired and what is affordable.

The user statements typically are termed DQOs, and they have been defined as "qualitative and quantitative statements of the quality of data needed to support specific decisions or regulatory actions" (EPA, 1987a). The DQO process is iterative as it translates the DQOs into quantitative and qualitative guidance for the sample design and the resulting quality assurance plan. These iterations between what is desired and what is possible and affordable are not easy, but they ultimately should lead to an acceptable resolution and plans.

One of the major components of the DQO process is the assessment of both the population variability (Vp) and the measurement variability (Vm) that will occur with each ecological indicator. These two components add to the total variability (Vt) ($Vt = Vp + Vm$) that any monitoring design will face upon implementation (e.g., van Ee et al., 1990), and the desire is to keep this total variability (i.e., noise) relatively small so that the indicator "signal" can be readily detected. Temporal and spatial variability are additional factors that may affect the total noise, and they must be identified and controlled. Lastly, systematic error (termed bias--it can arise from many causes such as a faulty sampling procedure) may be present and may accumulate during the measurement process. Hence, the signal may not be accurate, and the resulting bias must be assessed.

EMAP-Arid is a pioneering program, involving regional and national estimates of ecological population parameters (e.g., population characteristics such as extent, distribution, and condition) over an extended period and using a probability based design. The measurement variability for the proposed indicators is essentially unknown at the present time. Consequently, the DQO process cannot be utilized in the initial EMAP-Arid field efforts such as pilot studies. Instead, the focus will be on assessing actual systematic and random measurement error of the different measurement devices such as the AVHRR and MSS in order to determine what measurement quality objectives (MQOs) can be met for the selected indicators. The plan is to gradually build the indicator and other information data base for a future demonstration project that can attempt to incorporate the DQO process.

The QAPP plays the role of guiding the implementation of the sampling design to assure that the DQOs are satisfied. This plan is a detailed document that focuses on the implementation of the project and the accompanying quality assurance efforts. Although, there is some flexibility in the material that must be covered in the report, depending on the purpose of the data collection effort (EPA, 1987b), it typically contains 16 sections including the project description, DQOs, and data characteristics (precision, accuracy, completeness, comparabilities), sampling procedures, sample custody, calibration procedures, laboratory analytical procedures, internal quality control checks, performance and system audits, and some details on the forthcoming quality assurance reports to management. When completed, the QAPP becomes a basis for the justification of sample selection and quality assurance.

## 9.3 QUALITY ASSURANCE REQUIREMENTS

The MQO and DQO processes presently require that at least the five fundamental data characteristics of accuracy, precision, completeness, representativeness, and comparability be properly addressed. The following definitions of these requirements (e.g., Barth et al., 1989) present typical approaches to assessing each of them. Our initial proposal on how to handle each requirement also is included.

### 9.3.1 Accuracy

The degree to which a measured value agrees with a known "true" value (typically reported as amount of bias). This problem typically is controlled by the laboratory and its standard operating procedures. It usually is assessed by laboratory blanks or spiked samples.

The EMAP-Arid resource group believes that the idea of accuracy must be extended to the field and, hence, standard operating procedures (e.g., high-tech measuring devices, computerized data entry, field screening software) must be emphasized as much in the field as in the laboratory. This emphasis will require a system that will assure quick reporting to the laboratory and the field if accuracy problems are encountered.

### 9.3.2 Precision

The amount of variability among repeated observations from the same population (generally reported by calculating the variance or standard deviation of the observations). This quantitative description of the variability of a process enters the quality assurance situation at many stages. The particular sampling design, the sample taking, the sample handling, the laboratory analysis method, and other related activities all have precision components. Replicate colocated samples and splits typically are used to assess this dimension of data.

Attention to all of the above steps will be needed in order to reduce the random error which ultimately affects the total variability of the estimate. This attention will be emphasized in the design and implementation stages through training and periodic checks including field audit samples. Again, quick communication of the results will be needed in order for the audit data to serve its purpose.

### 9.3.3 Completeness

A measure of the proportion of the sample size that actually results in validated data. This requirement typically is handled by oversampling or by sampling in a phased approach. Completeness is measured by the ratio of the amount of validated data to the amount of requested data.

The EMAP-Arid team currently favors a phased or sequential approach to this problem believing that considerable emphasis should be placed on attempting to secure the necessary data from the designated site. We expect that it will not be possible to collect some proportion of the data from the designated sites and will watch this situation closely.

### 9.3.4 Representativeness

The degree to which data truly represent a characteristic of an *a priori* designated population. Representativeness largely is achieved by the monitoring network design, the field sampling design, the field sampling, and the detailed knowledge of the ultimate use of the data.

For EMAP-Arid, the current plan is to emphasize the above techniques to handle this problem and to include field training and self-reporting of problems in following the implementation protocol.

### 9.3.5 Comparability

The degree of confidence that one has that two or more data sets have been subjected to the same overall measurement process. This objective typically is addressed by proper training, standardized methods, and uniform attention to the actual measurement process by field crews, laboratory staff, data managers, and other participants. Field audit samples may help in assessing this dimension.

Again, EMAP-Arid will emphasize standardized and robust methods, training, and reporting of all problems encountered in the field or laboratory.

Although it will not be possible to fully address these requirements until after EMAP-Arid customers are identified and some pilot studies are completed, the design team will evaluate these design evaluation criteria frequently in order to build excellence into the design and implementation stages. Clearly, the monitoring design team ultimately should attempt to settle on appropriate values or levels for the above five data characteristics such that will serve both external and internal users.

## 9.4 A TOTAL QUALITY APPROACH TO THE QUALITY ASSURANCE PROGRAM

As already indicated, the EMAP-Arid group plans to incorporate the old with the new to create a QA system that is both responsive to customer needs and responsible for a unified team approach to providing excellent products throughout the stages of EMAP-Arid activities. Figure 9-1 presents some of the relations between the traditional QA and a version of the more recent total

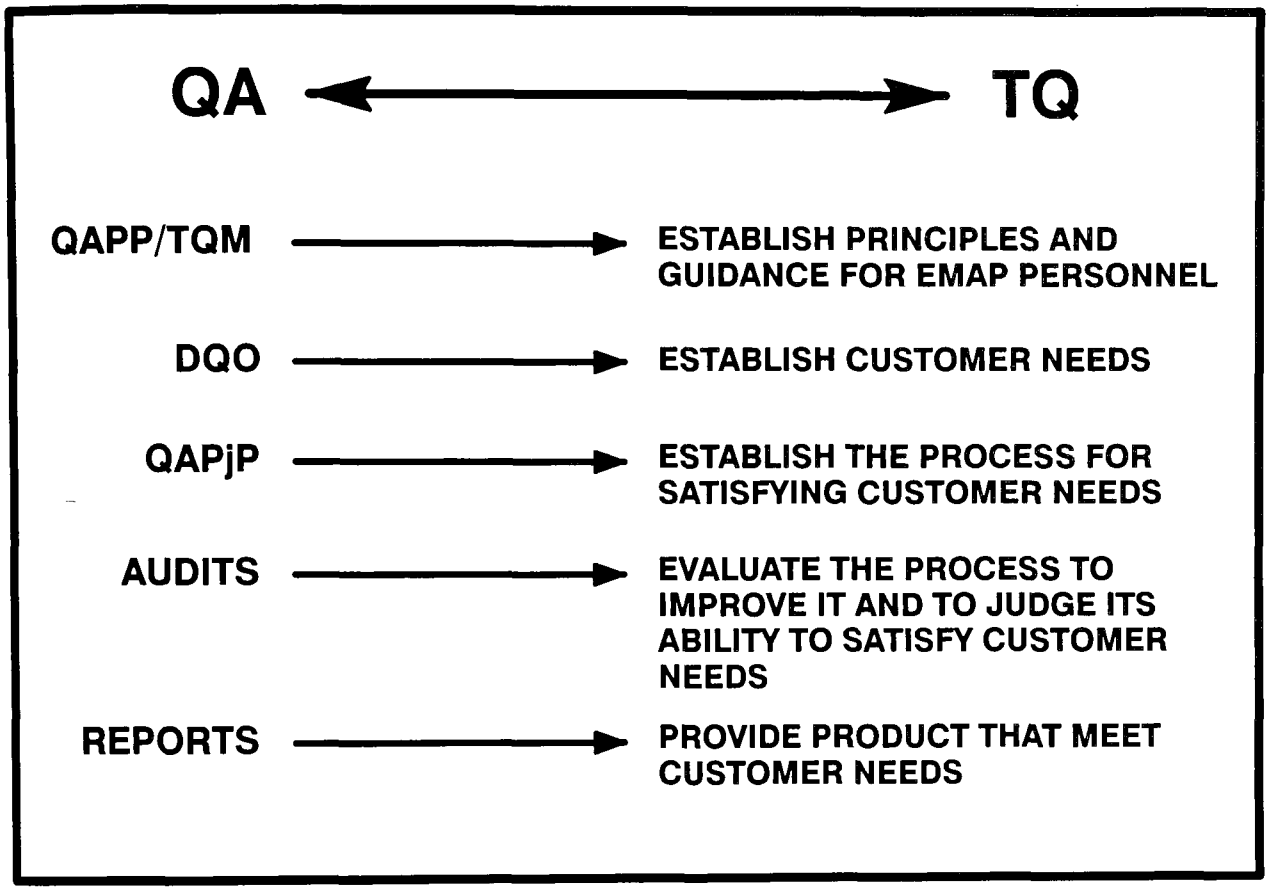



Figure 9-1. Relationships between traditional QA tools and the total quality primary tenet "customer satisfaction."

quality approach (Graves, 1990). The total quality approach to the QA problem has strong historical roots as evidenced in the 1920s statement by George Edwards, a member of a small AT&T engineering and inspection group at Western Electric, who stated the following in proposing the term "quality assurance":

> *This approach recognizes that good quality is not accidental and that it does not result from mere wishful thinking, that it results rather from the planned and interlocked activities of all the organizational parts of the company, that it enters into design, engineering, technical and quality planning specification, production layouts, standards, both workmanship and personnel, and even into training and fostered point of view of administrative, supervisory, and production personnel. This approach means placing one of the officers of the company in charge of the quality control program in a position at the same level as the controller or as the other managers in the operation. (Edwards, 1926?, in Harrington, 1983)*

The following subsections will provide some initial views and a strategy for a total quality (TQ) approach to the EMAP-Arid QA program (see Harrington, 1987, for how to organize for TQ). Further ideas and results will be forthcoming as some of these ideas are tested in the field and in the laboratory in the summer of 1991.

### 9.4.1 Products and Customers

All of the proposed EMAP-Arid product types should be identified early in order that the potential final customers (e.g., BLM, USFWS, and EPA regions) can understand what they will be purchasing in a joint venture. For all of the EMAP resource groups, the final product is information such as tables of results, visual displays, and interpretative comments (see Section 10); this information will focus on responding to the issues, endpoints, and critical questions of the particular resource (e.g., What is the condition of the cottonwood-willow vegetation type in the Southwest U.S.?).

A second, and equally important, question is who are the customers for whom the final EMAP-Arid products will be produced? Here both external agencies such as the BLM and USFW and internal decision makers such as the EPA Administrator and other EMAP ecosystems will be identified. In keeping with Deputy Alm's guidance, the EMAP-Arid team also will clearly identify what the users desire, need, and can afford. Although these questions may not be easy to answer at this time, early answers are important for planning activities.

### 9.4.2 Seven Stages of an Experiment

To illustrate how a TQ strategy for EMAP-Arid QA might function, Figure 9-2 presents the seven stages of the typical life cycle of a field monitoring project. The following text describes typical research activities for each of these seven stages (Flueck, 1986) and examples of associated TQ actions (Table 9-1). We will use four QA steps:

1. Goals: defining quality performance standards;
2. Evaluation: comparing results with the standard;
3. Corrections: taking corrective actions when needed; and
4. Improvements: planning for continued improvement to guide these examples.

#### 9.4.2.1 The Conception Stage

During the conception stage of an EMAP ecosystem survey, the planners have the responsibility to select the high priority customer issues, formulate some critical questions, query some experts and the relevant literature, develop some insights on possible endpoints, and perform preliminary investigations. The major study decisions will be to determine if there is sufficient interest and opportunity to continue.

The quality assistance role, under TQ, should emphasize the checks and balances needed to assure that the project is carefully designed and implemented (much like the industrial view of

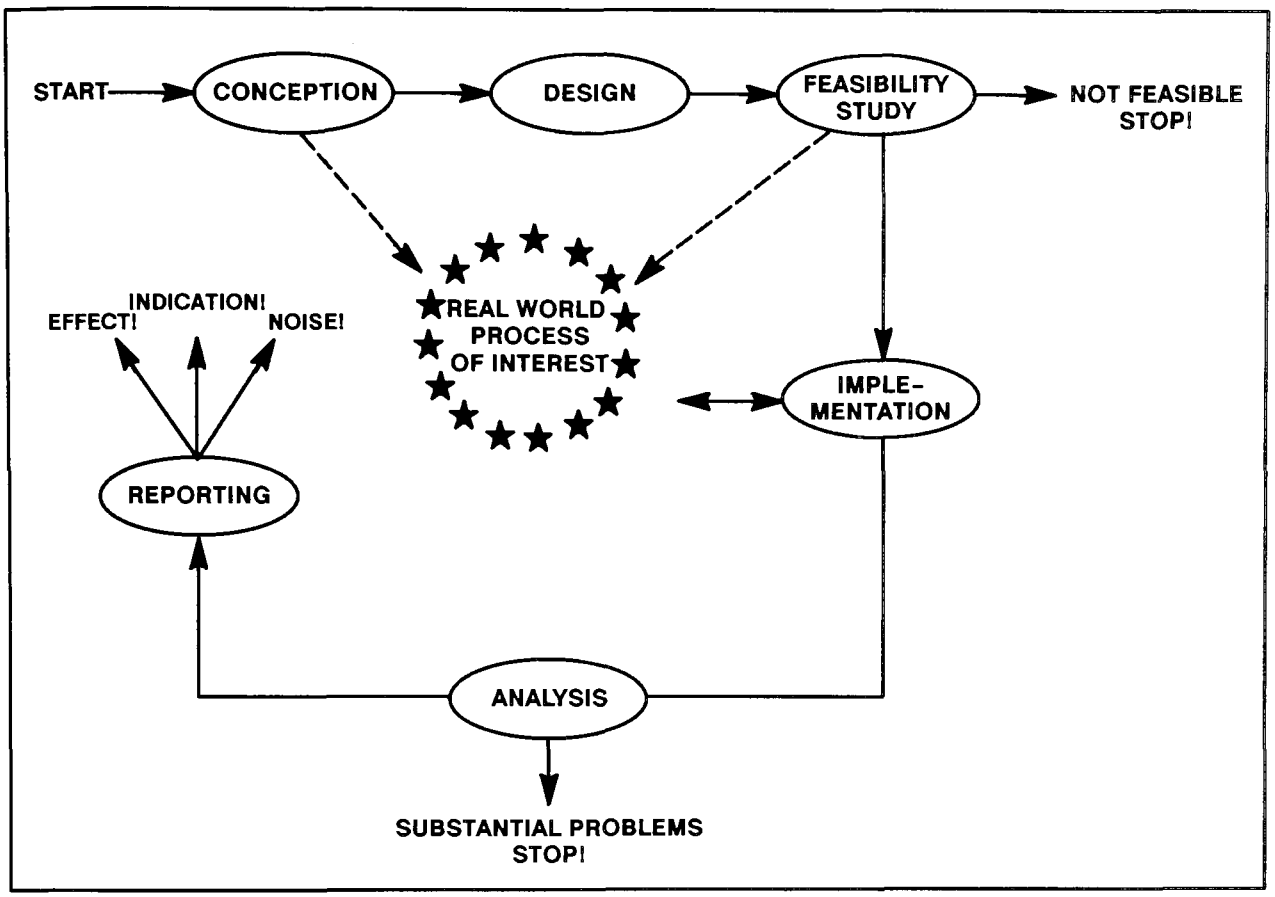



Figure 9-2. The typical stages or life cycle of an experiment.

"doing it right the first time", see Flueck, Paulsen, and Jones, 1990, for an EMAP example). Thus, as shown in Table 9-1, the specification of goals could include: (1) identifying high priority ecological issues, related EMAP critical questions, and important endpoints; (2) completing a comprehensive literature search; and (3) conducting some preliminary investigations.

The evaluation could involve evidence of frequent (e.g., weekly) discussions between and among the scientists and the Technical Director with monthly progress reports to the relevant EMAP Associate Director. Finally, the EMAP Steering Committee should review periodically the major results of each ecosystem task group's activities. The corrections could range from further explanation and additional justification to stop and start again. Finally, the improvement process could entail a gradual raising in the level of required knowledge, the sharpness of the critical questions and the associated endpoints, and more focused preliminary investigations.

### 9.4.2.2 The Design Stage

The design stage is responsible for the construction of a formal research plan including the EMAP-Arid goals and scope,the critical questions,the proposed conceptual model, and the

TABLE 9-1. AN APPLICATION OF THE FOUR BASIC STEPS OF TOTAL QUALITY TO THE SEVEN STAGES OF A HYPOTHETICAL FIELD PROJECT FOR THE EMAP-ARID ECOSYSTEM RESOURCE GROUP

## 1. The Conceptual Stage

a. Goals

i. Identification of high priority issues and related EMAP critical questions and important endpoints

ii. Completion of a comprehensive literature search

iii. Preliminary investigations and possible solutions

b. Evaluation/Verification

i. Weekly reporting to Technical Director and monthly progress reports to the relevant EMAP Associate Director (AD)

ii. Review by EMAP Steering Committee at major junctures

c. Corrections

i. Additional explanation or small course changes

ii. Start again

d. Improvements

i. Better method to identify high priority issues, resulting critical questions, and endpoints

ii. Perform more focused preliminary investigations

## 2. The Design Stage

a. Goals

i. Clear statements of goals, products, customers, and scope of the project

ii. Description of the relevant conceptual model

iii. Clear specification of sampling design with quantitative evidence of its competitive advantage

iv. Specification of data quality objectives (DQOs) and related data quality requirements

b. Evaluation/Verification

i. Review of EMAP Design Report by internal committee

ii. Review of Design Report, or sections, by external panels

c. Corrections

i. Clarify sections of the Design Report

ii. Revise the Design Report

iii. Scrap Report and start over

d. Improvements

i. Better focus and clarity of Design Report

ii. Quicker redesign time

iii. Better QA coverage of activities

TABLE 9-1. (continued)

## 3. The Feasibility Study Stage

a. Goals
   i. All benefits and costs properly estimated
   ii. Well-formulated questions for the pilot tests
   iii. Prepare required QA documents
   iv. Pilot testing gives needed answers the first time

b. Evaluation/Verification
   i. Review of pilot tests by the ecosystem Technical Director and other scientists
   ii. Review of results by the EMAP Steering Committee

c. Corrections
   i. Revise the Design
   ii. Revise the pilot study

d. Improvements
   i. Plan more effective and efficient pilot studies
   ii. Plan for iteration of pilot tests

## 4. The Implementation Stage

a. Goals
   i. Utilization of a detailed Field Operations Plan and Manual
   ii. Well-trained field workers
   iii. Data completeness of 100%
   iv. No deviations from the design

b. Evaluation/Verification
   i. Daily and weekly discussion of operations by Technical Director, his staff, and other scientists
   ii. Frequent check of equipment and calibration

c. Corrections
   i. Revision of the schedule and work assignment
   ii. Revision of the operations plan
   iii. Replace equipment and personnel

d. Improvements
   i. Plan more realistically for future operations
   ii. Provide better contingency plans
   iii. Improved training of field workers

TABLE 9-1. (continued)

## 5. The Analysis Stage

a. Goals
   i. Clean data
   ii. Appropriate estimators or tests
   iii. Proper basis for inference
   iv. All QA components of variance are small

b. Evaluation/Verification
   i. Inspection of data for compliance
   ii. Review of each analysis upon completion
   iii. Duplication of some analyses

c. Corrections
   i. Transform data to meet assumptions
   ii. Select new estimators
   iii. Delete the analysis

d. Improvements
   i. Select better estimators initially
   ii. Separate exploratory from confirmatory analyses
   iii. Better estimators of QA components of variance

## 6. The Reporting Stage

a. Goals
   i. Clear and complete reports
   ii. Timeliness of reports

b. Evaluation/Verification
   i. Internal review of reports
   ii. Frequency and type of report

c. Corrections
   i. Revise report
   ii. Require more frequent reporting

d. Improvements
   i. Improve formats of reports
   ii. Plan for more journal articles

TABLE 9-1. (continued)

**7. The Ex-Post Studies Stage**

a. Goals
   i. Uncover other relevant results
   ii. No mistakes in the old or new data

b. Evaluation/Verification
   i. Review each analysis
   ii. Re-check data and data-reduction

c. Corrections
   i. Re-do analyses
   ii. Revise data

d. Improvements
   i. Plan for broader exploration
   ii. Plan better data collection and reduction

two-tiered survey design, the relevant indicators and estimators, the measurement processes, and the desired analyses. At the completion of this stage a formal design document should be available.

The TQ opportunities at this stage are numerous, and they include the presence, clarity, and succinctness of the study goals, scope, products, customers, conceptual models, and indicators. In addition, as seen in Table 9-1, quality goals or objectives should be set for selecting the "best compromise" sampling design and evidence of its advantages. Also, although the emphasis is on DQOs, they often become measurement quality objectives (MQOs) and thus, the inherent population variability is not considered.

The evaluation or monitoring of this stage appears to be the responsibility of both internal and external groups (e.g., the design team, the technical directors, and the EMAP Steering Committee on the inside and designated review panels and committees, such as the American Statistical Association Statistical Design Review Committee, on the outside). As indicated in Table 9-1, corrections can range from small revisions of the design report to scrapping of the entire report and starting over. However, the extreme action (scrapping) typically occurs only after the feasibility study stage. Finally, the improvements step is not much different from that mentioned in the conception stage. But the reaction time typically is much shorter in the design stage because the pressure is on to get to the field.

### 9.4.2.3 The Feasibility Study Stage

The feasibility stage is dedicated to the examination, exploration, and testing of the current proposed design (e.g., the EMAP-Arid Research Design). The activities include a benefit-cost assessment of the project, a list of expected deliverables, and some pilot testing of the proposed design.

The corresponding TQ activities (Table 9-1) should include the goals of properly estimating all benefits and costs, answering well-formulated questions by the pilot test, efficient pilot tests, and acquiring useful answers, as a result of the pilot test, the first time. Also, a number of standard QA documents must be completed (Table 9-2). The evaluation should include review of test results by

TABLE 9-2. QUALITY ASSURANCE DOCUMENTATION FOR EMAP PROJECTS

- EMAP Quality Assurance Program Plan (QAPP)
  - Describes the philosophy and QA policies of EMAP and provides guidance for designing and implementation QA programs within EMAP.
- EMAP-Arid Quality Assurance Project Plans (QAPP)
  - Detail the quality control and assessment activities that will be used in the EMAP-Arid QA program.
- Field Operations Manuals
  - Describe standard operating procedures for sample collection, handling, and processing; collection of field data; and data management activities (including QA and QC procedures). Also describes other logistical procedures (e.g., sample shipping, waste disposal, communications, and safety) conducted in the field.
- Analytical Methods Manuals
  - Describe standard operating procedures for sample analysis (including QA and QC procedures).
- Quality Assurance Project Plans from EMAP Support Groups
  - Landscape Characterization
  - Information Management
- Other QAPPs and appropriate QAPPs for other participating groups (agencies, laboratories, principal investigators).

the relevant scientists, the Technical Director, and ultimately the EMAP Steering Committee. Corrections typically would be focused on revising the design, and improvements could aim at better pilot testing of the design.

#### 9.4.2.4 The Implementation Stage

The implementation stage is focused on the field performance of the study guided by a detailed field operations plan and manual. This document specifies steps and procedures for each field activity including sampling preparation, sample taking, data recording, and field data checking. At the end of field efforts for each year, a year-end summary document of all field activities, by days, should be prepared for internal distribution and review.

The possible quality assistance or TQ activities could include the clear and concise goals from the field operations plan and manual, solid training of all field workers, 100 percent data completeness, and no deviations from the final study design (Table 9-1). The suggested evaluations include daily and weekly discussion of operations among the Technical Director and the associated scientists and frequent checking of equipment and calibration. Corrective actions could range from revisions of the work schedule or assignments to replacement of equipment or personnel. Improvements could include better planning, more complete contingency plans, and better training of field workers.

#### 9.4.2.5 The Analysis Stage

The analysis stage typically includes final data verification, data reduction, database construction, and performance of the exploratory and confirmatory analyses.

The quality assistance activities will focus on obtaining clean data (e.g., validated data) and appropriate and complete analyses. Thus, Table 9-1 presents goals of clean data, appropriate estimators, and proper basis for inference. Evaluation or monitoring could then be accomplished by data screening programs, close inspection of each analysis, and duplicate analyses, as in pharmaceutical research and development. Corrections could take the form of transforming data to better meet the statistical assumptions, utilization of more appropriate estimation or analyses, or more careful accounting for multiplicity (e.g., exploratory analyses of the data and hence little basis for formal inference). Improvements might focus on selection of better methods or analytical procedures and the proper separation of exploratory from confirmatory results.

#### 9.4.2.6 The Reporting Stage

This stage is concerned with the publication of the study design, results, conclusions, and data with information on the availability of the latter. The suggested TQ activities (Table 9-1) include the goals of clarity and completeness of reports, monitoring through internal review of all reports, corrective action by report revisions, and improving the reporting process.

#### 9.4.2.7 The Ex-Post Studies Stage

The final stage in a study, the often overlooked poststudy evaluation, is composed of reanalyses of the data, revisions of the conceptual model, and evaluations of study performance. The suggested TQ activities could be directed to uncovering additional results and evaluating the performance of the study against the original expectations.

## 9.5 CONCLUSION

Finally, it should be noted that the two management concepts of building quality into the product at the beginning and making the quality task everyone's business (e.g., Juran, 1945) are major characteristics of a TQ approach. For it is important to remember that one cannot inspect excellence into a product.

# 10.0 INFORMATION MANAGEMENT

The information collected and analyzed from during EMAP-Arid projects must be available for many types of users: the field crews; the EMAP-Arid researchers; other EMAP resource groups; local, state, and federal organizations; decision-makers; and academic institutions. The needs of these users, in terms of type and format of the information and response time, may be different for each group and at various times over the life of EMAP. The research needs of the EMAP program, in general, and of the arid ecosystem component may also change in the future. These specifications require that an information management system be created and used and that it be computerized, flexible in design, efficient, and responsive to the user needs. This section describes the strategy that will drive the EMAP-Arid Information Management System (EAIMS) and will satisfy the requirements of these users over time.

## 10.1 ROLE OF INFORMATION MANAGEMENT

Information management plays a significant role in a research project of this size and complexity. Its role is not defined by other aspects of the project (bottom-up approach). Instead it shares complementary roles with the research objectives and quality assurance in defining how the project will be implemented (top-down approach). Information management is the backbone of the research effort and ties the pieces together from data collection, through data analysis and trend assessment, to the use of the information by decision makers and the public.

EMAP-Information Management is working with the information managers for each resource group (RGIMs), the Office of Administration and Resources Management (OARM), and the Office of Information Resources Management (OIRM) to help each resource group define the requirements for information management and automated data processing (ADP) resources as early as possible in the research project. These requirements and the method for their implementation will provide timely, cost-effective, and accurate access to all data generated or utilized by the Program. The EMAP-Arid activities covered in this research strategy include, but are not be limited to, the following areas:

1. Project management, planning, and logistics;
2. Field activities, including sample collection, tracking, and processing;
3. Archiving, cataloging, retrieving, and analysis and dissemination of all pertinent data; and
4. Data base design and management.

The EMAP-Arid Information Management Group (EAIMG) will interact with the Technical Director, project managers, researchers, statisticians, and quality assurance and quality control (QA/QC) personnel to determine their requirements and to tailor the capabilities of the EAIMS to suit their needs. The EAIMG will also interact with other EMAP information management staff to address the needs of the project on the overall EMAP level.

### 10.1.1 Objectives of EMAP-Arid Information Management

The objectives of the EAIMG are to:

- Design an information management system that meets user requirements for information from within the EMAP-Arid resource group and within and outside of EMAP;
- Develop a flexible information system that can adapt to the changing needs of the program;
- Provide state-of-the-art information management technology within the guidelines of OIRM and OARM policy and the confines of available resources;
- Coordinate with EMAP-Arid information management and other RGIMs to share information management technology for the efficient use of EMAP resources;
- Facilitate the wide use of EMAP-Arid data;
- Ensure integration among users within EMAP and coordinate integration outside of EMAP; and
- Provide for the timely distribution of information.

### 10.1.2 Levels of Information Management Activities

Information management within EMAP will occur at three distinct levels. Although each level will function independently, their individual activities will be integrated to form a data management system that will encompass all ecosystem types and associated EMAP activities. These levels of organization are described below:

1. Regional--Each region (e.g., arid regions of the southwest) within a resource group;
2. National--Data for each resource group aggregated over all regions; and
3. Program wide--The overall EMAP, integrated among all resource groups (i.e., national evaluations across multiple resources).

## 10.2 USER REQUIREMENTS

### 10.2.1 Levels of Data

Data will be disseminated to users in the categories listed below:

- raw data--unmodified data collected in the field or analytical laboratory;
- verified data--raw data that have been reviewed for completeness and accuracy;
- validated data--verified data that have undergone validation analysis;
- enhanced data--validated data files that have missing values filled in using established procedures; and

- summarized data--data that have been analyzed and summarized for presenting in reports.

### 10.2.2 Users

The users of EMAP-Arid information can be described by the level of data processing required to meet their needs:

(1) The EMAP-Arid resource group members who are individuals and groups involved with daily field operations and tasked with the design, implementation (e.g., logistics and QA/QC personnel), and interpretation of data from the field sampling programs or involved with the assembly and interpretation of historical data, both synoptic and retrospective.

This group will require access to a comprehensive data set, on a real time basis, including:

- raw data files (from the field and laboratory),
- project management information,
- sample tracking,
- QA/QC reports,
- field logs,
- logistics,
- summary reports,
- maps,
- verified and validated data sets, and
- applicable historical data sets.

These individuals will work primarily with raw data that have not been verified or validated, but may also require access to the data required by the other levels of users.

(2) The EMAP-Arid group members who are involved in the overall program, but not necessarily involved with daily field operations. This category includes cooperating organizations (e.g., NPS and USFWS), GIS support personnel, program reviewers, and EPA Headquarters personnel.

This group will require access to summary information related to project management and logistics. It will require access to data that have been verified and validated. Group members will not require real-time access to the comprehensive data sets.

(3) EMAP individuals and cooperating organizations directly involved in design, implementation, and analyses for the overall program. These individuals include members of other ecosystem resource groups, members of the Integration and Assessment Resource Group, and personnel in other agencies directly involved in EMAP.

This group will require final summaries related to project management and logistics. These participants may require access to some verified and validated data files. They do not require real-time access, nor do they require access to a comprehensive data set. They need data in a context which can be integrated with data from other disciplines. Document summaries with interpretation and graphic outputs will be most useful.

(4) Other local, state, and Federal agencies involved in similar environmental monitoring programs, including the EPA regions, other EPA offices, state environmental agencies, academic institutions, and the scientific research community.

This group will require access to verified and validated data sets and to data summaries. Its members will also require access to an index of available EMAP and historical data. Documented summaries with interpretation and graphic displays will be most useful to this user group.

(5) Legislators, environmental managers, and the public.

This group will require access to summarized, interpretive data through published reports or specific retrievals.

### 10.2.3 Issues

#### 10.2.3.1 Data Integrity and Security

Data base security is essential to help ensure the integrity of the data. Direct access to the EAIMS will be restricted to users from Level 1 (Section 10.2.2). When data have been verified and added to the EMAP-Arid data base, these users will be able to access the data for numerous tasks (e.g., analysis, plotting, and transfer to other computers) from a read-only mode to prevent accidentally compromising the integrity of the data base. Changes that need to be made to the EAIMS after data verification will be handled through a procedure formalized for QA tracking purposes. Access to data will be limited or flagged where the quality of the data are suspect. Other measures that will be taken to maintain the integrity of the EAIMS include protection against mismanagement (accidental alteration or destruction), viruses, unauthorized access, and hardware and software failure. Written procedures will be defined and implemented to handle all aspects of data base management and security.

#### 10.2.3.2 Data Confidentiality

Other agencies may have data bases that EMAP-Arid needs to access. Agreements may be necessary, depending on the agency, that ensure the confidentiality of and controlled access to that data. Such an agreement would apply to use of the data base within or outside of the EAIMS. The EMAP-Arid resource group does not expect to be using much confidential data, but information about range sites from the BLM would be one example of such confidential data. Issues related to EMAP, EPA, and interagency policies on data confidentiality are currently being studied and addressed (Franson, 1990).

#### 10.2.3.3 Interactions with Other Information Systems

Coordination with agencies that may have or will be collecting information useful to EMAP-Arid should begin early in the EMAP-Arid research efforts. This early effort will enhance the sharing of limited funding resources, provide some preliminary information to the research effort, and result in better information products from both sides in the future.

If EMAP-Arid will be collecting information on certain indicators, but information on these indicators is available from an existing agency information system, it is important that an interface to that data be established to help the researchers assess variability in the indicators before new sampling begins and explain conditions deriving from the interpretive or diagnostic stage of the research efforts. EMAP-Arid resource group will also make an effort to discuss strategy and design

with other agencies to enhance their monitoring efforts and to provide a better interface with future designs of their information systems.

## 10.3 ARID ECOSYSTEM RESOURCE GROUP REQUIREMENTS

The information to be used by this resource group will be based on synoptic, retrospective, and traditional field-sampled data. Some of the data will be current, some will be historical; some will be collected by the EMAP-Arid resource group and some will come from other organizations. EMAP-Arid has three functional levels of operation: Resource Group Projects, the Resource Group Program, and the overall EMAP Program. In order to support the needs of these levels, the EAIMG will provide the following products and services:

Resource Group Projects:

- field data collection (e.g., data loggers, bar code readers, communications),
- field user support and training,
- sample tracking,
- analytical laboratory data collection,
- QA/QC analysis and reporting,
- data transfer from other agencies, and
- configuration management;

Resource Group Program:

- handling and analysis of remote sensing data,
- access to EAIMS,
- data base security,
- data confidentiality,
- data base management,
- documentation,
- data integration and analysis,
- presentation and reports,
- archiving and backup of data, data base, and supporting documentation,
- EAIMS user training and support, and
- communications;

Overall EMAP:

- data base transfer and access,
- integration of data from multiple resource groups,
- data base cataloging, and
- archiving and backup of data.

The EAIMS will be developed by addressing the requirements that users can currently identify. Its structure and management will be designed, given current technology, to allow for changes in future requirements without a significant redesign of the system. An overall design for the EAIMS and for the required management procedures will be developed before the field or

analytic activities begin. Actual implementation of the EAIMS will take place in stages. A beta-level information management function for a given activity will be available for use at the time of the pilot test. Refinements will be made to the beta-level function based on the results of its operation during the pilot study. This function will then be incorporated into a more permanent operational mode for the EAIMS. Currently, identified requirements for the EMAP-Arid IMS are described in the following subsections.

### 10.3.1 Data and Sample Collection, Transfer, and Tracking

This aspect of the EAIMS will be in place prior to initiating field activities. A sample data base will be developed that includes information relevant to each sampling site to ensure that samples and field data are collected at the proper sites. The EAIMG will monitor the transfer of data from field collection, through laboratory analyses, and to the EAIMS.

Field data will be entered directly into portable field data recorders. These data include direct field measurements (e.g., water conductivity) and site information (e.g., site identification number, latitude/longitude, state and county, and classification code). Procedures will be in place to automatically verify the data as described in Section 10.3.2. Field data will be downloaded from these recorders in established time frames for further verification before they are included in the EAIMS.

A sample number will be assigned by the field sampling coordinator and entered into the EAIMS prior to the sampling event. All sample labels will be produced prior to the sampling event. This procedure will ensure that all samples are properly identified and tracked.

When samples are transferred to a laboratory, a record of the exchange will be entered into the EAIMS. A manifest of all samples collected will be produced and delivered with the samples. A central log in the EAIMS containing the identity of each sample will track the status of all analyses and results for a given sample. A flag will automatically be set when all the expected analyses for a sample are completed. Bar codes on sample and shipping labels will be used where possible to facilitate sample tracking and to reduce transcription errors. Laboratory data will be submitted to the EAIMG in established time frames for QA processing before they are included in the EAIMS.

The EAIMS will keep track of the status of records received, processed, and still outstanding for each EMAP-Arid sampling site. The addition of verified analytical results to the EAIMS will indicate the completion of sampling and laboratory analysis for an arid ecosystem site.

### 10.3.2 Quality Assurance

Quality assurance for research data bases includes procedures to ensure that data entered into the system are of high quality. A program of the magnitude of EMAP requires utmost confidence in the validity and integrity of the final data bases.

Ensuring quality data begins with identifying sources of error in the data base system. There are essentially two general types of errors: (1) incorrect information; and (2) missing, incomplete, or nonretrievable information (Kanciruk et al., 1986). Examples of errors of the first type include

typographical errors, incorrect plant species identification, and inaccurate instrument calibration. Although all errors cannot be completely eliminated through data management protocols, the potential for including incorrect information in the data base can be reduced. The EMAP results will not be accepted without the backing of appropriate quality levels.

Where appropriate, data will be directly entered into portable data recorders. The principal QA advantage of direct data entry is that data are computer scanned as they are entered for correct type and range to prevent typographical errors. Corrections can be made immediately on site. The EMAP-Arid data dictionary will contain ranges of acceptable values for each variable measured. Data that are suspect based on these ranges, but are accepted by the computer, will be automatically assigned a data quality flag. The flagged data will be reviewed at a later date on a case-by-case basis. These data will then also be used to evaluate the appropriateness of the ranges used in the data dictionary. Sample labels will include bar codes to facilitate accurate sample number entry and identification in the field.

The second type of error is the omission of important information relating to a legitimate data value (Kanciruk et al., 1986). Such pieces of information, called data qualifiers, assist in the correct interpretation of data values. Standard operating procedures will document the use of field computer systems and portable data recorders for entering field data. Again the use of direct data entry into portable recorders provides a QA advantage. Pertinent information that has not been entered can prevent entry of information for the next sample. Data qualifier flags can be assigned based on the nature of the information. For example, flags will be assigned when data were gathered without following the proper protocols. Default flags may be assigned based on known data (e.g., sensor calibration). Qualifying information will be anticipated and a structured system for recording and retrieval of this information will be developed. The system will be designed with flexibility to allow for the inclusion of unanticipated qualifiers identified and added in the field.

Errors may arise in the transmission of data sets. QA protocols will be developed to ensure proper data transmission. These data files may be verified by duplicating the transmission and comparing the transmitted files.

Verification reports will be developed that summarize the data and highlight the flagged and qualified data. The reports will be reviewed by personnel with adequate specific knowledge to allow them to make decisions about whether to accept, modify, additionally flag, or reject data values (Kanciruk et al., 1986). Whereas verification examines individual data values, validation evaluates the entire data set using selected graphical and statistical techniques. Validation of a data set is the next step in the QA process to ensure that the data are acceptable for data summaries or analyses used to answer EMAP questions or for transfer to any other user. Figure 10-1 illustrates the data flow through this process.

Quality assurance and information management staff members will work closely to develop an information management system that prevents corruption of data throughout all phases of activities. QA measures will be applied during field data collection, data transfer, sample tracking, data entry and verification, data validation, data analyses, archiving and backup, and configuration management.

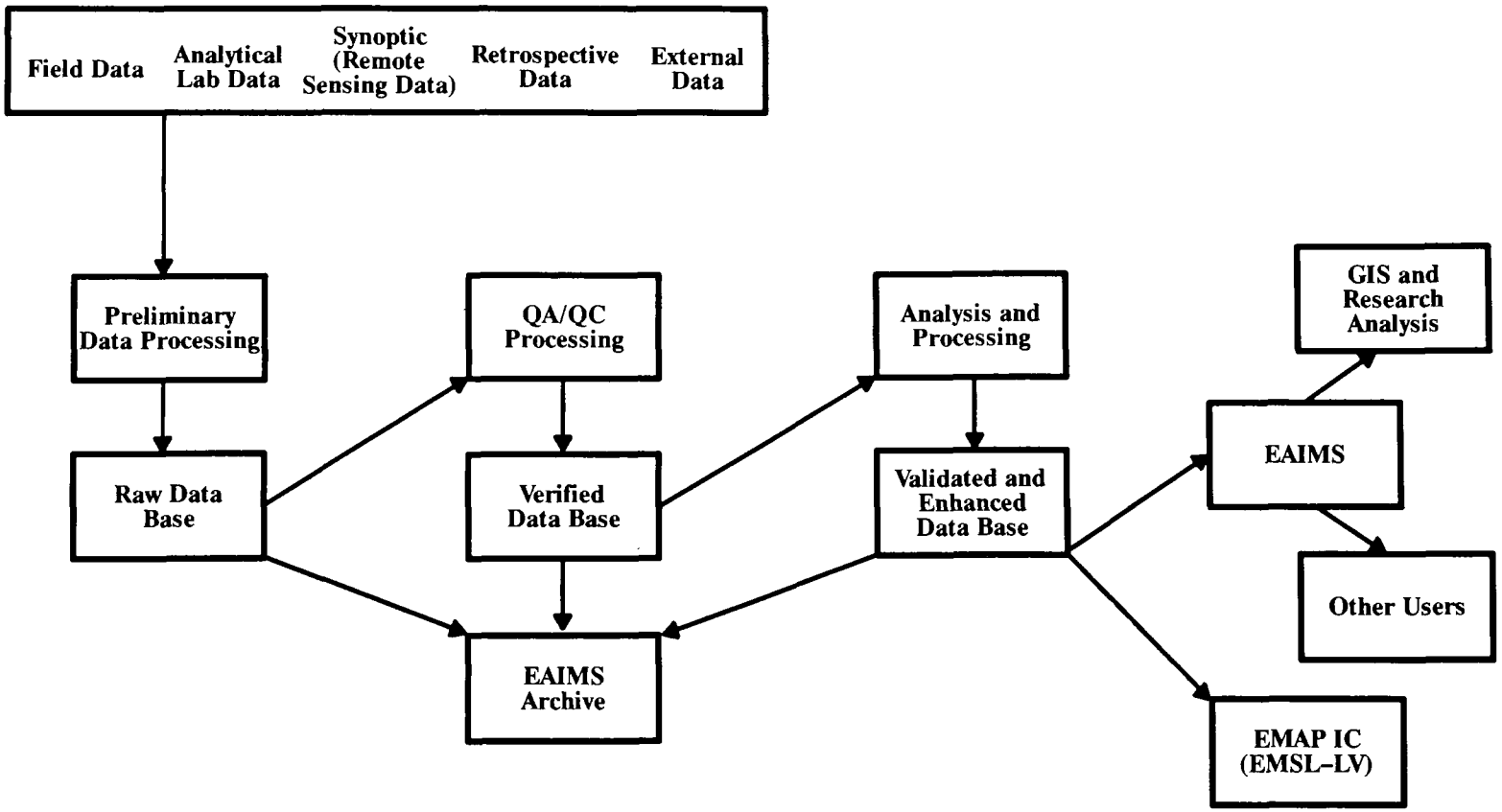



Figure 10-1. EMAP-Arid information data and flow.

### 10.3.3 Data Management, Analysis, and Reporting

The EAIMS will be developed and maintained on the network of computers resident at the Desert Research Institute (DRI) facilities. The data base management system (DBMS) for EMAP-Arid will be ACCELL/UNIFY 2000, which is currently available on the DRI system. At the point where an EMAP relational DBMS is available on the computers at the EPA Laboratory in Las Vegas, Nevada (EMSL-LV), an assessment and decision will be made about converting the EAIMS to that system. Until that time, the design of the EAIMS will be made as consistent as possible with what would be expected at EMSL-LV with such a DBMS. The design of the EAIMS will also take into account any design decisions made for an EMAP data base at EMSL-LV.

Figure 10-1 describes the information and data flow for the EAIMS. Data exchange interfaces will be developed between the DBMS, geographical information systems, and other tools available for data analysis. The Statistical Analysis System (SAS) is an industry standard statistical package capable of performing both simple and complex data analysis and modeling. Since SAS is available on the EMSL-LV system, it will serve as one of the statistical tools to be used by the EMAP-Arid researchers. Other tools will include software that will be available for the PCs or for the networked computers at DRI.

A critical requirement of the EMAP-Arid resource group is the ability to generate maps and perform geographically based analyses. Spatial analyses will be prepared on a geographical information system using ARC-INFO software. The EAIMG will work with other information management groups within EMAP and with other agencies to develop standards and coverages for GIS applications. Standards will be developed for data accuracy, naming conventions, and documentation and archiving of completed maps.

### 10.3.4 Data Documentation, Access, and Archival

All data sets received by the EAIMG will be converted into ASCII files and stored on tape at specified points in the process to add them to the EAIMS archive (Figure 10-1). Complete documentation of all data sets stored on these tapes or in the EAIMS is of paramount importance. A Data Set Index (DSI) will be the principal source of information for these data sets. It will be contained within the EAIMS and will provide users with important information about the contents of each data set (e.g., variables measured, site locations). A Central Data Dictionary (CDD) will document information on standards that have been developed for data sets which are generated by EMAP and for external data sets which have been processed for incorporation into the EMAP information system. These standards will include field names, formats, documentation, acceptable ranges, and codes. A data base backup system will be developed for complete and rapid recovery of all data and documentation in the event of a hardware or software system failure.

Access to the EAIMS for EMAP-Arid researchers will be available through the DRI network. Access authorization will be established under the direction of the Technical Director and in conjunction with the DRI computer systems managers. Where data are deemed confidential, access will be limited. If the quality of the data are suspect, access may be limited. Data sets that have served their purpose (e.g., quality assurance validation files) or which are not likely to be used

(e.g., files containing non-EMAP data that do not meet QA standards) will be maintained on tape and not in the EAIMS. Information about these data sets will be included in the DSI.

### 10.3.5 Communications Support

Research and information management efforts for the EMAP-Arid resource group will be performed on PCs, the DRI network of SUN computers, portable data recorders, and the VAX at EMSL-LV, with most of the effort focused on the first two. Connections from the DRI network to EMSL-LV are currently available through dial-up communications. The current path of communications is shown in Figure 10-2. This current connection allows EMAP-Arid staff to have access to SAS, the EMAP IMS, other analytical tools, and mail services to other EMAP participants. Other transfers of data may be facilitated by use of magnetic disks, magnetic tapes, and optical disks. If necessary, an additional communications system and procedures will be set up to allow field crews to transfer information from and to or to have access to the EAIMS.

### 10.3.6 Existing Data

Existing data bases constitute an important source of information for developing the indicators, designing the sampling program, and interpreting the data (Section 5). Data bases identified as pertinent to the EMAP-Arid monitoring program will be included in the DSI (Section 10.3.3) with descriptive information for each entry. Data sets that are frequently used will be converted and added to the EAIMS with an annotation of the origin of the data.

## 10.4 EMAP-ARID INFORMATION MANAGEMENT CENTER

Data processing activities for the EMAP-Arid resource group will take place primarily in the EMAP-Arid Information Management Center (EAIMC) at the DRI facilities as described in sections 10.3.3 and 10.3.4. In time, a secondary center for these activities will be the Computing Center at EMSL-LV. The EAIMC staff will be responsible for:

- designing and implementing an information management system which will meet the needs of the users of EMAP-Arid ecosystems data;
- interfacing the EMAP-Arid information management effort with the EMAP central information management effort;
- interfacing the EMAP-Arid information management effort with the efforts of other EMAP resource groups;
- establishing information management standards and procedures for EMAP-Arid activities;
- maintaining a comprehensive EMAP-Arid data inventory, data dictionary, and sample tracking system;
- maintaining and disseminating summary information;
- supporting data processing requirements of the field crews;

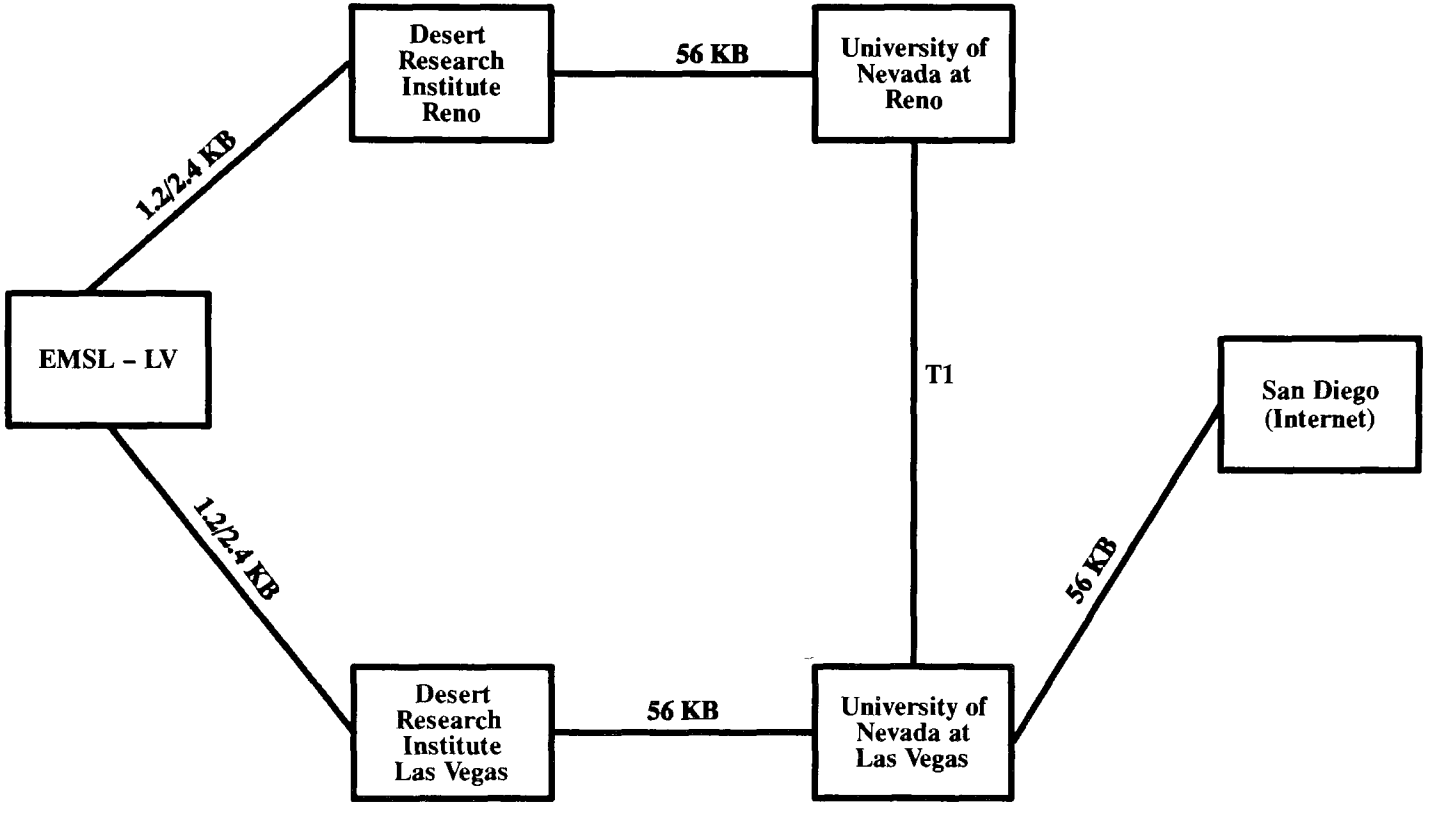



Figure 10-2. EMAP-Arid DRI connections to EMSL-LV.

- coordinating communications support; and
- establishing liaisons with appropriate data management personnel in other agencies to arrange for cooperative information exchange.

When EMAP-Arid is fully implemented, the EAIMC will be supported by professional staff with responsibilities as indicated below.

**EMAP-Arid Information Manager**: Senior information management staff member who directs the EAIMC and is responsible for planning, coordinating, and facilitating information management activities. The Information Manager reports to the EMAP-Arid Technical Director and is responsible for ensuring that data and information collected are properly captured, stored, and transmitted. As an executive member of the IMC, the Information Manager serves as a liaison between EMAP-Arid and the Information Management Director, representing the needs of the Arid Ecosystems Resource Group.

**Data Base Administrator**: Responsible for assembling, documenting, and administering the EAIMS described in the EMAP-Arid information management documents and for helping coordinate the tasks of the following staff members.

**Geographical Information System Programmer**: Responsible for implementing and maintaining the GIS portion of the EMAP-Arid information management requirements and for interactions with the EMAP GIS support staff at EMSL-LV.

**Programmer**: Responsible for development of programs to manage data collection, tracking, and dissemination including data entry screen design, reports, sample tracking, and analysis.

**Data Clerk/Librarian**: Responsible for documenting and archiving EMAP-Arid data sets, documenting and archiving other pertinent data sets received by the EMAP-Arid resource group, preparing data for transfer by tape or diskette to other agencies, and preparing and reviewing routine reports on data QA and day-to-day processing.

**Technical Support**: Responsible for the installation and maintenance of all hardware, software, and communications.

The EMAP Information Management Program support structure includes the following:

**EMAP Information Management Technical Director**: Responsible for the development, implementation, and administration of the overall EMAP Information Management Program.

**EMAP Information Management Committee**: A coordination and advisory committee responsible for providing insight, recommendations, and guidance to the Information Management Director on the information management requirements and activities for EMAP.

**EPA OIRM and OARM**: EMAP personnel will work with OIRM and OARM to ensure that the EMAP Information Management Program is properly planned and coordinated with the Agency program and that EMAP resource requirements are conveyed through the appropriate channels.

## 10.5 IMPLEMENTATION STAGES

This section summarizes the phased approach to implementation of the EMAP-Arid Information Management Program for FY91 through FY96. The EAIMC will be considered to be in operational status when basic information management systems are in place and initial data collection activities have begun. The plans and operations are subject to change as the program develops.

Activities for FY91 will focus on staffing of the EAIMC and start-up of the EAIMS. EMAP-Arid will make use of existing resources (staff, hardware, and software) to the extent possible, and will only acquire additional resources as necessary.

The EMAP-Arid Information Manager will assess user needs and produce plans, as required, for the EAIMC activities and will begin design of the EAIMS. Initial prototypes of the field system, communications, and sample tracking data bases will be developed to be ready for the pilot studies in 1992. Prototype data bases for the field and analytical activities for these pilots will also be created. These data bases will be used in preliminary data validation and verification. External data will be integrated with EMAP-Arid data as required.

The activities for FY92 will expand the areas of development and operation. The prototypes developed in 1991 will be tested through the pilot studies and modified as necessary. This procedure will allow for a more concrete implementation of the information management procedures and the EAIMS. A core EAIMC staff will be in operation. External data will be integrated with EMAP-Arid data and analyses will be initiated. Procedures for the inventory and archival of data sets in the EAIMS will be defined and implemented.

In FY93, the EAIMC will expand human and hardware and software resources as required. The EAIMS will be fully operational. Extensive use will be made of external data.

In FY94 through FY96, the EAIMC will continue to enhance the core systems as well as the design of the EAIMS according to the needs of the resource group. More advanced applications will be implemented as required.

# 11.0 DATA ANALYSIS

## 11.1 APPROACH TO DATA ANALYSIS

The EMAP-Arid study is designed to provide assessments of ecosystem status and trends on a regional scale. Arid ecosystems are known to respond dynamically to short-term climatic fluctuations, such as variations in annual precipitation and temperature. Therefore, the detection of trends and ecosystem impacts caused by stressors requires the integration of meteorological data. In order to accomplish this need, three primary data bases will be collected and analyzed: (1) regional and finer scale synoptic satellite images (e.g., SPOT, AVHRR); (2) hexagon-based measurements of indicators and stressors; and (3) meteorological data. Additionally, surface-interpolated data layers will also be used in assessments. This will be the primary source of geographic data on air pollution and deposition. These composites are similar to climate information and are considered as the same type of source. In essence, the scientists will be working with time series and numerically removing or controlling data for climatic influences in assessing ecosystem status and trends. The techniques for performing this style of transfer function analysis have already been developed under the rubric of the general linear model (GLM).

The linkage of the three primary data bases is essential to conducting analyses that will achieve EMAP objectives. The three general types of data bases are described below.

1) Synoptic satellite data available from the AVHRR instrument extends back to 1978. A raster data base depicting vegetation vigor (a vegetation index) and surface albedo will be constructed covering the period 1979 to present. The AVHRR data will be geometrically corrected in order to register it to the map base selected by EMAP. The EMAP-Arid group proposes to use one AVHRR scene every month for the period from 1979 to 1989. Beginning in 1990, we propose to add one scene every two weeks. This procedure will produce 186 scenes covering a 15-year time span to the point of EMAP-Arid implementation (1993). This record will be updated with the addition of new satellite data approximately every two weeks during the period of EMAP-Arid field operation.

2) Ground-based sampling of indicators and stressors will be performed in EMAP Tier II hexagons. Subsamples of Landsat Thematic Mapper imagery will be obtained for use in hexagon-level landscape measurements and for potential calibration with the ground-based measurements. These data records will begin to be collected in limited areas as early as 1991 with the inception of a pilot project. With full implementation (1995), the data record for ground-based indicators will be initiated at all Tier II hexagons. A refined list of indicators will be determined via additional workshops.

3) Meteorological data from the existing national system will be utilized in the analysis of the satellite data and ground-based indicators. The meteorological data for factors such as temperature, precipitation, and the Palmer Drought Severity Index (PDSI) will be contoured to

produce raster images, registered to the selected map base. The contouring will incorporate digital elevation data (from the USGS) in the development of transfer functions for use in interpolating values across the raster grid. Other data layers such as air pollution and deposition will be of this type.

Historical Climate Network data from 1895 to the present are available from the Department of Energy, Oak Ridge National Laboratory. These data have been subjected to extensive evaluation and corrections to ensure that the information is of the highest quality. Variables include monthly minimum, maximum, and mean temperature, total monthly precipitation, and the Palmer Drought Severity Index (PDSI).

The PDSI, described fully by Palmer (1965), will be used as an index of meteorological drought, as opposed to a specific biological or hydrological measure. Thus, drought will be evaluated as a meteorological anomaly characterized by a prolonged abnormal moisture deficiency, with its severity depending on the duration and magnitude of the abnormality.

The definition of drought used in this study is taken from Palmer (1965:3). He defines a drought period as "an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply. Further, the severity of drought may be considered as being a function of both the duration and magnitude of the moisture deficiency."

The empirical method adopted by Palmer for dealing with the availability of water from the soil is based on dividing the soil into two layers. The upper surface layer is assumed to retain 1 inch of moisture at field capacity. Evapotranspiration is assumed to take place from this surface layer until all the available moisture in it is removed. Only then is moisture removed from the underlying layer. It is further assumed that no recharge takes place in the underlying layer until the surface layer is brought to field capacity. Available water capacity in the lower layer depends on the depth of the effective root zone and the soil characteristics of the area. Water loss from the underlying layer depends on initial moisture content, the computed potential evapotranspiration, and the available water capacity of both layers. It is also assumed that no runoff occurs until both layers reach field capacity.

Estimates of evapotranspiration require a realistic value for the available water capacity of the soils in an area. This varies widely from one soil to another, but Palmer surmises no more so than microclimate and suggests using a value more or less representative of the area in general. The PDSI class intervals are given in Table 11-1.

The EMAP-Arid meteorological station grid will be comprised of the Historical Climate Network (HCN) data supplemented by data from operating climate stations in areas with sparse HCN coverage. When necessary the PDSI will be calculated on a monthly basis for the supplementary stations where it is not routinely calculated. Existing software for PDSI hydrological accounting computations has been extensively tested.

These three data types need to be linked into a single display and analysis system. Results depicting the status and trends in the various ecosystem elements need to be summarized and

TABLE 11-1. PALMER DROUGHT SEVERITY INDEX CLASS INTERVALS

| PDSI VALUE | CLASS |
|---|---|
| ≥ 4.00 | Extremely wet |
| 3.00 - 3.99 | Very wet |
| 2.00 - 2.99 | Moderately wet |
| 1.00 - 1.99 | Slightly wet |
| 0.50 - 0.99 | Incipient wet spell |
| 0.49 - -0.49 | Near normal |
| -0.50 - -0.99 | Incipient drought |
| -1.00 - -1.99 | Mild drought |
| -2.00 - -2.99 | Moderate drought |
| -3.00 - -3.99 | Severe drought |
| ≤ -4.00 | Extreme drought |

reported using several designated geographic boundary patterns. Examples of geographic boundary options include state, congressional district, National Forest, or ecological unit (e.g., grasslands of central California).

To our knowledge, no software system has been developed to accomplish these objectives in an effective manner. It will be extremely valuable to have a data analysis system which is optimized for the visual display and analysis of the three data bases. The EMAP-Arid resource group proposes to develop the required software system. The functioning of the software system is described in the following section.

## 11.2 TEMPORAL IMAGE PROCESSING SYSTEM

Traditional image processing systems are optimized for the display and analysis of single dates of imagery. The utilization of such systems for performing analyses of multiple dates of imagery involve subtracting one date of imagery from the other to produce a change image. For projects involving the analysis of two or three dates of imagery, such a system is adequate. To perform an analysis of a long series of images (up to hundreds of dates) a new software system will be required. The EMAP-Arid resource group proposes to develop such a system, optimized to perform the functions required by EMAP. We call this software the Temporal Image Processing System (TEMPIST). A prototype of this software is already under development as a collaborative project between DRI and WRJ Software Services.

TEMPIST is designed to provide a display and analysis tool for long-term time series of images and ancillary data. The basic display screen layout is shown in Figure 11-1. An example formulated with hypothetical data is presented in Figure11- 2. The system will provide a display

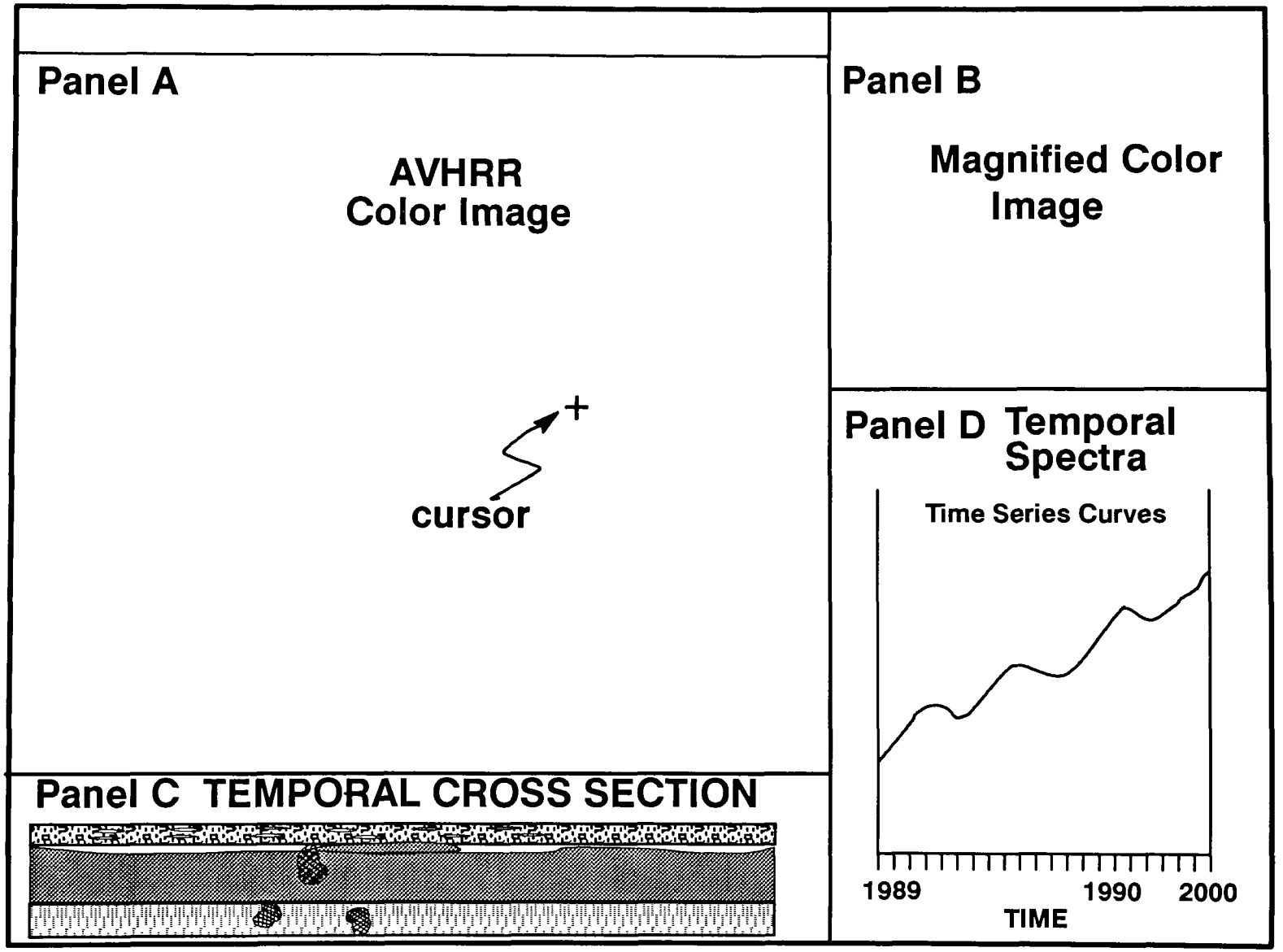



Figure 11-1. The basic display screen layout for the Temporal Image Processing System.

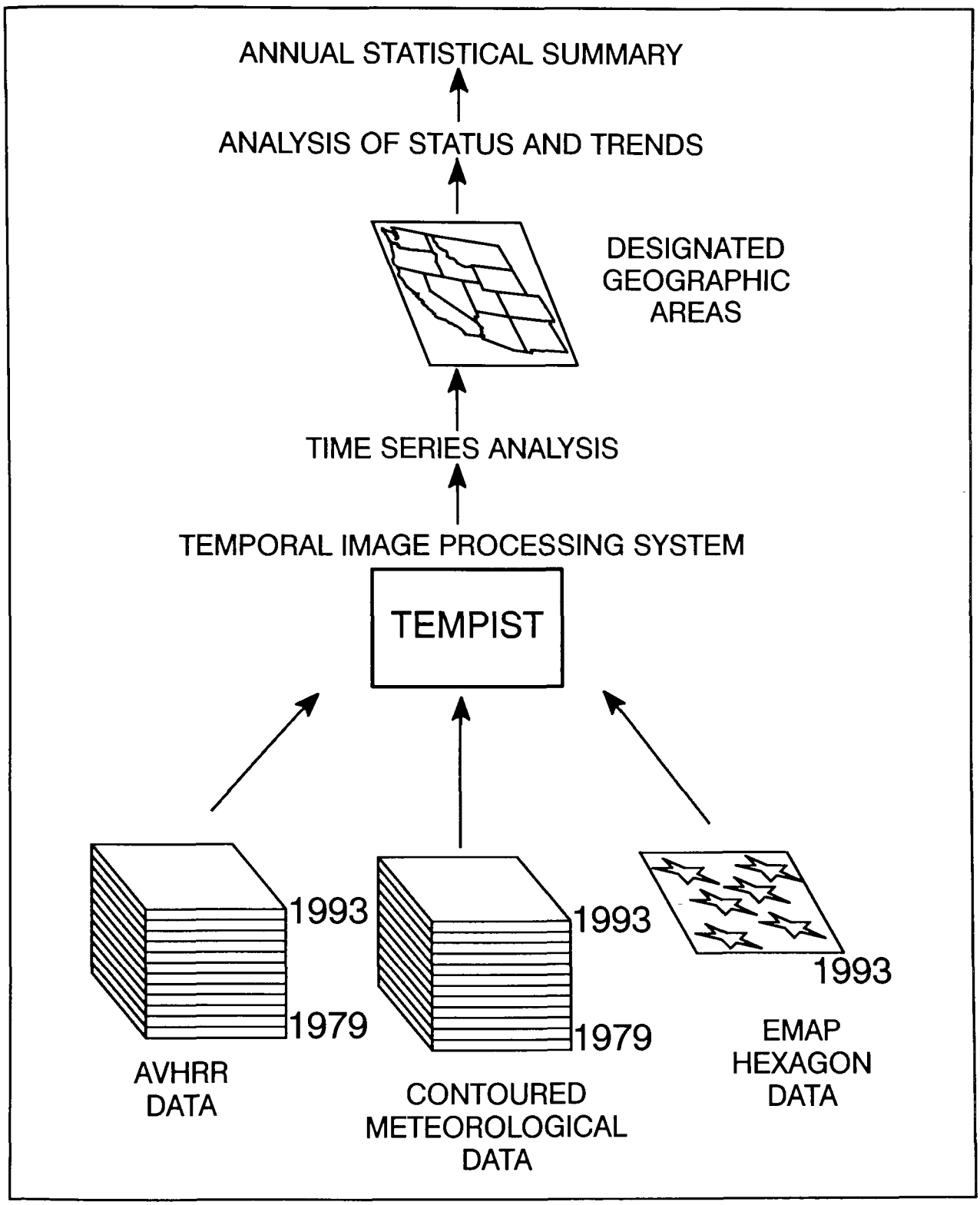



Figure 11-2. Conceptual model of the Temporal Image Processing System analysis.

and analysis link between the three primary data bases. To operate, the three data bases must be spatially registered to a common geographic base. This spatial registration will be performed outside of TEMPIST, using the functions available on conventional image processing systems.

The TEMPIST workstation will consist of a microcomputer with a large hard disk (more than 500 megabytes), and an 8-bit color monitor (1024 by 1024 resolution) for displaying data from the three databases. The initial software system will be capable of displaying and processing 300 data layers. These layers could be 300 AVHRR vegetation index images covering a 20-year period. The full databases will be stored on the hard disk. At any one instant TEMPIST will have a single line of data from each data base in memory (RAM). The following is a description of the four panels present on the TEMPIST display.

**Panel A:** Color Image. Size: 700 by 700 pixels. This panel will be used to display a color image of the work area. It is anticipated that this panel will be used most frequently to display a color image from a single AVHRR scene. However, it will be possible to specify any three image layers from the data bases for display as a color image in this panel. Using AVHRR Global Area Coverage (4-km pixels) this panel would provide coverage over an area 2,800 by 2,800 km, covering the entire western United States. With the AVHRR Local Area Coverage (1.1-km pixels), the screen would cover an area 770 by 770 km. The locations of EMAP sampling hexagons will be displayed in the graphics overlay plane. In the normal mode of operation the cursor is confined to this panel. The cursor location in panel A provides the required locational data for the displays in the other three panels.

**Panel B:** Magnified Color Image. Size: 300 by 300 pixels. This panel will be a magnified version (3 times or more) of the color image, centered on the cursor location within panel A.

**Panel C:** Cross Section. 700 by 300 pixels. This panel provides a cross section of the data bases at the line of the cursor located in panel A. The most recent data is at the top of the cross section and the oldest data is at the bottom of the cross section. This panel can be interactively switched to provide cross sections of the AVHRR vegetation index data, AVHRR albedo data, or the meteorological data.

**Panel D:** Time Series Line-plots. The time series of data from the pixel designated by the cursor on panel A will be plotted here. The X axis will be time. The default curve to be displayed will be the time series from the data base selected for the cross section (panel C). Time series curves from the other data bases can be added to the display. In addition, when the cursor is located on an EMAP hexagon, it will be possible to display the time series curves for the various indicators or stressors being measured at that hexagon.

There are two output modes from the above described display. The entire screen (panels A through D) can be written to a file for printing on film or paper. The second output form is a digital file for the time series curves present in panel D. This output from panel D will be used to develop transfer functions via the time series analysis module (TSAM) described below.

### 11.2.1 Time Series Analysis Module

Three possible scenarios for calibrating AVHRR and long-term meteorological data, such as the PDSI, depend on whether the imagery is regarded as the dependent or independent variable in a transfer function analysis.

In the first situation, the digital number (0 - 255) of each pixel in the image provides values of the dependent variable and meteorological data obtained at weather stations provide values for the independent variable. The locations of weather stations have a resolution of one pixel. The set of values for the dependent variable is much larger than the set of values for the independent variable because each 1 by 1-km pixel has a digital number, but meteorological data are only available from a relatively sparse network of weather stations.

Pixel digital numbers at meteorological station locations from one to many images that represent an array of meteorological conditions (dry to mesic) are calibrated with the temporally equivalent meteorological data field(s). If the calibration equation generated with the training data set verifies satisfactorily with a test data set, it can be applied to the long-time series of meteorological data to retrodict a long-term set of synthetic images. The merit of this approach is that long-term estimates of central tendency and variability can be obtained for pixels or groups of pixels in the vicinity of meteorological stations. Knowledge of the moments of the probability distribution of pixel values at given locations allows an immediate probabilistic evaluation of newly acquired images. For example, it allows the determination of locations with significant (e.g., alpha = 0.05) departures above or below the mean and, similarly, of areas with no major changes.

The second context in which the imagery provides values of the dependent variable and the meteorological data provide values of the independent data offers a methodological approach to control for, or numerically remove, the effects of climate on images from two or more different time periods. In this situation, separate calibration equations are created between imagery and meteorological data for each time period. The sets of imagery residuals remaining after each calibration represent the original image with the effects of climate removed. The residual images can then be subjected to change analyses to determine the effects of other stressors, such as grazing, fire, off-road vehicle use, and various land management practices.

In the third type of calibration between imagery and meteorological data, the imagery digital numbers comprise the values of the independent variable and the meteorological data are the dependent variable. If a viable calibration between the two data sets can be achieved, the equation can be applied to the pixel dn's to generalize meteorological conditions over the complete scene at very high resolution (1 by 1 km). This type of information is extremely valuable in watershed studies and wildfire management.

The calibration equations defining relationships between imagery and meteorological data are based on the general linear model. In the simplest situation one dependent variable is regressed against one independent variable, while in more complex transfer function analyses a set of dependent variables is calibrated with a set of independent variables. In situations where a set of dependent or independent variables is available some type of data reduction operation,

usually principal components analysis, must be performed. Creating a set of orthogonalized (uncorrelated) variables from a set of correlated variables is an efficient procedure for removing the complicating effects of multicollinearity in linear model analyses. It is also scientifically parsimonious because a smaller set of principal components normally can be used to represent the variability within a data set. In addition, this procedure allows transfer functions to be based on more degrees of freedom than equations utilizing the original set of correlated variables.

### 11.2.2 Designated Geographic Area Module (DGAM)

After performing the numerical analysis to remove short-term climatic influences from the data, the next step towards the final output will be to integrate the data within designated geographic boundaries by using a designated geographic area module (DGAM). These designated boundary areas will be the reporting units from EMAP-Arid. It is anticipated that the data will be segmented in a variety of ways, for example, by:

- EPA Regions
- Congressional Districts
- States
- Counties
- National Forests
- BLM Land Management Units
- Ecological Units
- Physiographic Provinces

The outlines for these various geographic units will be stored in TEMPIST and used like "cookie cutters" to retrieve data for use in the analysis of status and trends. However, the field-based probability sampling will represent particular predesignated Tier 1 resources. This makes it difficult to reallocate (poststratify) to some of these units and to integrate point data that represent predefined units.

EMAP-Arid has proposed a tiered sampling design, with most of the measurements at the top tier made via remote sensing techniques and most of the measurements at the bottom of the tier obtained with intense field-based sampling procedures. It will be necessary to integrate observations made on nominal, ordinal, interval, and interval-ratio scales of measurement within and among tiers of the sampling design. Because the basic data and measurement scales constitute the building blocks of more sophisticated numerical operations, they should be thoroughly investigated at the earliest stages of analysis.

The most cogent reason for a thorough evaluation of the raw data is that the most frequently used statistical techniques are parametric, that is, they rely on assumptions about the distributions of the variables being analyzed. Single variables are usually assumed to be normally

distributed, pairs of variables are assumed to have bivariate normal distributions, and sets of variables are expected to have multivariate normal distributions. In our analytical strategy variables will be tested for normality in order to determine whether additional statistical tests should be performed with parametric or nonparametric techniques. Nonparametric techniques, in contrast to the parametric alternatives, do not require as rigorous distributional assumptions.

Because it is virtually impossible, and unnecessary, to obtain all of the information contained in the distribution of a variable, several descriptive properties that summarize its most important attributes must suffice. The most frequently used types of information pertain to a distribution's location and dispersion. Measures of location include the mean, median and mode, and various quartiles, while the most common measure of dispersion is the variance (or standard deviation). The other two moments that we will be concerned with are skewness and kurtosis.

The EMAP-Arid resource group will use cumulative distribution functions (CDFs) to analyze the status and trends of ecosystems within designated geographic areas. CDFs were chosen because they encapsulate the central tendency (e.g., mean, median) and extreme values for all data categories in an easily interpreted graphical format. For example, consider CDFs of the Palmer Drought Severity Index for normal, dry, and mesic years. Figure 11-3 depicts a simulated CDF for 1,000 PDSI locations for a particular year, using a mean of 0 and a standard deviation of 1 (refer to Table 11-1 for the PDSI class intervals). Figure 11-4 depicts a simulated CDF for the same number of locations using a mean of 2.5 and a standard deviation of 0.7. Finally, Figure 11-5 shows a simulated CDF for the same locations, but for a dry year, with a mean of -3.0 and a standard deviation of 0.5. These CDFs graphically capture the main features of the distributions for each year's drought conditions over space.

Of concern are the types of probability distributions assumed for each variable because those distributions partially determine which statistical tests can be used to analyze and visually portray the variables. While parametric tests are generally more powerful and more widely applied than the nonparametric alternatives, their assumptions may not always be met, especially with small sample sizes. For these reasons, especially for graphical summaries of single variables, exploratory data analysis (EDA) techniques will be employed.

The EDA techniques emphasize the use of visual displays and robust and resilient numerical summaries. The basic philosophy underlying EDA is one of searching a data set using a number of alternative techniques in order to maximize what can be learned. In contrast to a more traditional statistical approach, EDA does not impose a hypothetical pattern on the data; it lets the pattern emerge from the data. It also emphasizes the re-expression of variables that are not normally distributed or might be expressed better on a different scale. The EDA, like more traditional parametric approaches, places a premium on analysis of single variables in an attempt to understand the central tendency, variability, and shape of the distribution of each variable. Techniques employed include the stem-and-leaf display, box-and-whisker plots, and resistant number summaries. Resistance means that the measures are not highly sensitive to departures from normality, and thus they are suitable indicators of location and dispersion for a wide variety of distributions. In addition to numeric summaries for single variables, box-and-whisker plots will be used to portray the major characteristics of a distribution. These plots have a higher information

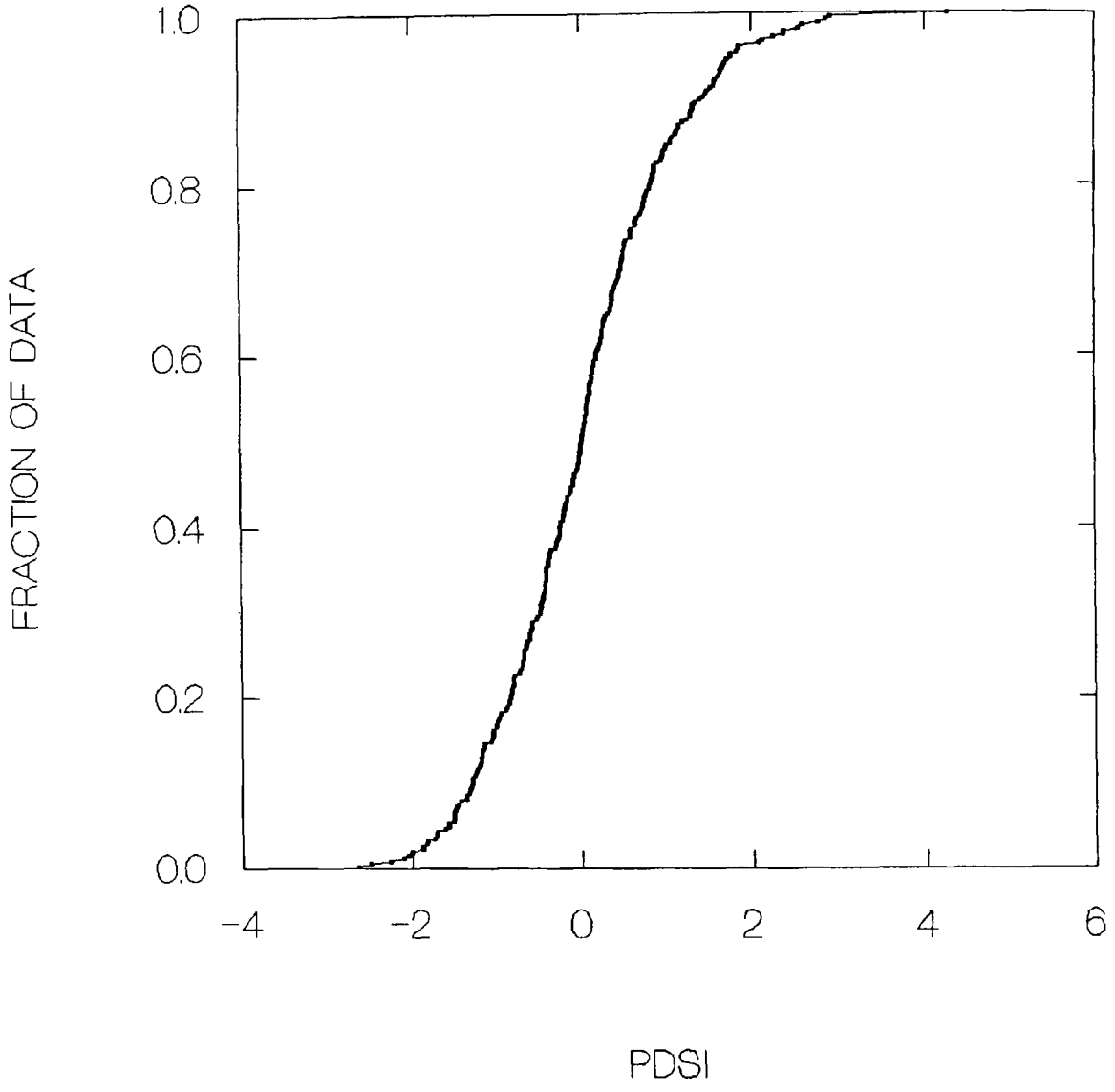



Figure 11-3. Cumulative distribution function for PDSI data.

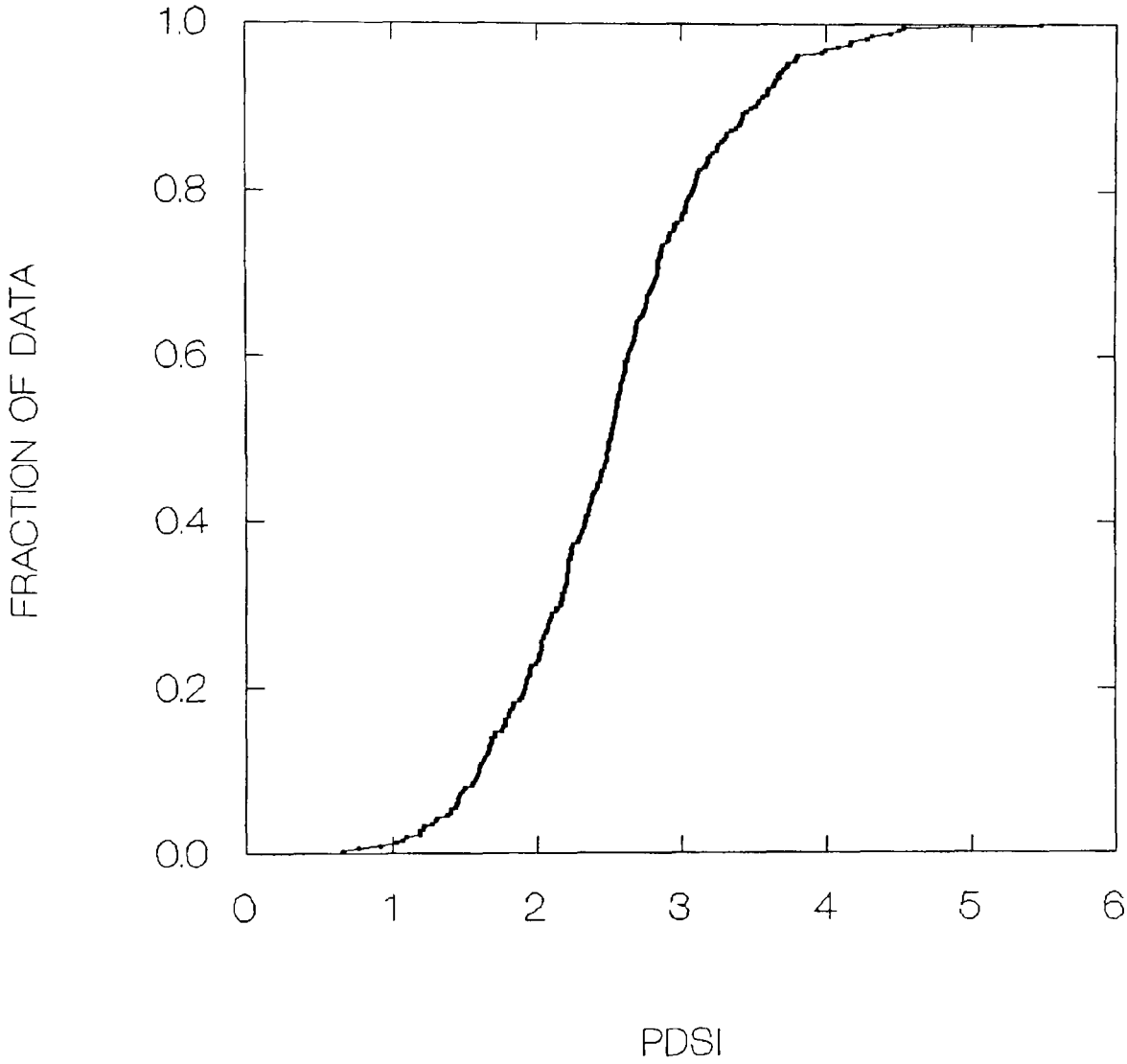



Figure 11-4. Cumulative distribution function for PDSI data.

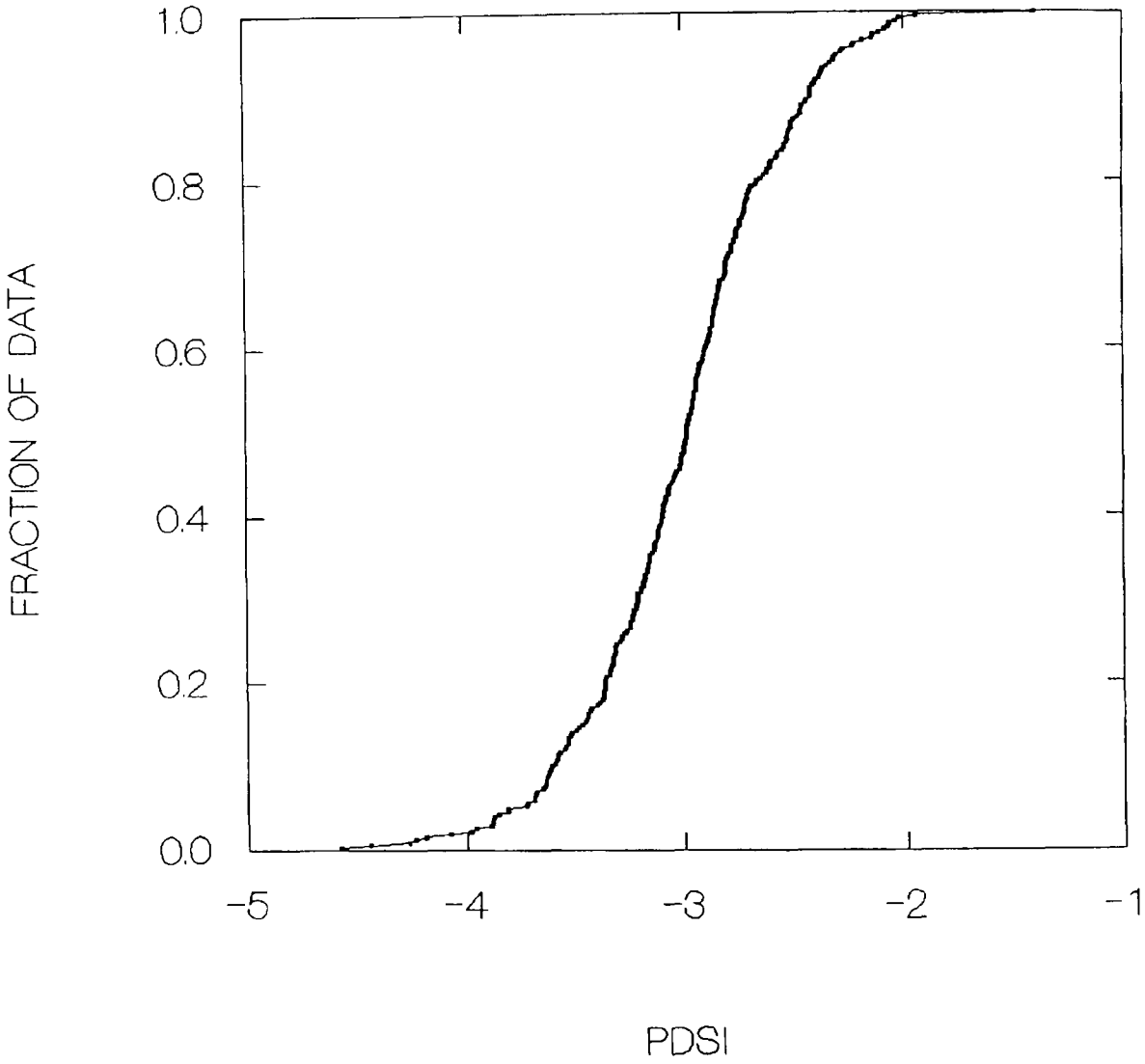



Figure 11-5. Cumulative distribution function for PDSI data.

content than simple mean and standard deviation limits and provide detail when it is often most needed--i.e., when the tails of a distribution contain extremely large or small values.

The use of the techniques outlined above as a prelude to constructing more complex relationships is necessary for several reasons. First, they assist in determining which variables meet the distributional assumptions of the parametric techniques (preferred over nonparametric techniques). If the variables do not meet the criteria for parametric statistics, nonparametric alternatives may be appropriate. Second, they make it easier to define the relationships between pairs of variables. And third, they make it possible to determine, and untangle, the complex relationships that can exist among several variables. Ultimately, all of these techniques help to identify a set of stressor and response variables that are useful in monitoring environmental processes. However, nonreductionist display and interpretation of data (e.g., suite of indicator measurements) will also be critical to the assessment process.

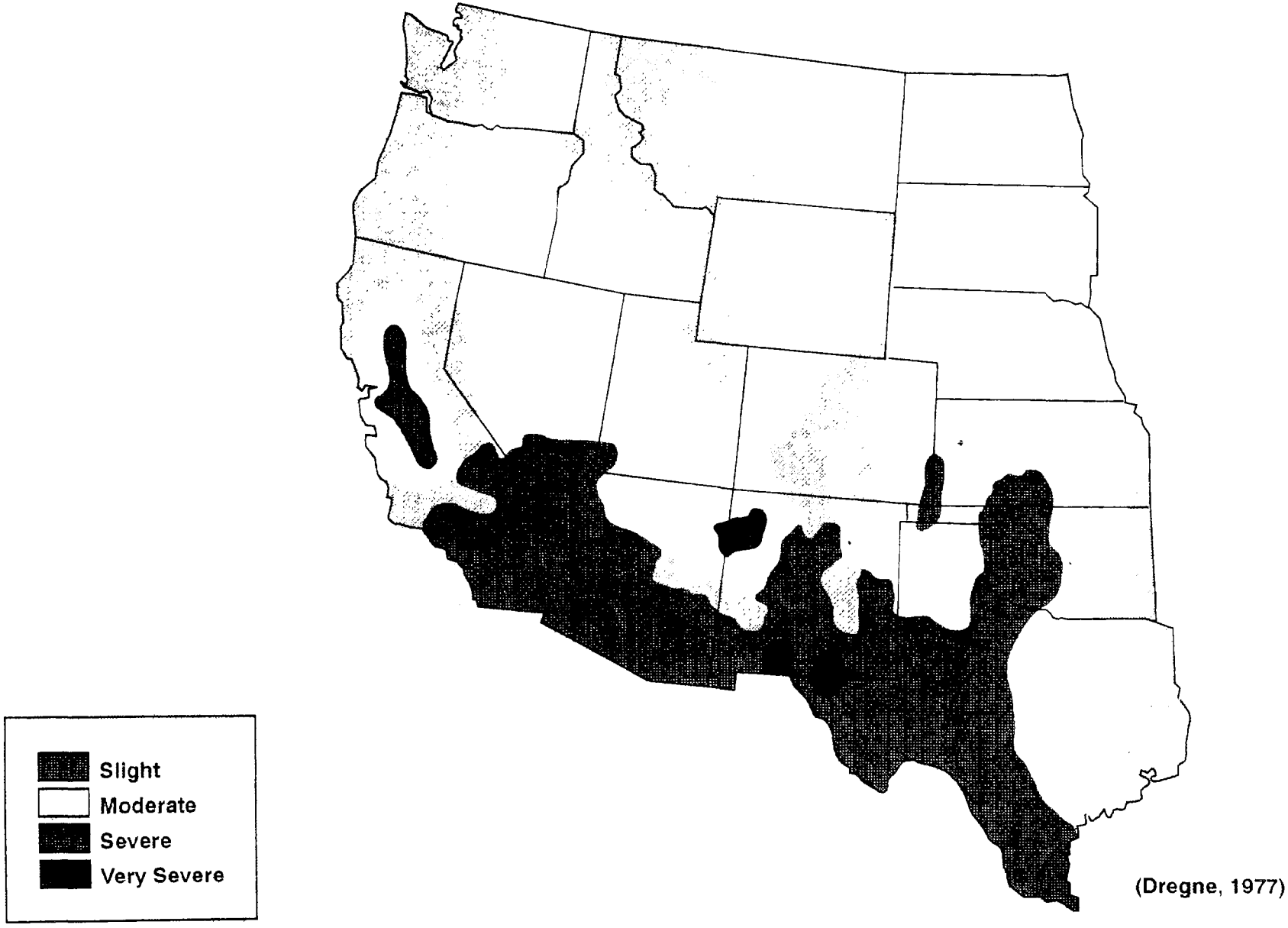
Establishing a relationship between one or more interval- or ratio-level independent variables and one or more interval- or ratio-level dependent variables can vary in terms of complexity. At the simplest level, bivariate regression can be employed and, when more than one independent variable is involved, a multiple regression scheme of one form or another can be used. If the independent variables are intercorrelated, a modification to the normal approach may be required. A principal components analysis can be used to create a new set of orthogonal variables that are linear combinations of the original variables. Or, in multiple regression situations, ridge regression or latent root regression may represent a viable alternative. When there is a set of dependent variables in addition to the set of independent variables, canonical regression with the original variables or with the principal components of each data set is required.

A final graphical summary product, useful for portraying a cumulative spatial view of how the state of the environment might be portrayed on an annual basis, is a map of the Dryland Risk Index (Figure 11-6). The Dryland Risk Index is a composite scale, not unlike the Dow Jones Index, that includes variables for which annual information exists on a reasonably fine spatial scale. The variables comprise observations made at several different tier levels. All of the variables may be represented as polygons, lines, or points within a GIS.

At the highest tier, a vegetation density index derived from AVHRR imagery with a 1.1-km spatial resolution is derived. Another layer represents values of the Palmer Drought Severity Index, described earlier, calculated for about 2,000 spatial locations in the western United States. A third layer considers grazing pressure. Another layer, reflecting a proxy of public access to land, could be comprised of different road classifications combined with distance to population centers of different size. Additional data layers may be defined as appropriate arguments of relevance are made for their inclusion. In the first analytical attempt to assemble this index, variables will be normalized to zero mean and unit variance. Because some of the variables are not orthogonal to one another, some type of data reduction scheme will also be employed. And, at some point, weighting factors for the different layers may have to be introduced. While the Dryland Risk Index will require a fair amount of exploratory research in terms of how it should be assembled, the end product of an environmental risk assessment index would be extremely valuable to EMAP clients.

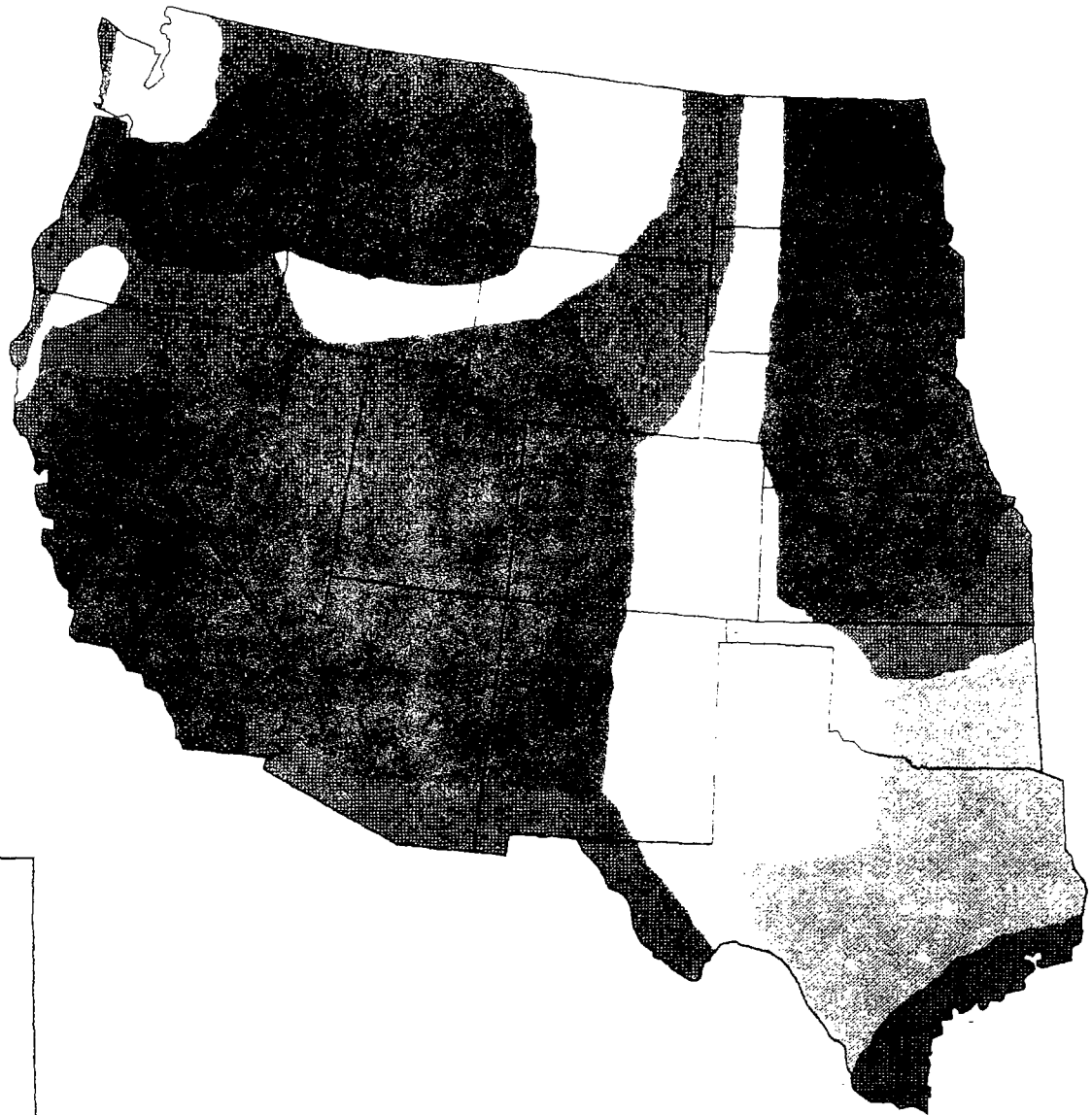
Figures 11-6a thru 6g.
Drylands Risk Index and the indices used in its formulation.

# The Status of Desertification in the United States




(Dregne, 1977)

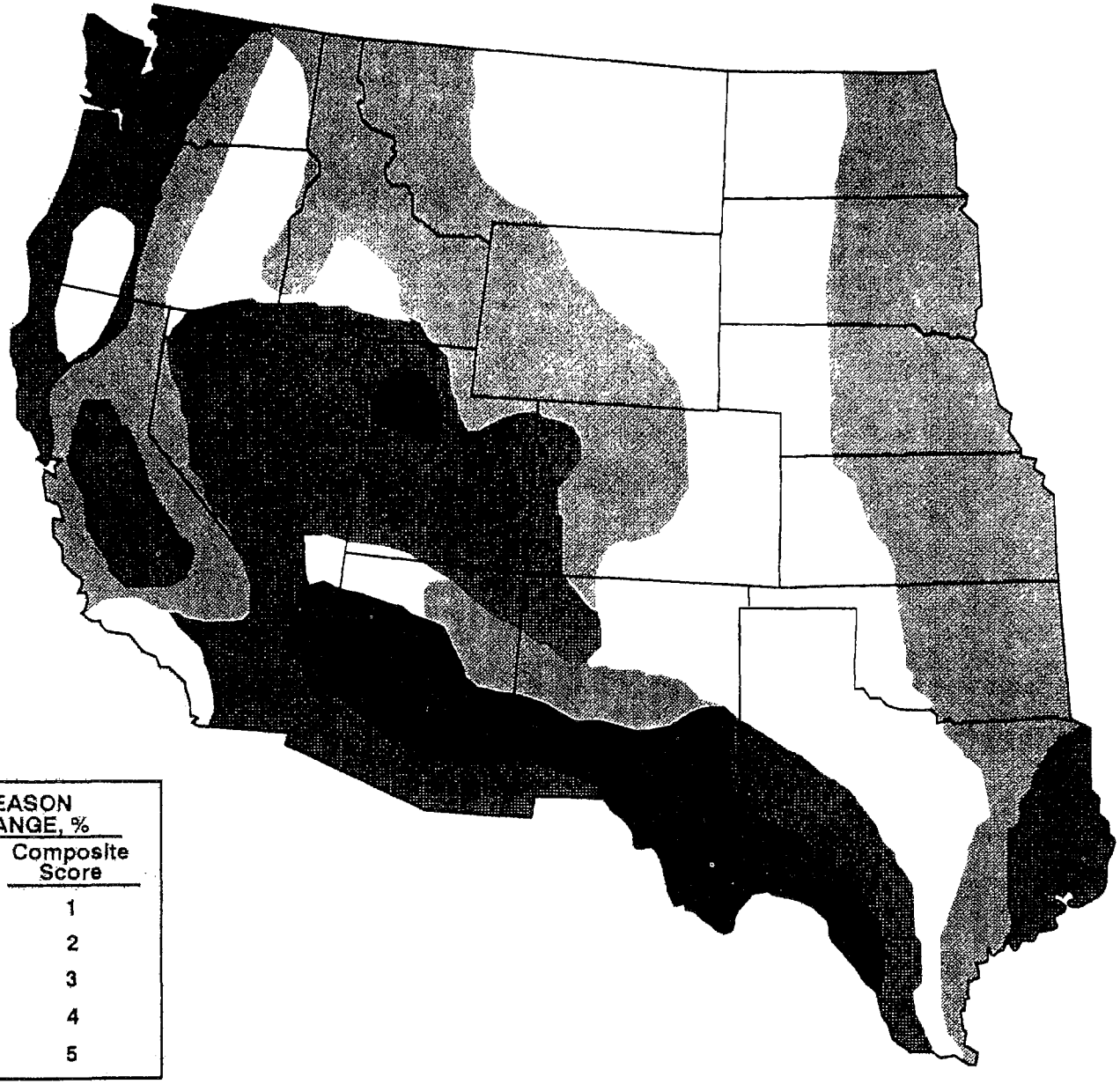
# Palmer Drought Severity Index



TEN YEAR COMPOSITE

| Category | Score |
|---|---|
| Unusually Moist | 1 |
| Moist | 2 |
| Near Normal | 3 |
| Moderate Drought | 4 |
| Severe Drought | 5 |

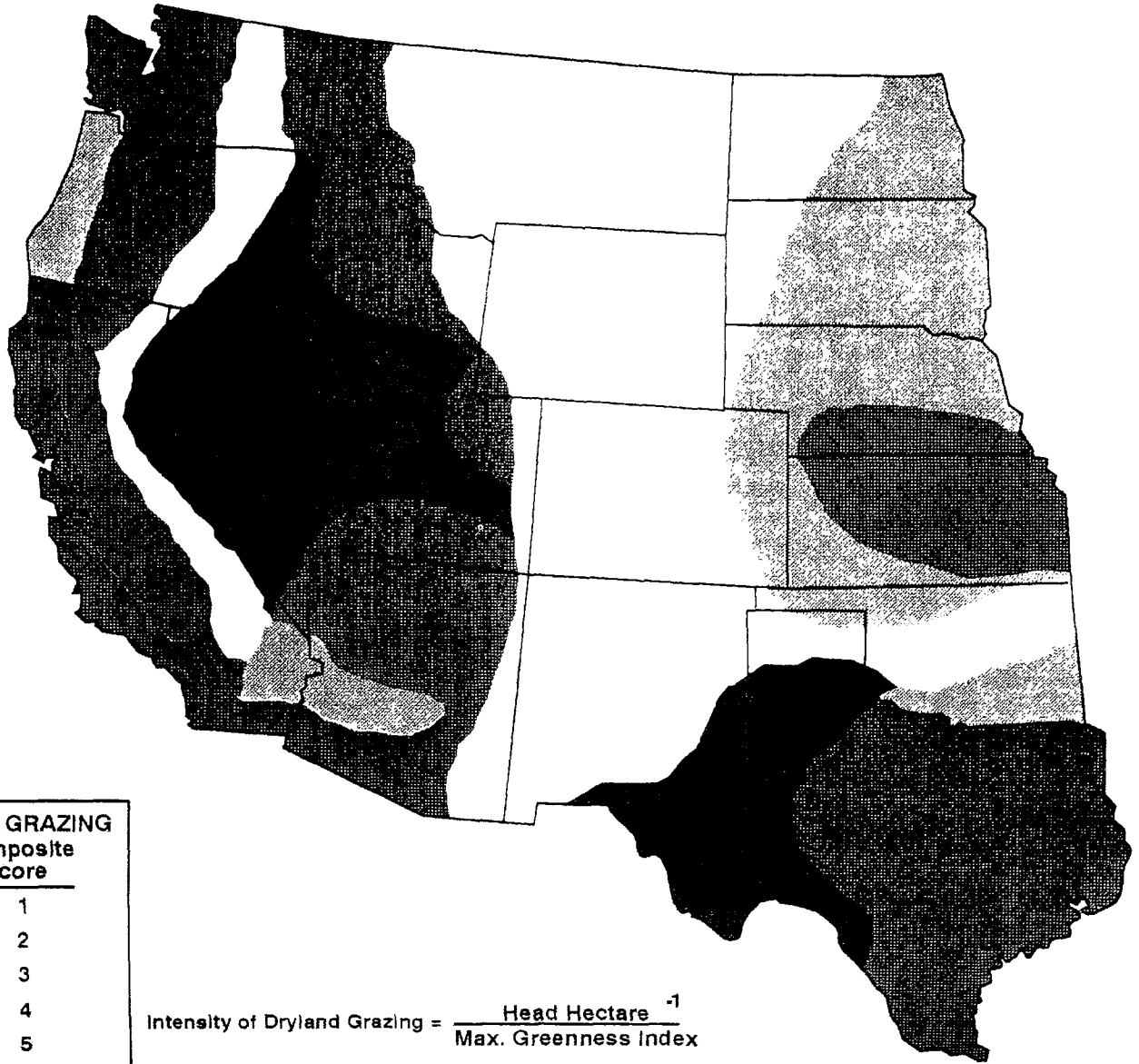
# Maximum Greenness Index



GROWING SEASON
TEN YEAR CHANGE, %

| Category | Composite Score |
|---|---|
| > 1% | 1 |
| 0 to 1% | 2 |
| -1 to 0% | 3 |
| -1 to -2% | 4 |
| < -2% | 5 |

# Grazing Index

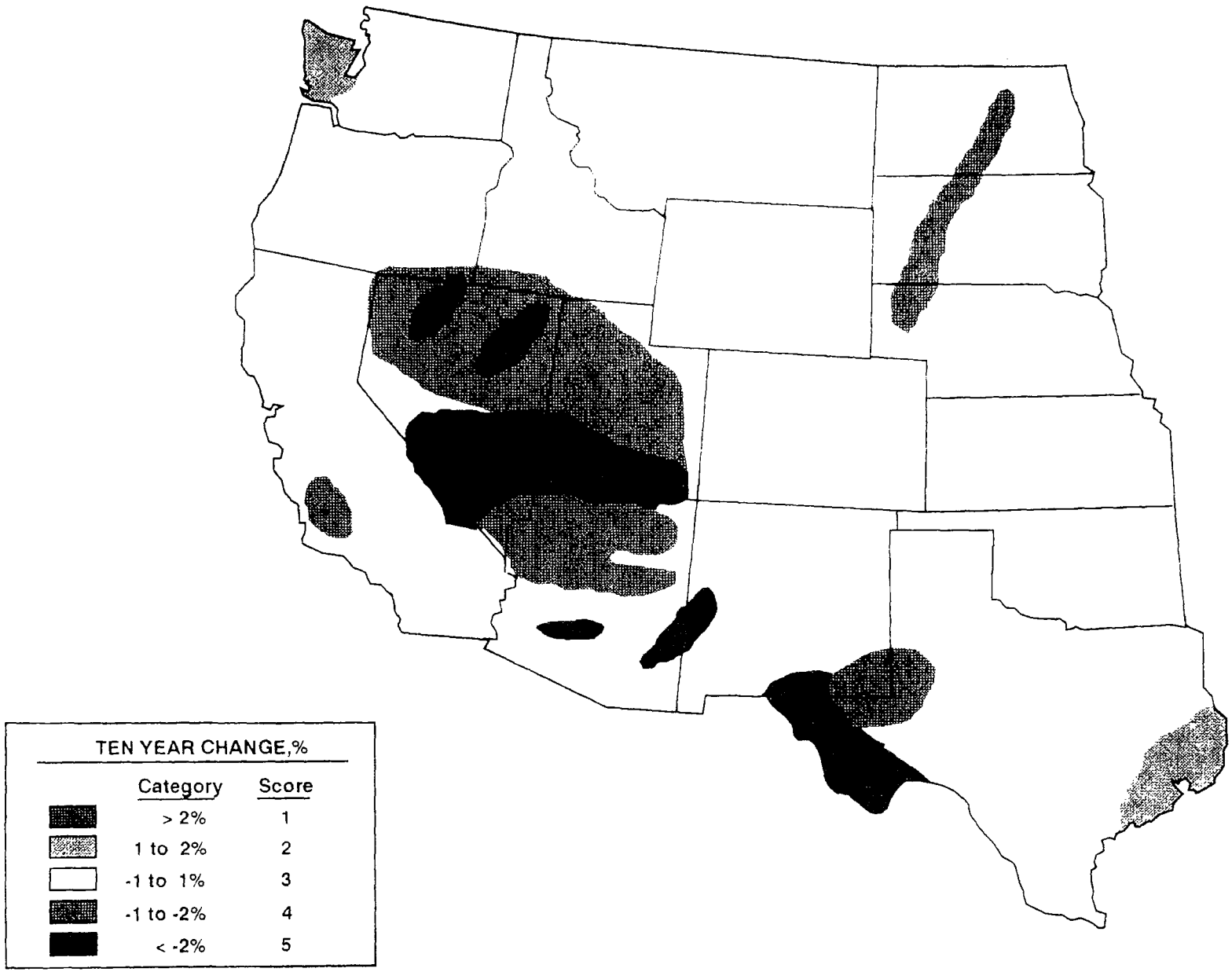


INTENSITY OF DRYLAND GRAZING

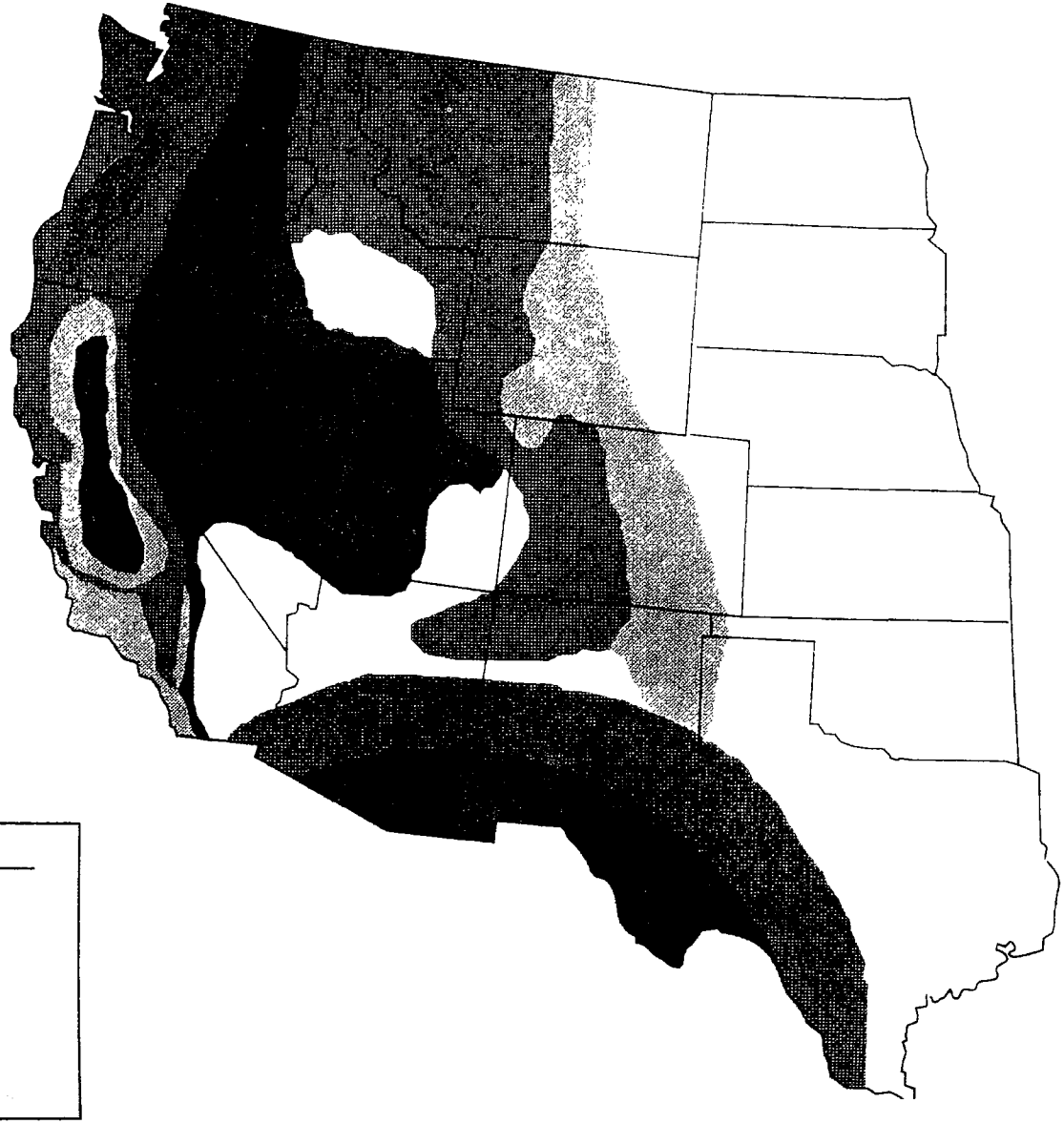
| Category | Composite Score |
|---|---|
| Light | 1 |
| Low | 2 |
| Moderate | 3 |
| High | 4 |
| Highest | 5 |

$$\text{Intensity of Dryland Grazing} = \frac{\text{Head Hectare}^{-1}}{\text{Max. Greenness Index}}$$

# Soil Carbon Nitrogen Ratio

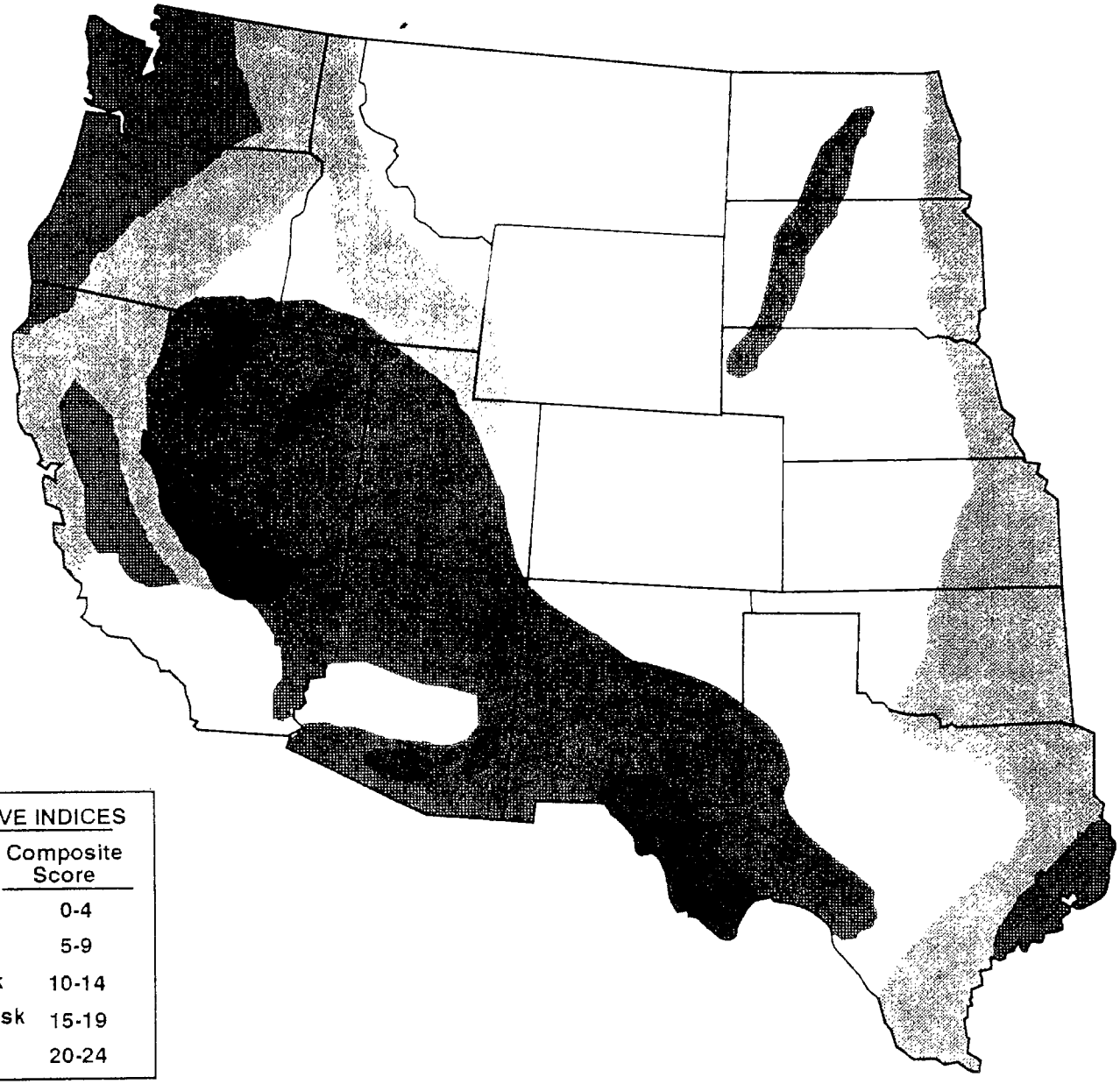


# Flammable Exotics



| PERCENT OF COVER | |
|---|---|
| Category | Score |
| 0-19% | 0 |
| 20-34% | 1 |
| 35-49% | 2 |
| 50-64% | 3 |
| ≥ 65% | 4 |

# Drylands Risk Index



A COMPOSITE OF FIVE INDICES

| Category | Composite Score |
|---|---|
| Lowest Risk | 0-4 |
| Low Risk | 5-9 |
| Moderate Risk | 10-14 |
| Substantial Risk | 15-19 |
| Extreme Risk | 20-24 |

# 12.0 INTEGRATION FOR ARID ECOSYSTEMS

## 12.1 DEFINITION OF INTEGRATION

The Science Advisory Board has determined a need for the EPA to monitor the Nation's ecological resources to assess their condition, look for changes and trends, and examine possible causes for these changes. The EPA cannot do this independently and has envisioned EMAP as an interagency program to accomplish these goals. Thus, one aspect of integration is the coordination of agencies involved in environmental monitoring. Beyond the political realities within which EMAP must operate, there are issues of integration in the scientific realm. Ecology is primarily a science of integrating patterns and processes of natural systems and EMAP must operate within this ecological perspective to succeed in its goal of monitoring the Nation's natural resources. Three levels of activities related to integration--policy, program, and technical--have been identified within EMAP.

Policy integration is the process of evaluating and coordinating the needs of various EMAP clients and constituencies and of ensuring that those collective needs are addressed by the respective EMAP components. Several activities must occur to achieve policy integration. The EMAP constituent groups, the appropriate contacts within each group, and the needs of each group must be identified. Interactions with constituent groups will be facilitated by developing a communication strategy that includes identification of effective presentation methods.

Program integration is the process of coordinating EMAP with existing monitoring and other environmental programs and of communicating EMAP goals to those charged with exploring the potential for consolidating programs in order to achieve a more comprehensive, efficient national monitoring scheme. Program integration will involve the identification of existing environmental monitoring programs and historical data bases. A consistent strategy to determine the relevancy of existing programs and data bases to EMAP should be developed. In some cases, EMAP could identify modifications to existing monitoring plans that would allow the EPA and a cooperating agency to consolidate programs to avoid duplication, improve efficiency, and enhance significance. In cases of cooperation among agencies and institutions, appropriate agreements will need to be put in place, such as memoranda of understanding and interagency agreements between governmental bodies and cooperative agreements with not-for-profit institutions.

Technical integration is the process of selecting, analyzing, and evaluating data collected from the various ecosystems sampled by EMAP, along with data from other sources, to transmit the resultant interpretation of those data into an environmental policy framework. Technical integration will facilitate our understanding of the association between anthropogenic and natural stressors on individual and multiple resources at regional and national scales. Such integration will maximize the likelihood of detecting changes in overall ecological condition.

The individual resource groups, including the EMAP-Arid group, will cooperate with the Integration and Assessment Group to achieve the overall goals of EMAP. The Integration and

Assessment Group will emphasize policy and program integration, while the individual resource groups will deal primarily with technical integration.

A partial list of agencies and institutions with which EMAP-Arid will interact is presented in Table 12-1. The details of how EMAP-Arid will accomplish this integration with other EMAP groups, other EPA programs, and non-EPA programs are discussed in Sections 12.2 through 12.4, respectively, along with some examples. Further details of the technical integration of EMAP-Arid into the whole of EMAP are discussed in Section 12.5.

## 12.2 RELATIONSHIP TO OTHER EMAP GROUPS

The EMAP monitoring tasks have been split among seven resource groups: Forests, Agroecosystems, arid ecosystems, Surface Waters, Wetlands, Near Coastal, and Great Lakes. This partition represents an operational division of the EMAP monitoring tasks rather than an ecological reality. The condition of arid ecosystems must be interpreted in the context of other nearby resources. Arid ecosystems will be influenced by, and in turn influence, the condition of nearby forests, agricultural lands, surface waters, wetlands, and near coastal environments. These interactions will be explored in more detail in Section 12.5 on Technical Integration.

While each resource group is responsible for a particular aspect of monitoring activities, many activities are common to each of the individual resource groups. Whenever possible and appropriate, EMAP-Arid will interact with these crosscutting groups, the responsibilities of which are briefly described below:

- *Statistics and Design* - Coordinate the design and statistical methods to be used in the individual resource group monitoring programs with the overall EMAP approach.
- *Logistics* - Facilitate field collection of data for each of the individual resource groups. For further detail see Section 7.
- *Information Management* - Ensure that EMAP data will be available. For further details see Section 10.
- *Air and Deposition* - Coordinate EMAP activities with those undertaken by the EPA Office of Air Quality. In particular, existing data on air quality can provide critical information on stressors to all resource groups.
- *Integration and Assessment* - Ensure coordination among the resource groups in policy, programs, and technical arenas.
- *Indicators* - Several resource groups may use common indicators. In such cases, the indicators crosscutting group will ensure that comparable methods are used to facilitate integration among EMAP resource groups. For further details see Section 5.
- *Quality Assurance* - This crosscutting group will advise all EMAP groups on methods to achieve total quality management. For further details see Section 9.

TABLE 12-1. SOME AGENCIES AND INSTITUTIONS WITH WHICH THE EMAP-ARID ECOSYSTEMS RESOURCE GROUP WILL INTERACT

DEPARTMENT OF THE INTERIOR

- Bureau of Land Management
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- Bureau of Reclamation
- National Park Service
- Bureau of Indian Affairs
- Mineral Indian Nations
- Management Service (e.g., Navajo)

DEPARTMENT OF AGRICULTURE

- U.S. Forest Service
- Soil Conservation Service

DEPARTMENT OF DEFENSE

- U.S. Army
- Corps of Engineers
- Land Condition/ Trend Analysis Program

DEPARTMENT OF ENERGY

- ParkNet

NATIONAL SCIENCE FOUNDATION

- Long Term Ecological Research
- (LTER) sites

STATE RESOURCE MANAGEMENT AGENCIES

NATURE CONSERVANCY

OTHER EMAP PROGRAMS

ENVIRONMENTAL PROTECTION AGENCY

- Program Offices
- Regional Offices
- Administrator

U.S. GENERAL ACCOUNTING OFFICE

U.S. CONGRESS

INTERNATIONAL

- Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia

- *Landscape Characterization* - Provide the landscape context for interpreting on-ground sampling and, in some cases, monitor condition of selected resources.

## 12.3 RELATIONSHIPS TO OTHER EPA PROGRAMS

Whenever possible, EMAP-Arid will cooperate with other EPA programs in joint monitoring efforts or collaborative use of data. It is expected that the efforts to monitor air quality and visibility in our Nation's National Parks, particularly the Grand Canyon, will be prime candidates for such collaborative efforts. In addition, EMAP-Arid data will form the foundation for cumulative environmental condition and risk assessments within EPA and other agency regions.

Information obtained from all EMAP activities will be available to the EPA Regional Offices, EPA Program Offices, and the EPA Administrator for use in monitoring the success of existing regulatory programs and in developing new regulatory programs to continue the EPA mission to protect our environment. In these interactions, the EMAP information will provide a foundation for the ecological risk assessment process as discussed in Section 1.

## 12.4 RELATIONSHIPS TO NON-EPA PROGRAMS (State, Federal, Private, International)

Approximately 65 percent of arid lands in the continental United States are publicly owned. Thus, many state and Federal agencies will be associated with EMAP-Arid. The extent of the cooperative effort may vary among the different state and Federal agencies. All will likely be interested in the results of EMAP-Arid; some may be active collaborators in the implementation of EMAP-Arid. For example, the BLM manages extensive holdings of Federal lands that support grazing programs. An Interagency Agreement between EPA and the BLM is currently being developed to ensure through the experience of BLM in arid lands and the monitoring efforts of EMAP-Arid that rangelands will be a sustainable resource long into the future.

For extensive areas of the Southwest, access is restricted because of the sensitive nature of the activities conducted there. These are generally Department of Defense or Department of Energy sites. Examples include the Nevada Test Site, Edwards Air Force Base, Yuma Proving Grounds, and the White Sands Missile Range. In these cases, special negotiations will be needed to determine if sampling, either by aerial overflights or on-ground visits, may be conducted on these restricted access areas. The statistical implication of such constraints on the sampling design must be addressed.

Interactions with universities and regional research institutes will continue to ensure that the best expertise in arid ecosystems is used in developing, implementing, and interpreting the results from the EMAP-Arid program. Additionally, collaboration in developing ecological monitoring programs for arid resources has been initiated on an international level such as with the Division of Water Resources of Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO).

## 12.5 TECHNICAL INTEGRATION

Integration of data into ecologically meaningful assessments must occur at many levels. In particular, it is important to understand and combine both natural and anthropogenic stressors to make assessments on the condition of ecological resources. Integration begins within a resource group through the statistical analyses of data and presentation of results. Data analysis is discussed in detail in Section 11. The data collected in the field will be the result of measuring many variables. Often measurements of these variables can be integrated into an index or evaluated as a suite for concordance that has more meaning for ecological interpretation than do the values for the individual variables taken separately. For example, species composition and abundance can be combined into any one of a number of different diversity indices that each have particular value for data interpretation. Additionally, trends in climate help us understand and interpret trends in biotic and ecological indicators.

Data on anthropogenic factors such as land use and natural factors such as climate may be combined into an integrated assessment. One example of such an assessment, the Drylands Risk Index, was obtained through the integration of climate, grazing intensity, greenness, exotic flammable species, and carbon/nitrogen ratio data layers (see Section 10). The types of such indices are numerous and many more will be developed as EMAP-Arid begins to collect data from pilot studies and evolves toward full-scale implementation.

Such indices currently are limited to describing a particular site from which data have been obtained. To begin to make regional assessments of the condition of arid ecosystems, the data from many sites must be integrated into estimates of condition. While the presentation of data in cumulative frequency distributions begins to explain regionwide condition, multivariate statistical methods will allow more detailed examination of trends in condition and lead to suggestions of possible cause for a degraded condition (see Section 11). For example, it may be found that riparian zones in areas of intense grazing are generally in poorer condition than those in areas where grazing pressure is less. Such findings will begin to allow EMAP to provide scientific evidence on the ecological soundness of current management practices.

Perhaps no other EMAP program reflects the need for integration among all the resource groups as strongly as does EMAP-Arid. This need is most easily understood when one begins to define what specific types of resources fall under the purview of EMAP-Arid. Arid ecosystems can most simply be defined in terms of average yearly rainfall. By this definition, EMAP-Arid would encompass much of the area west of the Mississippi. However, some landscapes within this region do not fit well into the standard concept of arid ecosystems. For example, pinyon-juniper communities occur in arid ecosystems but contain enough trees to conceptually qualify as a Forest component, although the species are of little commercial value. Many otherwise arid ecosystems have been irrigated to grow various crops and so function as Agroecosystems. EMAP-Arid will cooperate with the other EMAP resource groups in joint monitoring efforts to achieve a more comprehensive, efficient national monitoring program.

Because these close ties with other resource groups are best understood in terms of landscape, EMAP-Arid will have close ties with EMAP landscape characterization. In addition,

because of the vast areas covered by arid ecosystems, monitoring will most efficiently be conducted with aggressive use of remote sensing. Many aspects of the condition of arid ecosystems can be determined from satellite imagery and aerial photography. EMAP-Arid and landscape characterization groups are currently collaborating on a joint study to refine the techniques of multistage remote sensing in assessing the condition of arid ecosystems. This study will help to evaluate the benefits of placing some on-ground sample sites in the watersheds for which landscape characterization will be providing very detailed classification.

Data from EMAP-Arid can be integrated with those of other associated resource groups, and, in particular, the Landscape Characterization Integration Activity (EMAP-LC). EMAP-LC will provide nationwide coverage at coarse detail for qualities such as landscape types, soils, geological formations, climate, and human population density. For about 10 percent of the USGS hydrological units, more detailed land cover and land use data will be provided. Within these, samples will be selected for complete landscape characterization. Some EMAP-Arid on-ground sampling will occur in the watersheds that EMAP-LC has selected for detailed classification. This overlap will provide the context for the interpretation of data on arid ecosystems. Landscape indices such as amount of edge, perimeter to area ratio, patch size, and fractal index can help associate anthropogenic stresses with the condition of an arid ecosystems. For example, it could be found that arid ecosystems in relatively undisturbed areas are in better condition than are those that are becoming fragmented by encroaching urbanization. Or perhaps, arid ecosystems bordering irrigated agricultural lands where large amounts of fertilizers and pesticides are used are in poorer condition than those in areas where agricultural practices are less intense and fewer chemicals are used. These types of interpretations form the basis for risk assessments.

The possibilities for integrating data from all aspects of EMAP are almost endless. Ecological interactions can occur at various spatial and temporal scales. To detect some interactions, data must be collected from areas that have the potential to interact ecologically. This fact suggests some spatial and temporal closeness for data collection. For example, extensive media such as air, water, and wildlife can integrate the environmental response to stressors over large distances. The exact degree needed of spatial and temporal closeness of sample sites for integrating data among resource groups has not yet been determined and will vary with different types of ecological interactions. However, EMAP-Arid is aware of this limitation in the ability to integrate data and is considering strategies to answer the question of how close (in both space and time) areas must be to interact in an ecological fashion. The EMAP-Arid resource group supports the concept of a regional pilot involving all EMAP resource groups to test the programs ability to provide integrated assessment.

# 13.0 EXPECTED OUTPUTS

This section describes the types of products or outputs expected from the EMAP-Arid studies over the next several years. The number and timing of products will depend on data collection and analysis activities which will be a function of budget. A proposed implementation schedule is highlighted in Section 2.

## 13.1 DATA EVALUATION REPORTS

A key element of EMAP-Arid is the production of information derived from collected data in a timely manner and the dissemination of that information to users. Four types of reports are currently envisioned:

- annual statistical summaries;
- periodic interpretive reports;
- special interest reports; and
- scientific articles.

The EMAP-Arid resource group recognizes the need to transform data into useful information as quickly as possible. Therefore, EMAP-Arid will publish summaries of the preceding field season surveys within 9 months of data collection. These summaries will provide information on ecological indicators as well as climate and other factors that will help set an environmental context for that collection period. Rigorous statistical evaluation of trends and associations between indicators will not be made in these summaries; these are the subject of periodic interpretive reports. The objective of these reports is to distribute data to interested parties as quickly as possible. Annual statistical summaries are likely to be authored with other participating agencies, such as the BLM, NPS, USFS, and USFWS, thus resulting in one document rather than several summaries of the same data. An example Annual Statistical Summary is presented in Ball et al. (1990).

At a minimum, interpretive reports will be published following completion of 4-year sampling cycles, although reports may precede this cycle if significant results are found. These reports will attempt to summarize indicator results for the preceding 4 years and integrate information from a suite of ecological and stressor indicators to determine the regional and national status of arid ecosystems. Trends in indicators will be evaluated against trends in stressors in an effort to determine connections between response patterns and associations. This evaluation will be accomplished by analysis of the associations and relationships between trends in ecological and exposure indicators and natural and anthropogenic stressors, such as climate (from NOAA), human demographics (from the Census Bureau), and land-use (from the EMAP-LC). An example of this type of analysis and assessment can be found in Section 11. In addition to developing associations between stressors and ecological indicators, these reports will assess the cumulative benefit of regulatory and control programs as they might relate to observed associations, patterns, and trends. A more detailed example of an interpretive report will be developed in the upcoming year.

Investigations within EMAP and from programs outside of EMAP will be encouraged to produce analyses of EMAP-Arid results for publication in peer-reviewed literature. One of the best tests of the quality of the EMAP-Arid program will be the use of its data in both policy and science-oriented publications.

## 13.2 INTERNAL REPORTS

A series of reports and plans will be required before the program can commence field activities. These include but are not limited to:

- implementation plans
- methods manuals
- quality assurance plans
- information management plans
- field operations manuals
- quality assessment reports

Similar to the overall monitoring strategy, each of these plans should be considered a "living" document. This approach implies that they will be updated prior to field implementation each year as a result of activities and findings of the previous year. The implementation plan will contain the objectives and outline of the field activities for that season. This plan will include listings and locations of all sites to be visited along with indicators to be measured. Additional details for all aspects of each season's activities can then be found in updated program plans and manuals related to quality assurance, information management, and field operations. An assessment of the quality of data collected will be required following each field season, since a fundamental objective of EMAP-Arid is to have data of known quality. Additionally, since a great deal of data from other monitoring networks, such as satellite imagery and climate networks, will be used to conduct analyses and assessments, tight operational and quality assurance procedures for these types of data must be included in these plans. Similar to the data evaluation reports, many of these plans may be authored with other agencies.

## 13.3 ECOLOGICAL RISK ASSESSMENT

As pointed out earlier in this plan, EMAP data forms the baseline upon which ecological risk assessments will be conducted. The EMAP-Arid data will help determine the extent and evaluate trends in ecological resources within the western United States and should be the basis for identifying ecological resources at risk; process models also will form the basis for this assessment. By combining data on ecological indicators, natural and anthropogenic stressors (see Drylands Risk Index in Section 11), and landscape distribution and condition (e.g., simplified versus complex landscapes). EMAP-Arid will be able to determine ecosystems that are most sensitive to and at highest risk from further stress. Further, these data will be useful to a wide variety of managers in reducing overall risk within the western United States. EMAP-Arid proposes to use

state-of-the-science GIS technology to display and communicate these data to cooperating agencies and the public in addition to developing new tools (see Section 11). Reports that characterize and report on ecological risk will likely be a combined effort with EPA Program Offices and other Federal and state agencies.

## 13.4 OTHER OUTPUTS

In addition to reports, the EMAP-Arid resource group intends to make data available upon request through the EMAP information management center (EIC). Some information transferred to EMAP by other agencies may be confidential, but most EMAP data should be readily available upon request (see Section 10). The EMAP-Arid data should be shared with all types of users, ranging from the public to private industry. Additionally, EMAP-Arid will present findings at symposia, workshops, and conferences and develop brochures and videotapes for general public information. Frequent communication with cooperating and outside organizations on EMAP findings is one of the highest priorities of this program.

## 13.5 FUTURE RESEARCH, IMPLEMENTATION, AND TIMELINES

This section summarizes proposed major research tasks, implementation strategies and timelines, and projected budgets for the continued phased development and implementation of EMAP-Arid. Three general types of activities are necessary to develop and implement the program:

- analysis of existing data and simulations;
- field pilot studies; and
- regional demonstration projects.

All three of these activities will be conducted to evaluate the overall design, indicator performance, and field sampling; Table 13-1 provides a summary of these activities. We anticipate continuous evaluation of design and indicator performance. One of the key developmental areas for EMAP-Arid will be the use of remote sensing data to measure and determine status and trends in ecological indicators. Initially, EMAP-Arid will use remote sensing data to determine the distribution and extent of certain arid ecosystems and for the measurement of landscape indices (a measure of landscape condition). As new sensors become available (e.g., NASA EOS platforms), EMAP-Arid will evaluate the usefulness of using data generated from these sources in measuring ecological indicators.

Other developmental areas of priority to the EMAP-Arid resource group include:

- development of the "suite of indicators" concept whereby the resolving power of the suite of indicators is greater than the sum of the resolving power of individual indicators;
- development of nominal and subnominal classifications for indicators and indicator suites. Here it is important to develop an ecologically meaningful definition that is compatible with but not compromised by the variety of subjective definitions of ecological and environmental health;

TABLE 13-1. EMAP-ARID PROPOSED RESEARCH AND DEVELOPMENT OBJECTIVES

| TASK | DESIGN | INDICATOR |
|---|---|---|
| Analysis of existing data and simulation | Compare EMAP to previous sampling grid designs | Evaluate indicator responsiveness to major stressors |
| | Assess efficiency of proposed classification | Quantify spatial and temporal variability of proposed indicators |
| | Determine optimal sample sizes for field measurements | Initiate development of metrics and evaluation |
| | Develop statistical procedures to integrate satellite data with field measurements | From existing data, develop a suite of indicators likely to determine arid land conditions |
| | Develop statistical procedures to integrate paleoenvironmental data with field measurements | |
| | Develop strategy to link existing ecological monitoring sites with EMAP design | |
| | Develop approaches to integrate assessments | |
| Field Pilot | | Quantify the spatial and temporal variability of indicators |
| | | Determine whether to move certain indicators to the demonstration phase (based on variability and sensitivity) |
| | | Test and refine sampling methods |

TABLE 13-1. (continued)

| TASK | DESIGN | INDICATOR |
|---|---|---|
| Regional demonstration projects | Evaluate adequacy of EMAP grid | Evaluate indicator applicability and interpretability on a regional scale |
| | Quantify errors associated with misclassification, boundary delineation, denied access | Obtain first data to produce regional assessments of arid land conditions |
| Other research | Link design to global monitoring community | Develop nominal/subnominal classification for indicator measurements |
| | | Develop ecological indicator measurement techniques from satellite imagery |

- development of spatial statistics to enhance the understanding of trends, associations, and patterns among indicators (stressor and ecological indicators);
- incorporation of landscape condition data with field measurements to understand overall ecosystem condition and risk, including determining hierarchical relationships between measures on plots and landscapes.

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**Section 12**

NO CITATIONS

**Section 13**

NO CITATIONS

# APPENDIX A

## Possible Indicators for Use by the EMAP-Arid Ecology Resource Group as Developed in EMAP-Arid Workshops

# VEGETATION BIOMASS

**INDICATOR:** Leaf Area Index/Vegetation Index

**LINKAGE:** Response

**ENDPOINT:** Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** An important environmental value for arid and semiarid resource classes is the continued productivity of grassland, shrubland, and woodland vegetation. This value includes secondary and higher levels of productivity (animal habitat) as well as primary productivity (vegetative growth). Net primary productivity (NPP), the chemical energy stored or accumulated by vegetation per unit time, is critical to continued ecosystem function. NPP is perhaps the best integrator of ecological response to environmental stresses and perturbations and is, among other things, dependent upon resource availability and the lack of major disturbances.

When disturbance or levels of change are moderate (i.e., not at the intensity of fire or mechanical disruption), changes in annual NPP will generally precede changes in vegetation structure. When large or moderate disturbances occur, their impact can be judged in part by the recovery of vegetation toward predisturbance levels of NPP. Advances in remote sensing technology and an improved understanding of spectral signatures related to functional properties of plants offer exciting prospects for large-scale assessments of current and potential NPP.

**Leaf Area Index/Vegetation Index:** Total plant chlorophyll (green leaf material) is an excellent integrator of NPP in ecosystems, and it can be easily monitored with airborne and satellite remote sensing. Because the acquisition of carbon is among the highest priorities for plants, resource investment in leaves and their constituents is probably pushed to the point where the return on that investment (sunlight capture) is marginal in its effect. Thermodynamic complexities of capturing sunlight and carbon require that the ratio of chlorophyll to other resource-expensive leaf constituents remains within a narrow range. Thus any limitation or impediment to plant resource acquisition and growth is likely to be reflected by a decrease in the total green leaf material (i.e., chlorophyll) deployed by plants.

## MEASUREMENTS:

**Leaf Area Index/Vegetation Index:** The resources required to monitor chlorophyll content or greenness involve image acquisition and processing. Satellite data extends back to 1972 with the LANDSAT thematic mapper and LANDSAT multispectral scanner data sets. Satellite data having coarse spatial resolution (1.1 km) from the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) has been used to conduct long-term regional analyses of vegetative response to stressors (e.g., Asrar et al., 1985; Tucker et al., 1985; Becker and Choudhury, 1988). Extensive ground truthing (verification) of remotely

sensed measurements of vegetation is under way in the First International Satellite-Land Surface Climatology Program Field Experiment Program of the National Aeronautic and Space Administration (NASA). NASA plans to undertake a second such experimental program within the next several years.

**INDEX PERIOD:** To assess the potential NPP in seasonally active grassland, shrubland, and woodland systems, the sampling window for remote sensing should include the period of peak vegetation growth to facilitate repeatability among years. Growth increments in woody plants and annual standing biomass in ephemeral vegetation (e.g., grasslands) should be measured at the end of annual or seasonal periods of productivity.

**VARIABILITY:** The expected spatial variability of biomass measures within a resource sampling unit varies with habitat quality; the range can deviate > 100% from the mean value. Under some conditions vegetative cover and productivity are quite uniform, for example, across flat valley bottoms. Because the entire resource sampling unit is being monitored, the expected spatial variability of remotely sensed data is inconsequential. The expected temporal variability of the biomass measures during the index period have not been estimated.

**PRIMARY PROBLEMS:** The most significant problem is that the field measurements are all labor intensive. Additional research is needed to determine if spectral signatures other than that of chlorophyll can be used to determine specific details about the physiological or functional status of plants. Detectable changes in the quantity of other plant pigments should be useful in this regard. In assessing the impact of some environmental change, it would be extremely useful to quantify the potential NPP of a species by the availability of its limiting resources. This is a simplistic assumption, however, because in most cases plant growth is limited by multiple resources. In arid zones, for example, water is an important resource, but the growth rate of most plants inhabiting these areas also increases in response to nitrogen applications. Research to develop an improved understanding of the effect of resource limitations on NPP is therefore needed.

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**INDICATOR:** Aerial Extent

**LINKAGE:** Response, Habitat

**ENDPOINTS:** Biodiversity, Sustainability, Aesthetics

**STATUS:** High-Priority Research

**APPLICATION:** This indicator is designed to monitor the areal extent of riparian habitat in arid lands both as a threatened resource class that directly relates to environmental values such as water quantity and quality, soil erosion, and aesthetics and as extent affects animal and plant populations. Riparian habitats in the West have been widely depleted and degraded (U.S. GAO, 1988; Johnson and Simpson, 1985).

**INDEX PERIOD:** Satellite data of late spring to early summer is best for monitoring the status and extent of riparian systems, because the riparian vegetation is in a full leaf-out condition, and a high sun angle reduces shadow effects in steep terrain.

**MEASUREMENTS:** The areal extent of grasslands, shrublands, woodlands, and riparian vegetation can be readily tracked by using Thematic Mapper (TM) satellite data (e.g., Groeneveld et al., 1985). This can be accomplished with aerial photography or airborne video data, in conjunction with a field survey program.

The estimated costs of remote-sensing-based measurements performed on a landscape sampling unit are the following: (1) TM or airborne data purchase - ~$500; (2) computer time - ~$500; and (3) analyst time - ~$500. Thus, the total cost per landscape sampling unit would be about $1,500. The recommended interannual sampling frequency would be approximately 5 years.

**VARIABILITY:** TM data would provide full spatial coverage of each landscape sampling unit; therefore, considerations of spatial variability for parameters within a resource sampling unit are inconsequential. The expected temporal variability of riparian extent during the index period would produce a range that deviates < 10% from the mean value.

**PRIMARY PROBLEMS:** The tracking of species composition changes cannot be performed in detail by using satellite data. Monitoring for these changes must be done by low-altitude remote sensing and field surveys.

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**INDICATOR:** Life Form

**LINKAGE:** Response, Habitat

**ENDPOINTS:** Aesthetics, Biodiversity

**STATUS:** High-Priority Research

**APPLICATION:** An obvious characteristic that helps to distinguish ecosystems is the predominance of certain types of life forms such as trees, shrubs, and grasses. Changes in the relative proportion of life forms can be caused by natural processes (e.g., succession) and human intervention, and may presage a fundamental change in the system.

**INDEX PERIOD:** The optimal period for sampling would be during the peak growth period, probably late spring or early summer. However, many annuals have peak growth periods during different seasons.

**MEASUREMENTS:** Field surveys would be needed to establish the relative abundance per unit area and as a percentage of ground cover. Much of this information can be extended in space and time through aerial photography and satellite coverage. Images from the LANDSAT Thematic Mapper can be used to monitor boundaries between predominant life forms.

**VARIABILITY:** Annual plants have a large seasonal and year-to-year variation. Shrubs and trees are less prove to short time-scale changes more dependent on decadal influences (excluding catastrophic). The variation, then, between sampled resources is highly dependent on the resident species.

**PRIMARY PROBLEMS:** Ground truth information is required and the variability in survey results is exacerbated by the high variability in ephemeral life forms.

**INDICATOR:** Mechanical Disturbance of Soils and Vegetation

**LINKAGE:** Exposure, Habitat

**ENDPOINT:** Biodiversity

**STATUS:** High-Priority Research

**APPLICATION:** Mechanical disturbance of soils and vegetation is closely linked to several of the primary processes involved in land degradation (Webb and Wilshire, 1983), including loss of plant cover, fragmentation of habitat, acceleration of erosion, and introduction of exotic species. Mechanical disturbances can be caused by grazing animals (U.S. BLM, 1978), off-road vehicles, road and site constructions, mining, and mineral or fuel exploration.

This indicator would track the development of mechanical disturbance through time by using airborne and satellite imagery. It is conceded that the mechanical disturbances induced by grazing or single passes by vehicles on an undisturbed landscape would not be detected by this approach. However, it would be possible to detect and identify the new roads and trails, plus mechanically disturbed areas, created by mining and mineral or fuel exploration. The indicator is applicable to all arid resource classes.

**INDEX PERIOD:** The optimal sampling window is generally the growing season, from late spring to early autumn, when activities causing disturbances are likely to occur.

**MEASUREMENTS:** Standard change detection procedures would be applied to Thematic Mapper (TM) satellite data and low-altitude aerial photography or videography. Mechanically disturbed areas would be recognized by their spatial and spectral signatures; for example, they: (1) are brighter than their surroundings; (2) have low to negligible vegetation cover; (3) have sharp boundaries; and (4) are frequently linear in shape. The identification and mapping can be accomplished by using the visual approach of photo interpretation. Automated approaches may accelerate this procedure and reduce costs. Estimated cost is $400 for each landscape sampling unit.

**VARIABILITY:** The expected temporal variability for measurements derived from remotely sensed data during the index period would produce a range that deviates 5 to 30% from the mean value. The variability is due primarily to the loss of details in heavily shadowed areas of steep terrain; variation in shadowing is induced by systematic alterations in illumination conditions both seasonally and diurnally. The high sun angles of midsummer are best for reducing the obscuration of details in shadowed areas. Because the entire resource sampling unit would be monitored by remote sensing, the spatial variability of this indicator is inconsequential.

**PRIMARY PROBLEMS:** This indicator would not measure mechanical impacts due to grazing or single vehicle traverses on the landscape.

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**Webb, R.H., and H.G. Wilshire, eds.** 1983. Environmental Effects of Off-Road Vehicles: Impacts and Management in Arid Regions. Springer-Verlag, New York.

**INDICATOR:** Exotic Plants

**LINKAGE:** Exposure, Habitat

**ENDPOINTS:** Biodiversity, Aesthetics

**STATUS:** High–Priority Research

**APPLICATION:** A number of the introduced species in the western United States are widely regarded as indicators of degraded conditions, including cheat grass (Bromus tectorum), tamarisk (Tamarix sp.), and tumbleweed. These plants have proliferated widely during the past 200 to 300 years since their introduction because of their ability to adapt and thrive in disturbed habitats. The presence and abundance of exotic plants can be used as an indicator of the condition of arid lands and would be applicable to all sites.

**INDEX PERIOD:** The optimal sampling window would be late spring to early summer.

**MEASUREMENT:** Data required for this indicator would also be collected for the "Species Composition and Ecotone Location of Vegetation" wildlife habitat indicator by aerial photography and field surveys. The estimated cost is $100 a resource sampling unit.

**VARIABILITY:** Estimates of species composition for annual plants are subject to wide seasonal variation. Perennial plant measurements would be less variable. The expected spatial variability of field measurements of species composition within a resource sampling unit would produce a range that deviates 5 to 10% from the mean value. The expected temporal variability of species composition measures during the index period would produce a range that deviates 20% from the mean value.

**PRIMARY PROBLEMS:** No major problems are anticipated when this indicator is assessed.

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## WATER BALANCE

**APPLICATION:** Water is a resource critical to arid ecosystems and four indicators are grouped below. As precipitation amounts decline, the variability of precipitation generally increases markedly; this variability has important consequences for evolution and adaptation of arid zone organisms and the functioning of arid ecosystems. Some organisms have evolved structural, functional, and life history attributes specialized for dealing with variability in water supply, while others have evolved traits which allow them to exploit relatively stable water sources. Two examples of organisms that require relatively stable water supplies are mesquite (Prosopis spp.), which uses primarily ground water, and riparian zone species, which can use a combination of surface water and ground water. Despite adaptation of their component species to restricted and variable water supplies, both decreases and increases in water supply can significantly affect the productivity and species composition of arid lands. Water balance affects productivity of animals ranging from soil microorganisms to vertebrates. Plants have a major impact on water supplies, not simply because they consume the resource but, equally importantly, they intercept precipitation and contribute to soil conditions favorable for percolation of water into the soil. Monitoring of water balance in arid regions can thus be used as a predictor of ecosystem productivity and as an indicator of disturbance. Also, transpiration is a significant portion of the hydrologic cycle because it represents one of the important feedbacks of the biosphere to the atmosphere and climatic system. Any water balance monitoring program must be closely linked to synoptic and local weather monitoring efforts. Particularly important as an indicator of changes in ecosystem function is a change (increasing or decreasing) in the variability of values for the three water-balance parameters discussed below.

**INDICATOR:** Vegetation

**LINKAGE:** Response

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**Application:** Water consumption by plants is closely tied to photosynthetic activity. This is true not only because stomata must be open for photosynthesis to occur, but also because stomatal conductance to water vapor and to $CO_2$ is apparently linearly related to the photosynthetic rate of a leaf (Wong et al., 1979, 1985; Ball et al., 1986). In monitoring the Bowen ratio, the latent and sensible heat fluxes are determined separately so that a value for water flux can be obtained from vegetation. Recent work by Carlson and Buffum (1989) suggests that it may be possible to track evapotranspiration on a regional scale by using a combination of satellite remote sensing data and data from the meteorological network. Atmospheric stressors which enter leaves and affect photosynthesis (e.g., air toxics) would be expected to induce a decline in stomatal conductance and a decrease in water vapor and latent heat flux from vegetation. Such a change could be taken as an early-warning sign of long-term damage to vegetation. Any decrease in stomatal

conductance (reflected in a lower rate of water use) should render a plant less susceptible to damage from airborne toxics, which require direct access to the leaf mesophyll cells before damage can occur.

Measurement of the ratio of stable C isotopes ($^{13}C/^{12}C$) accumulated in leaves provides an integrated measure of the ratio of stomatal conductance to photosynthesis (Farquhar et al., 1982). Coupling stable C isotope abundance measurements with measurement of the H and O isotopes accumulated in leaf material appears promising as a direct integrator of the amount of water expended for each unit C gained and of the relative humidity of the air at the leaf surface. The interpretation of the H and O isotope abundances in leaves is less well established than that for C isotope abundances (White, 1988). Both the H and O in ground water tend to be enriched in the respective heavier isotopes ($^{2}H$ and $^{18}O$) relative to surface water and the meteoric water line. By sampling relative abundance of these isotopes in water within a plant and in the alternate water sources, it is possible to determine the portion of water coming from the two sources.

**INDICATOR:** Ground-water Depth and Use

**LINKAGE:** Response, Stressor

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**Application:** As mentioned above, some highly productive arid ecosystems utilize relatively stable ground water sources. Fluctuations may either force plants into drought stress or flood the root zone. Plants which normally use stable water supplies are less likely to withstand water stress than plants which normally encounter fluctuations in water supply. Fluctuations may also affect salinity or trace element accumulation. Lowered ground-water depth due to increased pumping, upstream impoundment, diversion, channelization, etc., could adversely affect such communities. In extreme cases, withdrawal of ground water has caused the ground to collapse or sink. In arid regions, ground-water levels can stabilize, once near-equilibrium between use and inflow is achieved. Salts accumulate in soil above such a water table, which becomes an "inverted leaching" profile. Shifts in a water table could result in changes in this salt accumulation profile, thereby providing a record of past shifts against which ongoing shifts can be gauged.

**INDICATOR:** Stream Flows

**LINKAGE:** Response, Habitat, Stressor

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**Application:** Runoff patterns vary markedly with differences in vegetation type, species composition, and areal cover, as well as with soil physical properties that influence infiltration. The

southern shrubland and grassland ecosystems in North America are prone to flash flooding, in part because of sparse vegetation, but more because they are near the source of energetic subtropical storms. In these areas, monitoring of flooding events would be important for documenting erosion and possibly shifts in vegetation. In areas where flow is less episodic, stream flow data properly coupled to synoptic and local weather data is a good integrator of vegetation and soil conditions. Accumulation of records of stream flow data would provide a good baseline against which purported hydrologic change can be gauged.

**INDICATOR:** Precipitation

**LINKAGE:** Stressor

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**Application:** The amount and seasonal variation in precipitation has marked effects on the structural, functional, and life history of arid ecosystems. Many plant species are dependent on surface waters being available at certain times of the year. Long periods of drought and/or high variability will reduce the overall productivity and recruitment into the area.

**INDEX PERIOD:** Most measurement systems would record in place continuously; for example, flow gauges in streams and floats in wells. Data might exist or be obtainable only during specific seasons, such as Bowen ratio and stream flow data collected during growing seasons or well records at time of peak and least ground-water withdrawal.

**MEASUREMENTS:**

(1) **Ground-water Level Monitoring:** Depth records to ground water and information about water table behavior are needed. Some ground-water data bases do exist (e.g., U.S. Geological Survey), but their extent and usefulness is not known at present. To reduce regional uncertainty, new wells may need to be installed in existing networks. Well installation cost varies but is approximately $80/m ($25/ft).

(2) **Long-Term Records, for Some Areas, are Available from the National Weather Service:** Additional locations of particular interest can be monitored in conjunction with energy balance measurements (see next indicator).

(3) **Vegetation Use of Ground Water Versus Surface Water:** Both H and O in ground water tend to be enriched in the respective heavier isotopes ($^{2}H$ and $^{18}O$) relative to surface water and the meteoric water line. By sampling the relative abundance of these isotopes in water within a plant and in the two alternate water sources, the contribution of water from each source can be determined.

(4) **Historical Fluctuations:** As wells are installed, exchangeable Ca, Mg, Na, and K are measured in soils above the water table. Graphic plots of exchangeable cation profiles as a function of height

above water table would indicate previous positions of the water table. Based upon an additional $20 a sample for analyses, 15 samples a core (25 to 50-cm intervals), and 10 cores per unit, the total cost is $3,000 for each resource sampling unit.

**VARIABILITY:** Ground-water depths will vary within a resource sampling unit. Water use by vegetation is likely to be rather consistent (with ranges that deviate < 10% from mean values) if the cover and slope exposure are uniform; however, this kind of uniformity in land surface is rarely found. Stream flow will be highly variable (with ranges that deviate < 100% from mean values) across a resource sampling unit, depending largely on topography, precipitation event size, and localization, but also on vegetation cover type and density.

**PRIMARY PROBLEMS:** Establishing a network of wells for ground-water measurements on remote sites would be expensive. H and O isotope methodology for plant-ground water and plant-atmosphere interactions needs more research. The use of these methods may be restricted to sites with stable ground water. They probably work less well in riparian zones, washes, or playas. Subsoil may be highly heterogeneous in texture and mineralogy, thereby increasing variability in analyses.

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**INDICATOR:** Energy Balance

**LINKAGE:** Response

**ENDPOINTS:** Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** The input of solar energy drives the interrelated biogeochemical cycles of carbon, oxygen, nitrogen, water, etc., in virtually all ecosystems. Solar energy impinging upon a site is dissipated through a mix of five primary flux processes or pathways: reflection, reradiation, conduction of sensible heat into the ground, sensible heating of the air, and evaporating water as latent heat in the air. The rates of several important biogeochemical cycles (e.g., $H_2O$, C, and O) are directly dependent upon or closely related to the particular mix of these dissipation processes occurring at any given time. Because these biogeochemical cycles are linked to energy dissipation processes in well-characterized ways, the rates of some biogeochemical processes, an indicator of ecosystem function, can be inferred from the relative rates of energy dissipation processes.

**Sensible and Latent Heating of Air:** A measure of particular importance is the Bowen ratio, the ratio of sensible heat flux to latent heat flux in air. This ratio in essence indicates the relative importance of the hydrologic cycle as an energy dissipater at the site of measurement. When vegetation is present, stomatal conductance and the resultant rate of plant transpiration are usually the factors controlling the Bowen ratio. Nowhere is this more true than in arid and semiarid environments (Jarvis and McNaughton, 1986). Other factors which influence the Bowen ratio are leaf area and surface aerodynamic roughness.

It has been demonstrated that stomatal conductance is primarily and linearly related to the leaf photosynthetic rate, given constant relative humidity and $CO_2$ concentration (Wong et al., 1979, 1985). The conductance-photosynthesis relationship increases linearly with relative humidity and as an inverse function of the $CO_2$ concentration (Ball et al., 1986; Ball, 1988). The photosynthetic rate, relative humidity, and the $CO_2$ concentration thus form a multiplicative index to which stomatal conductance responds linearly. The slope of the conductance response varies between species and particularly between $C_3$ (cool climate) and $C_4$ (warm climate) species.

The Bowen ratio, then, directly reflects the photosynthetic capacity of the area vegetation and would change if the site vegetation changed. Impacts on the vegetation by factors such as air toxics, which enter leaves and affect photosynthesis, would be expected to induce a decline in stomatal conductance and a decrease in water vapor and latent heat flux from vegetation. Such a change could be taken as an early warning sign to long-term vegetation change. Also, because the Bowen ratio reflects stomatal conductance and many pollutants must enter the stomata before they affect plant metabolism, this measure of stomatal conductance may indicate susceptibility of ecosystems to airborne pollutants. The plant-mediated flux of water vapor and accompanying latent heat into the atmosphere is one of the primary feedbacks that the vegetation has upon climate.

**Reflection:** Reflectance of the total solar spectrum (measured as surface albedo) can be a major route of solar energy dissipation. The albedo can range from near zero above heavy vegetation cover or above soils rich in organic matter to values as high as 0.7 in areas where a salt crust covers the soil. Particularly in arid and semiarid regions, loss of vegetation generally results in increased albedo. Thus with vegetation loss, incoming energy which might have been dissipated as latent or sensible heat in the lower atmosphere is reflected back through the atmosphere.

**Soil Heating:** Soil heat flux can be a major energy dissipation pathway, especially where vegetation is sparse and soil is dark or moist. On both a diurnal and annual basis, the net flux of energy to or from the soil will be near zero unless the climate is changing. Thus soil temperature measurements made at opposite points in either the diurnal cycle or the annual cycle give a good indication of the importance of soil heat flux to the energy balance of a site for the respective time scales, especially if soil heat capacity and thermal conductivity are determined. For example, Schmidlin et al. (1983) found that mean annual soil temperature of well-drained soils in Nevada can be estimated from as little as two readings taken on equally spaced months (e.g., January and July, February, and August). They then correlated mean annual soil temperature with elevation and geographical parameters. These parameters would, of course, change and have to be recalibrated if the climate warmed or cooled. Soil temperature records would be valuable in tracking climatic change and can be used in conjunction with soil water measurements. These parameters provide a baseline against which future changes in soils may occur in response to climate change (e.g., soil C and N content; Post et al., 1982, 1985; Parton et al., 1987).

**Solar Radiation:** There is a paucity of high-quality measurements of solar radiation across North America. In part, this lack of data stems from problems in interpreting remote measurements of solar radiation, such as the deposition of dust, on instrument lenses and the inability to differentiate types and altitude of clouds (which influence downwelling long-wave radiation). A well-executed, larger, long-term solar radiation sensor network would prove particularly valuable in testing the hypothesis that increased cloudiness tends to mitigate the influence of increasing "greenhouse gases" in the atmosphere.

**Reradiation:** Remote measurement of reradiation (i.e., terrestrial radiative flux) is probably not practical. Although durable, semiconductor-based thermopile sensors are available, their field of view is probably too small to capture the heterogeneity of radiative surfaces at a site. There are a number of approaches to estimating terrestrial radiative flux, including direct temperature measurement and application of the Stefan-Boltzman equation (Sellers et al., 1988).

In summary, regular and continuous monitoring of the surface energy balance parameters, particularly the Bowen ratio, constitutes an excellent means of assessing the functional state of the primary producers within an ecosystem. Linked with satellite measurements of plant canopy characteristics, the energy balance can be used to calibrate and validate inferences of the functional state of the vegetation. Continuity of measurements from simple automated stations can give critical temporal information at a frequency which is not practical for satellite-based measurements. Continuous solar radiation records could be a very significant data base, especially in addressing questions regarding climate change.

**INDEX PERIOD:** In general, data on energy balance in arid and semiarid ecosystems would be most valuable for the period when plants are metabolically active. Monitoring stations can be easily automated and should operate continuously; year-round solar radiation measurements might be especially valuable.

**MEASUREMENTS:** Measurements should emphasize an understanding of regional energy balance and its connection to remotely sensed data (Kittel and Schimel, 1987; Running et al., 1989). Advanced Very High Resolution Radiometer satellite data would be used to measure surface albedo and temperature on an annual or seasonal basis. Thematic mapper and SPOT satellite data would provide more detailed spatial resolution of albedo and temperature changes on a less frequent basis.

Field measurements provide information about process-level ecosystem function which cannot be directly measured with remote sensing techniques (e.g., Vukovich et al., 1987). Measurement of the Bowen ratio, for example, involves measurement of wind vectors, air temperature, and humidity at the base of the planetary boundary layer. A small station with appropriate pyranometers, thermocouples, humidity sensors, soil heat flux plates, and satellite-linked data retrieval would cost approximately $8,000.

**VARIABILITY:** Spatial variation in energy balance parameters is largely a function of vegetation type and land use. Temporal variation is a function of available soil water within and among seasons. Assessment of regional variation in surface energy balance is currently under way in tallgrass prairies by the International Satellite Land Surface Climatology Program of the National Aeronautics and Space Administration, First Field Experiment (Sellers et al., 1988)

**PRIMARY PROBLEMS:** Research is needed to determine what remotely sensed canopy parameters should be used to drive regional level models of energy balance. Data on stomatal responses to photosynthesis, humidity, and $CO_2$ need to be collected for a wider variety of species than is currently available. These data would need to be placed in a framework which links particular stomatal characteristics to plants typical of particular ecosystem conditions (e.g., disturbance). Maintenance and calibration of sensors, especially pyranometers, would be an important concern.

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## LANDSCAPE PATTERN

**INDICATOR:** Patch Size and Perimeter-to-Area Ratio

**LINKAGE:** Response

**ENDPOINT:** Biodiversity

**STATUS:** High-Priority Research

Five indices for patch size and connectivity are considered: (1) perimeter-to-area ratio; (2) contagion or habitat patchiness; (3) gamma index of network connectivity; (4) Patton's diversity index; and (5) fractal dimension.

### 1. Perimeter-to-Area Ratio

**APPLICATION:** Patch dynamics have implications for movements of biota, nutrient cycling, and energy flux. Studies in many different ecosystems have demonstrated that a number of spatially related habitat attributes or landscape indices are related to animal diversity and abundance. This indicator will provide an index of terrestrial biotic integrity which can provide a measure of population viability, and will provide critical information which can be used for analysis and assessment of migratory patterns. Patch size is a critical consideration especially when connectivity between patches is poor. Many habitat patches in fragmented landscapes are too small to support viable populations, or even a single home range or territory of certain large mammal or bird species. The distribution of suitable habitat among patches of various size is just as important for animals as the total area of suitable habitat in a landscape.

Patch perimeter to area (edge to interior) ratio is a measure of habitat fragmentation. It is useful for forests, where the amount of forest edge relative to forest interior is known to be an important determinant of vertebrate community structure and population viability of forest interior species. The relationship is best documented for birds, where artificial edge favors "weedy" species over native species and increases rates of nest predation and cowbird parasitism on many forest species. Numerous studies have documented the deterioration of bird populations in landscapes with high edge-interior ratios, yet this variable has seldom been measured directly. For wetlands, the significance of shape in a monitoring context is in its relationship to loss of acreage and function over time.

The frequency of patches in various size categories would be plotted for each habitat type. This distribution could be compared with home range sizes or minimum areas required for population persistence for native vertebrates. The fractal dimension of patches is a measure of perimeter to area ratio and quantifies the dissectedness of boundaries (O'Neill et al., 1988); this indicator is discussed separately.

**INDEX PERIOD:** The optimal sampling window for remotely sensed data from which patch size and perimeter-to-area ratio are calculated is the growing season.

**MEASUREMENTS:** Measurements of patch areas and perimeters are relatively straightforward in many landscapes. They can be made manually on an aerial photo; for large areas, however, the use of a GIS and digital data are necessary. The land-use and vegetation-cover data to calculate these indices would be provided by the EMAP-Characterization group. The recommended interannual sampling frequency is 5 to 10 years.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage in the sampling units, the expected spatial variabilities of patch size and perimeter to area ratios are inconsequential. The temporal variabilities of patch size and perimeter to area ratios during the index period will produce extreme values that deviate < 10% from the sample mean.

**PRIMARY PROBLEMS:** No significant problems are anticipated.

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## 2. Contagion or Habitat Patchiness

**APPLICATION:** The horizontal heterogeneity or patchiness of a habitat is a primary determinant of animal diversity and abundance. Up to a certain threshold, increases in heterogeneity correspond to increased diversity of species, resources, and abundances of animals dependent on those resources. Patchiness is caused by resource heterogeneity (e.g., sinkholes, seeps, outcrops, unusual soils) and by disturbances (e.g., treefall gaps, spot fires, insects).

Contagion is a landscape index derived from information theory (Shannon and Weaver, 1962) as applied to landscape pattern (O'Neill et al., 1988). Contagion (C) measures the extent to which land uses are aggregated or clumped:

$$C = 2n \ln n + \bullet i \bullet j \, P_{ij} \ln P_{ij}$$

where $P_{ij}$ is the probability that a grid point of land use *i* will be found adjacent to a grid point of land use *j*. The term $2n \ln n$ represents a maximum in which all adjacency probabilities are equal; that is, for a randomly chosen spot on the landscape, there is an equal probability that any land use type is adjacent to the chosen point. At high values of *C*, the landscape tends to be composed of large, contiguous patches. At low values, the landscape is dissected into many small patches.

The index *C* used by O'Neill et al. (1988) retains a sensitivity to the number of land-use types that is avoided by using the recommended formulation:

$$C = \bullet i \bullet j \, P_{ij} \ln P_{ij} / 2n \ln n$$

Their study analyzed contagion for 94 quadrangles in the eastern United States and quantified the regional variability of this indicator by using data with a spatial resolution of 200 m. The contagion values ranged from 9.5 to 22.8, with a coefficient of variation of 0.16, and are believed to be fairly representative of landscapes in North America; however, this needs to be verified in the western United States.

**INDEX PERIOD:** The optimal sampling window for landscape data from which contagion is calculated is the growing season.

**MEASUREMENTS:** The land-use and vegetation-cover data to calculate this indicator would be provided by the EMAP-Characterization group. The recommended interannual measurement frequency is 4 to 5 years. At the landscape scale, contagion is a measure of patchiness.

Several measures of habitat patchiness for small geographic areas have been proposed. Roth (1976) used the coefficient of variation (CV) of distance to nearest trees and shrubs in point-quarter samples and found that bird richness and abundance increased in more heterogeneous areas. Noss (1988) tested several measures of habitat patchiness in a Florida hardwood forest, including: CV of distances to nearest trees, nearest shrubs, and all combined; CV of shrub density; CV of canopy openness, diversity of tree species, shrub species, and both combined; and proportion of plot area in canopy gaps, bayheads (dense broadleaf evergreen vegetation in seepage areas), and both combined. The best predictor of bird abundance was proportion of area in canopy gaps and bayheads combined. Species richness was significantly related only to variation in shrub density. Mapping these patches on sample plots through field surveys is straightforward, though time-consuming (but less time-consuming than using point-quarter samples). Current aerial photos, when observations are verified on the ground, may be more useful.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage within the landscape sampling units, the expected spatial variability of contagion or habitat patchiness within resource sampling units is inconsequential. The temporal variability during the index period was not estimated.

**PRIMARY PROBLEMS:** Some measures of habitat patchiness require detailed field surveys. However, direct measurement of patchiness for EMAP will be calculated from the program's landscape characterization data.

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## 3. Gamma Index of Network Connectivity

**APPLICATION:** The connectivity of habitat in a landscape is a measure of how easily individuals of a given animal species can travel about, which in turn is important to meeting daily and seasonal life history needs, allowing juvenile dispersal, escaping disturbance, and providing for gene flow. While in theory the usefulness of such as index appears logical, the data are lacking to support the application of this index to a specific species.

**INDEX PERIOD:** No optimal sampling window exists for remotely sensed data from which gamma indices are calculated.

**MEASUREMENTS:** The gamma index of network connectivity is the ratio of links in a network to the maximum possible number of links in that network. The formula is $y = L/Lmax = L/3(V - 2)$, where L is the number of links (i.e., corridors), Lmax is the maximum possible number of links, and V is the number of nodes (i.e., habitat patches; Forman and Godron 1986). The recommended interannual sampling frequency is 4 to 5 years.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage in the landscape sampling units, the expected spatial variability of the gamma index within resource sampling units is inconsequential. The temporal variability of the gamma index during the index period was not estimated.

**PRIMARY PROBLEMS:** This is a simple measure, but its ecological relevance is unknown. Connectivity in real landscapes would depend on habitat structure within corridors, the nature of surrounding habitat (matrix), corridor width:length ratio, and details of the autecology of species expected to use the corridor.

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## 4. Patton's Diversity Index

**APPLICATION:** Patton's diversity index (DI) is actually a measure of the amount of edge within an area of a given size (thus, it is a measure of habitat diversity). The amount of artificial edge in a landscape is a good index (inverse) of terrestrial biotic integrity, even though wildlife managers traditionally have considered edge to be beneficial because many game species are edge-adapted. A landscape is "less natural" the larger the amount of artificial edge.

**INDEX PERIOD:** The optimal sampling window for landscape data from which Patton's diversity index is calculated is the growing season.

**MEASUREMENTS:** This index is based on measurements from aerial photos. The land use and vegetation cover data to calculate these indices would be provided by the EMAP-Characterization group. The formula is DI = TP/2A (Patton, 1975), where TP is the total perimeter of an area plus any linear edge within the area and A is the total area. Thomas et al. (1979) split Patton's index into two indices, one each for inherent edge (the natural boundary between two plant communities) and induced edge (a boundary caused by disturbance, human or otherwise). Other considerations suggest separating edge into natural (created by either natural gradients or disturbances) and artificial (created by human land-use), because the latter tends to be longer-lasting and often associated with continuing human impact. Edges may also be classified on the basis of contrast between the two habitats. The recommended interannual sampling frequency is 5 to 10 years.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage in the landscape sampling units, the expected spatial variability of this index within a resource sampling unit is inconsequential. The temporal variability of Patton's DI during the index period was not estimated.

**PRIMARY PROBLEMS:** Thomas et al. (1979) comment that Patton's DI assumes that the total perimeter of an area is actually edge, whereas this is usually not true in an ecological sense. However, it would be simple to focus only on true edge (and, perhaps, only artificially-created edge) simply by not including perimeter of the sample area that abuts similar habitat.

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## 5. Fractal Dimension

**APPLICATION:** The fractal dimension, F, is a measure of the fractal geometry (Mandelbrot, 1983) and an index of the complexity of shapes on the landscape. If the landscape is composed of simple

geometric shapes like squares and rectangles, the fractal dimension will be small, approaching 1.0. If the landscape contains many patches with complex and convoluted shapes, the fractal dimension will be large (Krummel et al., 1987). F is calculated from maps of land use or vegetation cover and appears to be useful for characterizing landscape pattern (Krummel et al., 1987; O'Neill et al., 1988).

**INDEX PERIOD:** The optimal sampling window for remotely sensed data from which fractal dimensions are calculated is the period that best allows one to discriminate the habitat patterns of interest.

**MEASUREMENTS:** The fractal dimension is estimated by regressing the logarithm of polygon perimeter (dependent variable) against the logarithm of area (independent variable) for all patches on a digitized map. The fractal dimension is related to the slope of the regression, $S$, by the relationship (Lovejoy, 1982):

$$F = 2S$$

The land-use and vegetation-cover data to calculate these indices would be provided by EMAP-Characterization. The recommended interannual sampling frequency is 5 to 10 years.

O'Neill et al. (1988) analyzed the fractal dimension for 58 quadrangles in the eastern United States. This study quantified the regional variability of this indicator by using data with a spatial resolution of 200 m. The fractal dimension ranged from 1.24 to 1.45 with a coefficient of variation of 0.04. These values are believed to be fairly representative of landscapes in North America; however, this index needs to be verified for the western United States.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage in the landscape sampling units, the expected spatial variability of the fractal dimension within resource sampling units are inconsequential. The temporal variability of fractal dimension during the index period was not estimated.

**PRIMARY PROBLEMS:** The fractal dimension, as with some other landscape indices, is probably not a good indicator for a single measurement in time because we currently lack knowledge of how this parameter relates to ecosystem function. However, as an indicator of landscape pattern change over large geographic areas it should be powerful. Also, this indicator is probably most useful when used together with other landscape indices such as contagion and proportion of land use.

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**INDICATOR:** Habitat Proportions (Cover Types)

**LINKAGE:** Response, Habitat

**ENDPOINT:** Biodiversity

**STATUS:** High-Priority Research

**APPLICATION:** Mapping and determining proportions (Pi) of various land use or vegetation cover types in a landscape is a basic measurement when considering both extent and change in vegetation and associated animal composition and diversity (Noss, 1983). In addition, land use is an important factor in determining the type and amount of nonpoint-source pollutants entering inland and coastal waters.

Habitat proportions should be valuable for monitoring purposes because of the extensive development of Pi as a landscape property permitting application of percolation theory (Gardner et al., 1987). If habitat is randomly scattered on the landscape, then Pi = 0.59 represents a "percolating" habitat. Above this value of Pi, the habitat tends to be connected throughout the landscape, permitting animal populations to move across the entire available habitat and fully utilize the resource. If Pi is less than 0.59, then the habitat is disconnected and isolated into patches that make it much less available to animals (O'Neill et al., 1988). If, however, the habitat of concern is susceptible to disturbances such as fire, large values of Pi permit the disturbance to propagate throughout the landscape (Turner et al., 1989). If the assumption of random distribution of the habitat is relaxed, then percolation theory becomes more useful as an indicator for real landscapes.

**Near-Coastal and Inland Waters:** Proportions of land use have consistently explained variation in water chemistry for large geographic areas, especially for sediments and nutrients (Omernik, 1977; Hunsaker, 1986; Osborne and Wiley, 1988). This relationship exists because of the biogeochemical cycling that links terrestrial and aquatic systems and is dominated by nonpoint-source pollution in surface runoff from disturbed areas.

**Forests:** Monitoring the distribution of tree species is important for assessing the total extent and rate of change in extent of different forest types. Distribution patterns of vegetation result from interactions between natural and human-altered climatic, terrestrial, and biological habitat conditions (Braun, 1950; Daubenmire, 1947; Walter, 1973). Patterns of vegetation are thus in response to environmental conditions. Changes in conditions, either from natural (e.g., succession) or human-induced (e.g., timber harvest) influences can affect or stress the ecosystem and can alter the distribution patterns.

Monitoring the vegetative and physical structure of ecosystems is important because changes in structure may result in loss of desirable vegetation components (e.g., species, life forms, communities) or in acute cases, alteration of ecosystem function. An example of the latter case occurs in the northern forested region of the upper Midwest where historic logging, followed by extensive fires, entirely altered the forest vegetation, the forest floor litter, and the associated

surface water chemistry. Additionally, structural diversity has generally been shown to have a positive relationship with animal and plant species diversity (Short and Williamson, 1986).

**INDEX PERIOD:** The optimal sampling window for remotely sensed data from which habitat proportions are calculated is the growing season. An optimal measurement window for field surveys in all terrestrial resource classes is when perennial vegetation is in leaf-out condition; for arid lands, late spring to early summer is optimal. For remote sensing images, a high sun angle is good to reduce topographically induced illumination differences.

**MEASUREMENT:** Land use and land cover data can be classified from remotely sensed data, and the area of each type can be determined. If the images are in digital form, areal measures can be calculated by computer. The land use and vegetation cover data to calculate this indicator would be provided primarily by EMAP-Characterization studies and augmented by field survey data such as the USDA Forest Service FIA and FPM inventories. Standard digital image processing techniques would be employed, involving image-to-image registration and change detection procedures coupled with spectral classifications (Pilon et al., 1988). The recommended interannual measurement frequency is 5 to 10 years. The development of classifications for relevance to animal indicators is more difficult. Animal species can be associated with different vegetation types to estimate faunal composition, diversity, and relative abundances in sampling units. Such relationships will likely require field data collection to verify habitat classifications, but this work could be done when the animal data are being collected.

**VARIABILITY:** Because the remotely sensed data will provide 100% spatial coverage in the landscape sampling units, the expected spatial variability of habitat proportions within a resource sampling unit is inconsequential. The temporal variability of habitat proportions during the index period will produce extreme values that deviate $<10\%$ from the sample mean.

**PRIMARY PROBLEMS:** Ground verification and correspondence with selected animal indicators will require significant effort.

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**INDICATOR:** Linear Classification and Physical Structure of Habitat

**LINKAGE:** Exposure, Habitat

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** The structure of animal habitats in many terrestrial and in some wetland communities can be considered to consist of vertical layers and a horizontal distribution of habitat variables within each layer. The Habitat Linear Classification System (HLCS; Short, 1990) is a simple way to translate the vertical and horizontal dimensions of habitats into a numeric whose status and trends can be compared between sites or regions. The HLCS can be applied to different types and resolutions of monitoring data, such as satellite imagery and aerial photography (both verified on the ground and field surveys). Like the HLCS, The Habitat Layers Index (HLI; Short and Williamson, 1986) can be calculated from data at several spatial scales, and together these indices provide a way to evaluate and monitor habitat structure and to predict potential animal diversity from that structure.

Application of the HLCS to field survey data from south central Colorado indicated that the algorithm provides values that are linear as the number of clumped cells within the grid is increased, that an interpretable distinction could be made between n-cells that were clumped or dispersed within a grid, and that signatures from different habitats varied in a way that seemed related to the way animal species used those habitats.

It is important to have a habitat indicator that can measure fundamental land-use changes in agroecosystems and forests and reflect changes such asplant succession, urbanization, desertification, because these changes impact wild animals. Use of the HLCS will allow EMAP to characterize the effects of changing habitat on animals at a regional and national scale.

**INDEX PERIOD:** Field surveys to measure habitat variables for the HLCS should be conducted when vegetation is in full leaf.

**MEASUREMENTS:** To calculate the HLCS, map-based data are overlaid on a grid, or field survey data are collected from a gridded sampling unit. While only habitat layers are distinguished from remotely sensed data, a variety of habitat variables are distinguished from field surveys. Two metrics are developed for data about layers and variables: (1) the proportion of grid cells that contain a particular habitat layer or important habitat variable; and (2) the proportion of grid-cell perimeter segments that surround occupied cells. The HLCS will be most useful if field surveys in all terrestrial and suitable wetland resource classes are standardized, have a consistent format, and measure for the same variables. Variables include habitat layers, surface cover, and a variety of vegetative variables in surface, midstory, and overstory layers. The product of the analysis is a series of linear traits describing the individual habitat variables or layers within the grid. This series provides a "signature" that is descriptive of the habitat, and it is this signature to which status and trends can be compared among sites.

The analysis of habitat structure to implement the HLCS would cost approximately $500 to $1,000 for each resource sampling unit, the amount depending on habitat complexity. The recommended interannual sampling frequency is 5 years.

**VARIABILITY:** The expected spatial and temporal variabilities within a resource sampling unit and during the index period, respectively, were not established.

**PRIMARY PROBLEMS:** Research is needed to determine a best size for a survey grid and survey grid cells and the most efficient and cost-effective method to sample habitat variables.

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**INDICATOR:** Livestock Grazing

**LINKAGE:** Exposure, Habitat

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** The majority of areas to be monitored by the EMAP-Arid ecosystem group is subjected to livestock grazing, on both public and private lands. Although grazing is restricted or prohibited at some federal land holdings (national parks and wilderness areas), these areas account for only a small fraction of the total land area under consideration. Cattle and sheep grazing in the western United States has produced major impacts on 40 to 80 million hectares (100 to 200 million acres) of federal land (U.S. GAO, 1988). In addition to cattle and sheep, grazing by feral animals (wild horses and burros) must be considered. Grazing alters plant species composition and vegetation cover, impacts riparian systems, and can accelerate erosion (U.S. BLM, 1978). This indicator would provide estimates of grazing intensity, and it is applicable to all arid resource classes.

**INDEX PERIOD:** A seasonal record of actual use is required to document in terms of "animal unit months" the time over which an area has been grazed.

**MEASUREMENTS:** A livestock grazing record should be acquired for each resource sampling unit. The U.S. BLM (1978) describes the methods for collecting actual-use data. Actual use data consists of livestock counts, the kind or class of livestock, and the period(s) of time the livestock actually grazed the sampling unit (e.g., animal unit month). Several sources of actual use data exist and include the following:

(1) **Livestock Operator Reports:** Operators of grazing enterprises can be asked to submit reports documenting actual livestock grazing use. The U.S. Bureau of Land Management (BLM) and U.S. Department of Agriculture-Forest Service (USDA-FS) commonly request these reports to assess actual use and to calculate billings for federal land use.

(2) **USDA-FS and BLM Counts:** These two land management agencies often conduct head counts when livestock are moved onto or off their respective grazing allotments.

(3) **Direct Counts:** Field counts, aerial counts, and counts derived from low-altitude aerial photography are performed on localized areas by both the BLM and USDA-FS. Similar counts should be performed by EMAP field and aerial crews at the sampling units. This is the only technique that provides data on actual grazing by wild horses and burros.

The actual use data records would have to be acquired and processed to produce seasonal estimates of actual use. The estimated cost to acquire and process actual use data for a resource sampling unit is $500 a season.

**VARIABILITY:** The expected spatial variability of direct counts within a resource sampling unit would produce a range that deviates up to 100% from the mean value; the large variability is

expected because of the mobility of livestock within grazing units that include portions of sampling units. Because the measures integrate grazing intensity throughout the season, an estimate of temporal variability of direct counts during a season was not required.

**PRIMARY PROBLEMS:** The primary problems with estimating grazing intensity would be the development of reliable and sustainable sources of actual use data. EMAP crews would not be in the field often enough to produce an adequate record of actual use data; therefore, the reliability and coverage of the data record would have to be thoroughly reviewed and assessed.

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**INDICATOR:** Abundance or Density of Key Physical Features and Structural Elements

**LINKAGE:** Exposure, Habitat

**ENDPOINT:** Biodiversity

**STATUS:** High-Priority Research

**APPLICATION:** Research in many different ecosystems has demonstrated that certain physical features of habitats (e.g., cliffs, outcrops, sinks, seeps, talus slopes) and structural elements (e.g., snags, downed logs) are critical to animal diversity and abundance. Land-use practices, such as forestry, can alter the density and distribution of many important structural features. Many habitat features and elements are specific to particular resource classes, but determining what to measure in a given class can be based on existing literature.

**INDEX PERIOD:** No optimal sampling window exists for this indicator.

**MEASUREMENTS:** Identification of important features and elements in a particular resource class is the first step. This is followed by an inventory of these features through field and aerial surveys and a determination of their abundance or density in the resource sampling unit. The recommended interannual sampling frequency is 4 or 5 years.

**VARIABILITY:** The expected spatial variability for this indicator within a resource sampling unit and its expected temporal variability during the year have not been estimated.

**PRIMARY PROBLEMS:** Measuring the abundance or density of structural elements is straightforward, and is a longstanding tradition in wildlife biology. No problems are foreseen, except that the effort may be labor-intensive.

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## FIRE

**INDICATOR:** Occurrence and Area

**LINKAGE:** Exposure, Habitat

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High–Priority Research

**APPLICATION:** Fire occurs as a natural phenomenon in shrubland, grassland, chaparral, and woodland ecosystems. Fire plays a crucial role in the availability of plant nutrients in árid and semiarid regions where the rate of litter decay is low. In chaparral, fire removes overly matured stands of plants, allowing the vegetation in the burnt zone to be rejuvenated. Since the early 1900s, fires have been suppressed throughout the West. Gradually, however, land managers have realized the valuable aspects of wildfires and are reintroducing fire as a management practice in the USDA Forest Service and BLM.

Although fire is now recognized as having beneficial ecological effects, the timing and frequency of fires must be regulated to protect property and to avoid detrimental ecological effects. If fire occurs too frequently or if burning is too intensive, environmental damage such as the loss of soil nutrients, acceleration of erosion, or proliferation of less desirable plant species such as cheat grass (Bromus tectorum) can occur. For most areas there is an optimal frequency pattern for fire (e.g., once every 8 to 12 years) and an optimal season for producing a manageable and beneficial fire.

Fire frequency would be tracked by using remotely sensed data and verified with selective field surveys. In addition, fire hazard maps would be produced to indicate areas most prone to burning. This indicator is applicable to all arid resource classes.

**INDEX PERIOD:** The optimal sampling period is the peak growing season from midsummer to early autumn or when the incidence of fire is approaching zero.

**MEASUREMENTS:** The location and spatial dimension of recent burns would be determined by using Thematic Mapper (TM) satellite data. Burns retaining charcoal can be recognized by the unique spectral characteristics of charcoal: low reflectance in the visible and high reflectance in the TM bands at 1.65 and 2.22 $\mu$m. Burnt areas without the charcoal spectral signature would be identified by a combination of factors (Chuvieco and Congalton, 1988; Tanaka et al., 1983), including: (1) brighter reflectance than that of surrounding unburnt areas due the removal of litter and soil organic matter; (2) diagnostic shapes such as sharp boundaries, windblown stringers, and cleared firelines; and (3) a lower perennial vegetation cover inside recent burns or a higher annual vegetation cover than that of the surroundings. Burnt areas frequently remain visible to TM sensors for decades. Estimated cost of TM data analysis is $200 for each landscape sampling unit.

Fire hazard maps (Chuvieco and Congalton 1989) indicating the probability of burning would be prepared by using: (1) species composition and fuel loading; (2) elevation; (3) slope; (4) aspect;

and (5) proximity to roads, trails, or buildings. These data will be available from EMAP-Characterization studies and the "Species Composition and Ecotone Location of Vegetation". Estimated cost of constructing fire hazard maps is $200 for each landscape sampling unit.

**VARIABILITY:** The expected temporal variability during the index period for measurements of burn area derived from TM data would produce a range that deviates <30% from the mean value. The variability is induced primarily by systematic alterations in illumination conditions over the index period and can be largely eliminated by acquiring data with standardized illumination conditions. Because the entire resource sampling unit would be censused, the spatial variability of fire regime measures within a resource sampling unit is inconsequential.

**PRIMARY PROBLEMS:** Standardized measurement procedures must be developed.

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## RETROSPECTIVE

**INDICATOR:** Charcoal Record

**LINKAGE:** Response

**ENDPOINTS:** Biodiversity

**STATUS:** High–Priority Research

**APPLICATION:** The purpose of charcoal analysis in a monitoring program is to identify areas where plant communities are or were undergoing stress. When plant communities are under stress, fire frequency increases. Healthy communities are characterized by lower fire frequency. Actually, the relationship is much more complex than this description because, although a community may be unhealthy, the fire starting agent (e.g., lightning or man) must also be present. Fires reflect stress factors such as beetle kill, drought succeeding periods of wet climate when fuels were accumulating but not being burned off, or the impact of fires on accumulated fuels after fire suppression policies. In addition, periods of forest clearance by humans can be identified by periods in pollen records when charcoal abundance increases.

By constructing a charcoal record, a natural or baseline fire frequency can be determined for any plant community from which to judge current trends in fire frequency. Charcoal frequency is used more as a regional indicator than is pollen production. Because we can identify the origin of certain pollen types (e.g., aquatic and littoral plant pollen) as local rather than regional, we can separate between local and regional signals. This cannot be done with charcoal. Therefore, charcoal becomes by default an indicator of regional fire rather than local fire. Although a locally occurring fire may temporarily mask the regional charcoal fire record, with great quantities of charcoal, the use of several collection localities within a resource sampling unit would net a good regional record, because local fires can be factored out of the record.

**INDEX PERIOD:** Collection in early winter after the fire season is best, because the fire activity during the previous fire season can be assessed.

**MEASUREMENTS:** Two types of measurements must be taken: (1) Charcoal abundance: as with pollen abundance the use of tracers in the sample, given a standard sample volume or collection area size, can be used to derive charcoal abundance. (2) Charcoal size: changing size is monitored by direct measurement with an ocular micrometer. Both changing charcoal abundance and size can reflect both changing fire frequency and fuel type. Larger charcoal and more abundant charcoal is produced by pine forests than by sagebrush steppe. But when the environment remains the same, changing charcoal size and abundance reflect changing fire frequency and indirectly changing plant community health. Cost of charcoal analysis can be covered under the pollen analyses costs. As with pollen analysis, an interannual sampling frequency of the same frequency as is used for sampling fossil pollen cores would be adequate for revealing evidence of plant community stress or change.

**VARIABILITY:** The expected spatial variability of charcoal records within a resource sampling unit was not estimated. Because the charcoal records are temporally integrative measures, the variability during the index period is inconsequential.

**PRIMARY PROBLEMS:** As mentioned above, the primary problem would be a temporary masking of the regional charcoal record by local fires.

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**INDICATOR:** Dendrochronology: Trees and Shrubs

**LINKAGE:** Response

**ENDPOINT:** Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** Changes in growth-ring characteristics (e.g., annual ring width) over time can be calibrated with measures of plant productivity. For example, it would be feasible to reconstruct long-term (50 to several hundred years) changes of above ground biomass production in sagebrush or pinyon-juniper habitat types (Ferguson, 1964). Dendrochronology can also be used to date when trees and shrubs germinate and die and when growth is affected by anthropogenic factors such as pollution and land management practices.

The purpose of using time series of growth ring widths sampled from woody plants growing on climatically stressed sites is to 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. The long 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. For example, pollen records from locations with rapid deposition rates have the potential to be sampled at close intervals, so that each represents a brief period of time.

Although arid ecosystem research has focused on tree rings of conifers such as pinyon, the dendrochronological/ecological approach is potentially applicable to any woody shrub, including sagebrush, with definable annual growth layers.

**INDEX PERIOD:** Normally one ring a year is added, although in years of extremely favorable climate, a double growth flush may occur; in drought years a tree may not add a ring completely around its circumference. Radial increment cores can be obtained from trees and woody shrubs at any time of the year, but the complete growth ring for a given year will be present only after the end of the growing season. For example, in the Great Basin this occurs in early autumn.

**MEASUREMENTS:** Annual growth layers from radial cores are measured under microscopic magnification to the nearest 1 μm on a computer-compatible linear measurement apparatus. A large body of micromainframe software is available to analyze the resultant series of ring-width measurements. Each time series of tree ring widths (representing one core) is standardized to a mean of 1 and relatively constant variance over time by fitting a growth function to account for the age trend. This procedure allows the growth records from slower growing older trees and faster growing younger trees to be averaged into a mean value function. The older trees normally contain a stronger climatic signal than younger trees, whose growth often reflects the effects of competition for water, nutrients and sunlight, and canopy position. The mean value function represents tree growth for one species at one location (stand) over time. The annual growth record can normally be calibrated numerically with time series of climatic data during the years of common overlap. If a verifiable numerical relationship can be established for the period of instrumental climatic record, the equation can be applied to the lengthy tree ring series to reconstruct past climate. In many arid regions the potential exists to create climatic reconstructions for the past 500 to several thousand years. A concise record of climate may be essential in establishing the frequency of climatic events that can dramatically alter ecological systems.

**VARIABILITY:** The quantitative variability in ring-width index can closely correspond to macroclimatic variability, according to the sampling design employed. Growth of trees and shrubs sampled on sites where climate limits the physiological processes controlling growth can be highly correlated with climate (60 to 80% variance in growth attributable to climate). Because climate can limit growth simultaneously at many locations in a region, it is not unrealistic to expect 50 to 75% variance in common among chronologies within a resource sampling unit. Woody plants sampled on sites where climate is not the primary stressor will reflect the influence of other factors such as competition and microclimate and will have little correlation with regional climate or with one another. Because the dendrochronological records are temporally integrative measures, the variability during an index period is inconsequential.

**PRIMARY PROBLEMS:** Reconstructing climate from wood-ring series is normally not a problem in the West. One factor of prime importance is the availability of meteorological data to calibrate with the wood-ring series. Lower elevations generally have the greatest density of weather stations, whereas information from higher elevations is more sparse. Wood-ring series can be used to reconstruct climate at considerable distances from where the trees are sampled. One common misconception concerns the difference between ring counting to date annual growth layers and a dendrochronological approach involving a procedure referred to as cross-dating. Cross-dating establishes the exact calendrical date of every ring in every radial increment core, by an exacting comparison of the growth patterns among all specimens. Ring counting does not yield exact growth ring dates, because a ring may be locally absent along a radius, or there may be a double growth flush in one year. If a dendrochronological approach utilizing cross-dating is not employed, any environmental information present in the series may be lost.

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**INDICATOR:** Pollen Record

**LINKAGE:** Response

**ENDPOINTS:** Biodiversity

**STATUS:** High–Priority Research

**APPLICATION:** Pollen analysis can be used to identify past changes in plant communities. Interannual comparisons of stress are reflected in a decrease in both pollen production and pollen size. Once stress is removed (e.g., increased precipitation) both pollen production and pollen size increase. Over several years, changing proportions of pollen types will reflect community response to changing stress conditions. Pollen obtained from pollen cores of intense sampling can be used to extend these observations back in time beyond the brief period of environmental monitoring that is reflected in historical records.

**INDEX PERIOD:** The collection of samples is best in the autumn after the late summer and early autumn bloom is completed. This way the annual pollen output can be fully characterized.

**MEASUREMENTS:** In general, measurements of pollen production, size, and changing proportions are best taken from samples obtained near the edge of a plant community, where plants are most stressed naturally. Samples taken from well within a plant community would be less sensitive. Three types of measurements must be taken:

(1) **Pollen abundance:** Knowledge of the deposition rate through the use of tracers would reveal changing pollen production of both individual species and the community as a whole.

(2) **Pollen size:** Through measurements using an ocular micrometer, the mean and standard deviation of the pollen grain size distribution would reveal annual changes.

(3) **Relative abundance of pollen types:** Changing proportions would reveal the community response to stress factors.

Some species respond to stress more quickly and reflect this response in changed outputs of pollen; longer term changes in species distribution also affect pollen production. The estimated processing cost is $180 a sample; the collection of pollen cores adds about $50 a sample. A sampling frequency of one year is adequate for revealing evidence of stress or changes in the plant community.

**VARIABILITY:** The expected spatial variability of pollen records within a resource sampling unit was not estimated. Because the pollen records are temporally integrative measures, the variability during the index period is inconsequential.

**PRIMARY PROBLEMS:** The viability of this indicator is mainly constrained by logistics. To best implement such an indicator, hundreds of pollen collection localities would have to be located and traps prepared within each resource sampling unit. Collection would have to be completed by

winter snowfall, but after bloom-time. A network of pollen traps would have to be placed along elevation gradients and in areas where they would not be disturbed by vandals or human activities (e.g., plowing) that would resuspend pollen in the air.

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**INDICATOR:** Woodrat Midden Record

**LINKAGE:** Response

**ENDPOINT:** Biodiversity

**STATUS:** High-Priority Research

**APPLICATION:** The plant remains in strata of woodrat midden (den content) reveal long-term plant species community response to climatic and other environmental changes. Both plant species presence and health can be monitored on the scale of decades to tens of thousands of years. Community composition can be assessed by the presence or absence of plant species, and community health can be monitored by actual measurement of plant remains.

**INDEX PERIOD:** This indicator is insensitive to time of year and can be sampled at any time.

**MEASUREMENTS:** The sample interval depends upon the spacing of woodrat midden strata in time and the period included in each stratum. This can range from a woodrat midden sample with a decade to a century of material in each stratum and a century to many millenia between strata. The three primary measurements of woodrat midden data are as follows.

(1) The materials of identified plant species are weighed separately to arrive at nonparametric quantifying of the midden materials.

(2) The plant parts (e.g., seeds, fruits, leaves) of identified species are enumerated.

(3) The size of fruits and seeds is recorded, because a change in size through time and among strata can reflect stress upon the plant community.

Both (1) and (2) above are dependent upon not only abundance in the plant community, but also upon the foraging behavior of the woodrat. The estimated cost from collection to analysis is about $1,000 a sample.

**VARIABILITY:** Because woodrat midden strata are heterogeneous units, the spatial variability of plant species composition within a resource sampling unit can be considerable. Because the midden records are temporally integrative measures, the variability during the index period is inconsequential.

**PRIMARY PROBLEMS:** The primary problem is related to the influence of woodrat foraging behavior upon the material collected for the den and its placement in the den; therefore, data retrieved from a woodrat den cannot be quantified in the same way as dendrochronological, pollen, or charcoal data.

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## WILDLIFE HABITAT

**INDICATOR:** Species Composition and Ecotone Location of Vegetation

**LINKAGE:** Response, Habitat

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** Species composition and ecotone location are important integrators of environmental change in arid and semiarid regions. These parameters could :(1) determine the effectiveness of land management practices; (2) detect the response of vegetation to man-made stressors; and (3) detect vegetation response to fluctuations or alterations in long-term climate patterns.

Vegetation patterns in the arid zones frequently have sharp boundaries between competing plant assemblages. These boundaries are known as ecotones. A prime example of a prominent ecotone is the boundary between sagebrush and pinyon-juniper woodlands in the Great Basin area covering Nevada and Utah. Another example is the distinct boundary separating annual grasslands from chaparral on the central California coast. The position of these ecotones is known to respond to changes in climatic regime. These ecotones can be readily located on Thematic Mapper (TM) satellite data. This capability offers a tool for detecting vegetation shifts in response to climatic change or changes in land-use practices or other agents.

Species composition responds to a large number of factors, including grazing pattern, changes in soil properties, fire, mechanical disturbances, erosion, water availability, and climatic fluctuations and alterations. The spatial and spectral resolutions of current satellite data are too coarse to adequately determine species composition in most sparsely vegetated arid landscapes. The measurement of species composition would require low-altitude aerial photography and field measurements. This indicator would be applicable to all arid resource classes.

**INDEX PERIOD:** The optimal sampling window would be during the growing season from late spring to early autumn, when most species are flowering.

**MEASUREMENTS:** Species composition and ecotone locations would be measured by using low-altitude aerial photography ( < 1 m resolution) and field measurements. Trained interpreters can quantify species composition and delineate ecotones from aerial photographs or airborne video data. Driscoll and Reppert (1968) provide a description of these techniques. Field measurements of species composition would be reported in two ways: (1) number of individuals per unit area (density) of a species; and (2) the areal cover of a species as a fraction of the total ground cover. Methods for conducting field measurements are available (U.S. BLM, 1985). Estimated costs for the analysis of aerial photography is $1,000 for each resource sampling unit. Estimated costs for field measurements of species composition is $300 a resource sampling unit; cost will vary with each type of vegetation community.

Although satellite imagery is not useful for making diagnostic identifications of species composition, it can be used to monitor ecotone movement. TM data would be used to delineate the ecotone of adjacent vegetation types. This procedure can be performed by using the results of field and aerial photograph surveys to provide actual species compositions. Changes in ecotone location can then be monitored with repeated coverage by satellite sensors. Estimated cost is $500 per landscape sampling unit.

**VARIABILITY:** Estimates of species composition for annual plants are subject to wide seasonal variation; perennial plant measurements would be less variable. The expected spatial variability of species composition within a resource sampling unit would produce a range that deviates 5 to 10% from the mean value and would be different for each plant community.

**PRIMARY PROBLEMS:** The standardization of measurement practices would be the foremost problem encountered in the application of this indicator.

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**INDICATOR:** Relative Abundance: Animals

**LINKAGE:** Response

**ENDPOINTS:** Biodiversity, Aesthetics

**STATUS:** High-Priority Research

**APPLICATION:** The ecological condition of a community can sometimes be assessed by the condition of a few species or categories of species (guilds) that play critical roles. Although the indicator species concept has not fared well in recent reviews (Landres et al., 1988), many ecologists agree that attention to particular species is valuable for community-level monitoring. The relative abundance or, where more feasible presence or absence of species including exotics, keystone species, and sensitive species (e.g., listed threatened and endangered species) in a community should be tracked as an index of community condition. This indicator is related to many environmental values, including aesthetics, biodiversity, productivity, and sustainability.

To begin addressing which species or guilds should be monitored in each ecological resource class, EMAP hosted an animal indicator workshop in March 1990 that included a select group of biologists and ecologists whose specialties together spanned a range of animal types. The result of the workshop suggested certain animal types as appropriate indicators for each ecological resource category, based on the EMAP indicator selection criteria and field experience. Because of their consistently high relative score among all resource categories, birds were selected as the animal type that should be measured in all categories. Likewise, the low relative marks for large mammals and snakes prompted their elimination from immediate consideration. The nonavian vertebrate and invertebrate types that were suggested as appropriate indicators of the animal condition in each ecological resource category or subcategory are as follows:

### Inland Waters

Vertebrate: Turtles, Frogs, and Salamanders
Invertebrate: Snails

### Wetlands

Vertebrate: Turtles, Frogs and Salamanders
Invertebrate: Snails/Slugs

### Coniferous Forests

Vertebrate: Salamanders
Invertebrate: Ground-Dwelling Beetles and Snails and Slugs (Northwest only)

### Deciduous Forests

Vertebrate: Salamanders and Lizards (Southwest only)
Invertebrate: Ground-Dwelling Beetles, Ants, and Snails and Slugs

### Tundra

Vertebrate: Small Mammals
Invertebrate: Bees

### Arid Shrublands and Grasslands

Vertebrate: Lizards and Tortoises
Invertebrate: Grasshoppers, Ants, Termites, and Ground-Dwelling Beetles (Great Basin only)

### Mesic Shrublands

Vertebrate: Small Mammals and Lizards
Invertebrate: Butterflies and Ants

### Mesic Grasslands

Vertebrate: Small Mammals and Lizards
Invertebrate: Grasshoppers, Ground-Dwelling Beetles, and Termites

### Agroecosystems

Vertebrate: Small Mammals
Invertebrate: Grasshoppers and Bees

**INDEX PERIOD:** The optimal sampling window during a year depends on the season of peak activity of the species to be sampled. The suggested sampling season is spring for **lizards, tortoises, frogs, toads, salamanders,** and **bees**; summer for **turtles** and **termites**; late summer for **small mammals** and **grasshoppers**; early and late summer for **butterflies**; and spring to autumn for **ground-dwelling beetles, snails** and **slugs**, and **ants**. The suggested window for **birds** is a month in duration and depends on latitude, ranging from May in the south to early July in the north. Sampling should be avoided during moonlit nights and stormy weather.

**MEASUREMENTS:** Relative abundances or presence/absence of the identified animal types would be determined by means of standard sampling techniques for the taxa; a leading sampling technique for **small mammals, ground-dwelling beetles, lizards, frogs, toads, salamanders**, and some **ants** includes use of permanent pitfall can traps (opened only for optimal sampling periods). The pitfall traps would contain ethylene glycol to kill and preserve the specimens between site visits. The sampling technique for **snails** and **slugs** uses small squares of untreated lumber, whereas the technique for **ants** and **termites** involves placing toilet paper rolls in the traps. Standard sweep-sample techniques currently exist for sampling **grasshoppers**, but sticky traps may become the standard grasshopper collection technique in the future. **Bees** and **butterflies** can be collected by netting along line transects; colony bees can be collected from hives, and cavity-nesting bees can be sampled by using wood blocks with holes.

The most cost-effective census technique for **birds** would be point counts, whereby a trained observer notes all birds seen or heard during a specified length of time (usually 5 to 15 min). A trained birder can perform 5 to 10 point counts in one morning; ideally three replicates should occur

annually at a point. Another possible indicator taxon with high mobility is the **bat**; a sampling technique is being developed that utilizes tape recorders with photocells that record bat sonar at set intervals. Tape recorders are also being investigated for use in bird censusing.

For animal types other than birds, approximately 30 stations for each sampling technique would be placed along a line transect within a resource sampling unit. Stations must be located both in the center and edge areas of this sampling unit. These provide relative abundances, when all species in the taxonomic or functional group of interest are tallied from the sample. Absolute abundance, on the other hand, requires intensive mark-recapture or repeated observations, which are cost-prohibitive over large geographic regions. The recommended interannual sampling frequency would be four years.

**VARIABILITY:** The spatial variability of relative species abundances or presence or absence within a resource sampling unit using common techniques would be dependent on the taxa sampled. The expected temporal variability of relative species abundances during the index periods would also be dependent on taxa.

**PRIMARY PROBLEMS:** (1) Abundances of all but the most conspicuous species (such as large birds and mammals in open habitats) are notoriously difficult to assess with accuracy; however, standardized census techniques allow valid comparisons for a site (or better yet, a series or group of sites) over time. (2) Pitfall traps result in the destructive sampling of organisms. Sherman live traps can be used for small mammals; however, live traps would not be as cost-effective because they are not permanent, capture fewer animals, and require more frequent site revisitation. Destructive sampling, however, will enable the possible application of other indicator types (e.g., contaminants in tissues and biomarkers) and removes animals at a resource sampling unit only once every four years. (3) Bird point counts introduce a bias toward calling birds. (4) Presence or Absence measurements contain less information that relative abundance but may be logistically more feasible for EMAP.

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**INDICATOR:** Demographics: Animals

**LINKAGE:** Response

**ENDPOINTS:** Sustainability

**STATUS:** Research

**APPLICATION:** Population vigor is reflected in the recruitment of individuals (birth rate and their survivorship) into and through the breeding population. Analysis of demographic variables such as age structure, sex ratio, fertility, mortality, survivorship, and dispersal may be particularly worthwhile for populations of keystone species that are known to be sensitive to a particular disturbance. These measurements are the traditional tools of animal biologists and managers for assessing population "health" (Schemnitz, 1980).

**INDEX PERIOD:** The optimal sampling window during a year depends on species to be sampled, but should be within the season of peak activity regardless.

**MEASUREMENTS:** A detailed life table is informative but its construction is laborious. Estimates of fertility and mortality (birth and death rates) can be obtained through observations or estimates, especially of marked individuals. Dispersal may be difficult to document with the EMAP sampling design. For species that can be separated into general age classes, a portrayal of the age structure of the population may be a good indicator. Temple and Wiens (1989) suggest that primary population parameters (birth, death, and dispersal rates) for birds may provide a better indication of response to environmental change than secondary population parameters (population size, density, habitat occupancy, age structure, sex ratio, proportion of breeders). In addition, numerous studies of bird nesting and fledgling success have revealed that these may be sensitive indicators of response to stress. Many fish and game agencies collect information on sex ratio, density, birth/death, harvest, and dispersal rates. This data could supplement data collected by EMAP resource groups. The recommended interannual sampling frequency is 3 or 4 years, although some parameters may need more frequent monitoring.

**VARIABILITY:** The expected spatial and temporal variabilities of demographic parameters within a resource sampling unit and during the index period, respectively, were not estimated because specific demographic parameters, species, and individuals were not defined explicitly.

**PRIMARY PROBLEMS:** Most demographic variables can be measured only through detailed study. EMAP observations are expected to be limited to no more than two brief field visits at a resource sampling unit in any given year, so demographic parameters will probably not be estimated. When primary population parameters are used, it is important to look for compensatory effects (e.g., an increase in mortality accompanied by an increase in fecundity or survivorship). If secondary population parameters are used, then time lags, site fidelity, and compensation may prevent short-term responses to environmental perturbations from being noticed (which is sometimes helpful, but also obscures response to certain stressors).

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**INDICATOR:** Morphological Asymmetry: Animals

**LINKAGE:** Response

**ENDPOINTS:** Sustainability, Aesthetics

**STATUS:** Research

**APPLICATION:** Fluctuating asymmetry (FA) is the morphological variability demonstrated by an individual organism. FA in structures of bilaterally symmetrical organisms (e.g., fin rays, teeth, limb bones, fingertip ridges, wing length) can be an early-warning indicator of population responses to environmental and genetic stress. The application of this indicator may be worthwhile for species that are known to be sensitive to a particular disturbance, including exposure to pesticides, heavy metals, and other pollutants, hybridization, and inbreeding. Each has been found to result in FA for various species.

**INDEX PERIOD:** The optimal sampling window during a year depends on species to be sampled, but should be within the season of peak activity.

**MEASUREMENTS:** No single character may provide an adequate measure of response; hence, a composite index containing information from several characters is preferred. Many of these indices, including their statistical strengths and weaknesses, are discussed by Palmer and Strobeck (1986). Leary and Allendorf (1989) note that relatively sedentary organisms (closely associated with a local environment) and ectotherms (whose development may be more sensitive to environmental and genetic variation) may be the best candidates for measurement of FA. The recommended interannual sampling frequency is 4 or 5 years.

**VARIABILITY:** The expected spatial variability of the fluctuating asymmetry index within a resource sampling unit was not estimated because the index and species were not explicitly defined; however, the relationship of FA with character size is troubling, as variance increases with increasing character size. Because differences in FA among samples are usually small, confounding factors such as measurement error can be important. The expected temporal variability of demographic parameters during the index periods was not estimated because index periods were not defined explicitly.

**PRIMARY PROBLEMS:** Measurement error may be the largest obstacle in discriminating differences in FA among populations; however, a rigorous quality management program can keep such errors to a minimum.

## REFERENCES:

**Leary, R.F., and F.W. Allendorf**. 1989. Fluctuating asymmetry as an indicator of stress: Implications for conservation biology. Trends Ecol. Evolut. 4:214-217.

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**INDICATOR:** Biomarkers

**LINKAGE:** Exposure, Habitat

**ENDPOINTS:** Sustainability

**STATUS:** Research

## DNA Alteration: Adducts

**APPLICATION:** Recent field studies (Dunn et al., 1987; Varanasi et al., 1989; Stein et al., 1990) with benthic fish have begun to validate the use of DNA adducts (using the $^{32}P$-postlabeling assay technique) as a biomarker of exposure to genotoxic compounds. For example, comparison of the levels of total hepatic DNA adducts in English sole from Puget Sound, Washington, to sediment levels of high-molecular-weight polycyclic aromatic hydrocarbons revealed a general concordance between these variables that suggests that adduct counts appear to be reflective of the degree of exposure (Varanasi et al., 1989; Stein et al., 1990).

The $^{32}P$-postlabeling technique shows particular promise as a screening technique because it has a very low limit of detection (one adduct in $10^9$-$10^{10}$ nucleotides) and does not require the characterization of individual adducts before they are measured. A further important advantage is that it is a nonspecific procedure that can detect a variety of bulky aromatic adducts in animals exposed to complex mixtures of contaminants. Although a positive response is indicative of exposure to chemical(s), with sufficient toxicological information and identification of particular adducts, data obtained by this technique may be diagnostic of environmental genotoxicity.

The technique can be implemented immediately with little or no lag time; however, only a few "dedicated" laboratories are currently available to perform this type of analysis. The geographical range of test species within a resource class must be considered.

**INDEX PERIOD:** No temporal limitations are known to exist; however, no sampling period during the year is known to have minimal temporal variability in adduct measures.

**MEASUREMENTS:** DNA adducts, enzymatically tagged with a radiolabeled component [$^{32}P$], are separated by thin-layer chromatography (TLC), detected by autoradiography, and quantified by Cerenkov counting (Randerath et al., 1981; reviewed by Watson [1987]). In this procedure (summarized by Gupta and Randerath [1988]), DNA is enzymatically hydrolyzed to 3'-monophosphates of normal DNA nucleotides and adducts. The adducts are then enriched relative to the normal nucleotides, $^{32}P$ label is incorporated (leading to [5'-$^{32}P$]-3',5'-biphosphates), and the remaining normal nucleotides and adducts are separated by multidimensional TLC. Finally, the adducts are detected by autoradiography and quantitated by scintillation counting. Sample collection times for a suite of biomarker indicators are from 0.5 to 1.0 day at each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for DNA adducts is $150 to $200 per sample.

**VARIABILITY:** The expected spatial variability of adduct measures within a resource sampling unit and their temporal variability throughout the year were not estimated.

**PRIMARY PROBLEMS:** Although the cost is moderate, the $^{32}P$-postlabeling assay is currently more laborious than other biomarker-type assays, requires substantial training of personnel before it can be routinely used, and involves the use of high-specific-activity $^{32}P$, which necessitates the use of special precautions to minimize exposure to radioactivity. Additionally, this technique is semiquantitative, and generally the procedure for its use varies from one laboratory to another. Finally, in TLC chromatograms of DNA from organisms exposed to complex mixtures of contaminants, a radioactive zone is routinely observed, which appears to represent multiple overlapping adducts and makes it difficult to relate individual spots (adducts) to specific chemicals. Recent advances in chromatographic conditions (Randerath et al., 1989), however, suggest that the resolution of multiple adducts can be increased, which should aid in characterizing individual adducts in organisms exposed to unknown mixtures of chemicals, and thus may increase the chemical specificity of the $^{32}P$-postlabeling assay.

A recent study by Kurelec et al. (1990) illustrates, however, the need for further in-depth field studies of DNA adducts as a biomarker of exposure to genotoxic compounds. In this study, five species of fish exhibited several qualitatively similar adducts irrespective of whether the fish were sampled from apparently unpolluted or polluted sites. These findings emphasize the need to conduct future field validation studies that incorporate additional measures of contaminant exposure in individual organisms in order to clearly demonstrate that the levels of DNA adducts are related to exposure. Furthermore, these studies illustrate a disadvantage of the $^{32}P$-postlabeling assay, in that careful selection of appropriate control sites is a critical factor in the current use of this technique for measuring DNA adducts.

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**Watson, W.P.** 1987. Post-radiolabeling for detecting DNA damage. Mutagenesis 2:319-331.

## DNA Alteration: Secondary Modification

**APPLICATION:** Numerous toxic chemicals cause strand breaks in DNA, either directly or indirectly which causes an unwinding or secondary modification of the DNA molecule. The alkaline unwinding assay can estimate the increase in the level of breaks above background that result from exposure to toxins. The technique can be applied to the analysis of many samples without the need for costly reagents or laboratory equipment. For field studies, laboratory analyses are performed on live animals or frozen tissues. Data is available within a few hours and is best interpreted along with data collected from other biomarkers. The method is ideally suited as a screening technique for the routine in situ monitoring of environmental species because the analysis is easy and its cost is low. A positive result can be seen as a "red flag," because in theory, exposure to any genotoxic chemical will elicit such a response.

Using this method, Shugart (1988a,b) has demonstrated that alkaline unwinding is significantly faster in the DNA of fish that were chronically exposed to genotoxic agents than in control fish. Additionally, it was shown that fish DNA from polluted areas unwound faster than DNA of fish from nonpolluted areas, indicating sensitivity to xenobiotic substances in their environment (Shugart, 1990). In addition, analyses have been conducted in numerous environmental species including oysters and mussles (Nacci and Jackim, 1990), desert rodents (Shugart, 1989), and turtles (Meyers et al., 1988).

The method is sensitive, amenable to routine laboratory analyses, and immediately available for field studies. The geographical range of test species within resource classes must be considered.

**INDEX PERIOD:** No temporal limitations are known to exist; however, no sampling period during the year is known to have minimal temporal variability for measuring this indicator.

**MEASUREMENTS:** Alkaline unwinding is a sensitive analytical technique which has previously been used in cell cultures to detect and quantify DNA strand breaks induced by physical and chemical carcinogens (Ahnstrom and Erixon, 1980; Kanter and Schwartz, 1979, 1982; Daniel et al., 1985). To assess the level of DNA strand breaks in environmental species intact, highly polymerized DNA is required (Shugart, 1988a,b). DNA isolation is accomplished by homogenizing appropriate tissue in 1 N $NH_4OH$/0.2% Triton X-100. DNA is recovered by differential extraction with chloroform/isoamyl alcohol/phenol (24/1/25-v/v) and passage through a molecular sieve column (Sephadex G50). Strand breaks are measured in the isolated DNA by an alkaline unwinding assay (Kanter and Schwartz, 1979, 1982; Shugart, 1988a,b). The technique is based on

the time-dependent partial alkaline unwinding of DNA followed by determination of the duplex:total DNA ratio (F value). Because DNA unwinding takes place at single-strand breaks within the molecule, the amount of double-stranded DNA remaining after a given period of alkaline unwinding will be inversely proportional to the number of strand breaks present at the initiation of the alkaline exposure, provided renaturation is prevented. The amounts of these two types of DNA are quantified by measuring the fluorescence that results with bis-benzimidazole - Hoechst dye #33258. The test response is quite sensitive to toxins, and changes are readily discerned, provided proper baseline or reference data are available.

Rydberg (1975) has established the theoretical background for estimating strand breaks in DNA by alkaline unwinding, which is summarized by the equation:

$$\ln F = -(K/M)(tb)$$

where $K$ is a constant, $M$ is the average molecular weight between two breaks, $t$ is time, and b is a constant less than 1 which is influenced by the conditions for alkaline unwinding.

The relative number of DNA strand breaks (N value) of an organism from a control site can be compared to that from a reference site as follows (Kanter and Schwartz, 1982; Shugart, 1988a,b):

$$N = (\ln F_c / \ln F_r) - 1$$

where $F_c$ and $F_r$ are the mean $F$ values of DNA from the control site and reference site, respectively. N values greater than zero indicate that DNA from the sampled sites has more strand breaks than DNA from the reference site; for example, an $N$ value of 5 indicates five times more strand breakage.

Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day at each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for alkaline unwinding is $25 a sample.

**VARIABILITY:** Existing data suggest the spatial variability of this indicator within a resource sampling unit would be low. Its expected temporal variability throughout the year was not estimated.

**PRIMARY PROBLEMS:** No major problem is known to exist that would prevent the immediate use of this measurement in the field.

## REFERENCES:

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## DNA Alteration: Irreversible Event

**APPLICATION:** The measure of irreversible DNA alteration is a screening technique that indicates subclinical expression of mutagenic damage.

**INDEX PERIOD:** No constraints on the sampling period are recognized. Because the period with minimum temporal variability is unknown, no index period has been suggested.

**MEASUREMENTS:** Flow cytometry (FCM) measures various cellular variables in suspended cells (Shapiro 1988). Measurable variables include levels of DNA, RNA, protein, and specific chemicals (using immunofluorescent probes), and numerous morphological attributes that affect time of flight and various light-scatter parameters. Some flow cytometers can analyze as many as eight parameters from 10,000 cells a second. Cell-sorting capabilities are available on many flow cytometers.

The application of flow cytometry to the study of environmental mutagenesis was reviewed by Bickham (1990). The primary parameter of interest in such studies is DNA content, which can be measured with a high degree of precision and accuracy. Laboratory challenge experiments have shown that exposure to mutagenic chemicals and ionizing radiation result in a broader nuclear or chromosomal DNA distribution; a positive relationship between exposure and a broader

distribution exists, both in vivo (Bickham, 1990) and in vitro (Otto et al., 1981). Bickham (1990) concluded that FCM is a highly sensitive assay for the effects of environmental mutagens. Advantages of FCM over other cytogenetic and cytometric techniques include lower cost, greater rapidity, greater sensitivity due to the vast number of cells analyzed, and tremendous diversity of application to which FCM is suitable. For example, virtually any tissue can be examined (whereas chromosomal assays are limited to rapidly proliferating tissues such as bone marrow), so the effects of organ-specific mutagens can be investigated. With the use of multiparameter analysis, specific cell types can be differentiated and analyzed. Moreover, FCM is easily adapted for use on species in which chromosomal analysis is difficult (Bickham et al., 1988; Lamb et al., 1990).

FCM has also identified a potential qualitative difference in the response of animals to chronic environmental and acute laboratory mutagen exposure. Aneuploid mosaicism was observed in animals exposed at low frequency to environmental mutagens in each of three studies (McBee and Bickham 1988; Bickham et al., 1988; Lamb et al., 1990). Such mosaicism was not observed in animals from control sites or in animals exposed to acute laboratory doses (Bickham, 1990). This demonstrates the capability of FCM to identify multiple populations of cells that might have subtle differences in DNA content and to identify low-frequency variant cells.

For use as an initial screening procedure, FCM has tremendous potential because of low cost and high sensitivity. Hundreds of thousands of cells from scores of individuals can be analyzed quickly, in a matter of a few days if necessary. This techniques can be useful both in the initial screening for effects and in the subsequent evaluation of the level of damage of environmental mutagens. FCM can also be used to evaluate almost any species and tissue type, so the degree of impact of an environmental insult can be investigated. Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day at each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for flow cytometry is $25 to $75 a sample.

**VARIABILITY:** FCM has been extensively validated as a laboratory procedure for evaluating acute exposure to mutagenic chemicals. Field studies have demonstrated the efficiency of FCM in measuring the effects of chronic exposure to chemical pollutants (McBee and Bickham, 1988) and low-level radioactivity (Bickham et al., 1988; Lamb et al., 1990). The expected spatial variability of this indicator within a resource sampling unit and its expected temporal variability throughout the year were not estimated.

**PRIMARY PROBLEMS:** No major problem is known that would prevent its immediate use.

## REFERENCES:

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## Cholinesterase Levels

**APPLICATION:** The diagnosis of exposure to neurotoxic chemicals such as organophosphates and carbamates (insecticides) usually relies on the measurement of acetylcholinesterase (ACh-ase) activity, because inhibition of this critical enzyme is the mechanism by which these agents exert their neurotoxic effect. Measurement of ACh-ase activity not only monitors physiological response; the technique is also diagnostic because the enzyme activity can be compared to results from previous studies on the sublethal and lethal effects of these neurotoxic chemicals in a variety of vertebrates and invertebrates. Use of brain tissue is considered the most reliable approach because inhibition most closely correlates with other toxic effects, including mortality. However, nondestructive, sequential sampling can be accomplished in a single individual by examining blood for ACh-ase activity. Such repeated measures can be useful in a field situation to document exposure and subsequent recovery. It is anticipated that the degree of ACh-ase depression from normal levels could be used as an integrative, functional, nondestructive measure of exposure.

There is extensive literature available that is useful for interpreting ACh-ase activity data in a variety of species (e.g., Fairbrother et al., 1989). The biomarker has been extensively field tested.

**INDEX PERIOD:** An important consideration is the effect of generally short half-lives of organophosphorous compounds and carbamates (in the environment and in biological tissues) on the duration of ACh-ase activity. Seasonal effects also are a factor.

**MEASUREMENTS:** ACh-ase activities are measured in brain tissue and blood plasma. Ellman et al. (1961) is a generally cited reference describing the ACh-ase assay that is currently undergoing the American Society for Testing and Materials (ASTM) standardization process. For monitoring avian and fish exposures, greater than 20% inhibition of ACh-ase activity has been used as an index for significant exposures and greater than 50% inhibition as indicative of lethal exposures. Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day for each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for measuring ACh-ase activity is $25 to $75 a sample.

**VARIABILITY:** ACh-ase activity can be affected by physiological factors, and these need to be considered in interpreting data. The expected spatial variability of Ach-ase measures within a resource sampling unit and their temporal variability during the year were not estimated.

**PRIMARY PROBLEMS:** No major problems are recognized.

## REFERENCES:

**Ellman, G.L., K.D. Courtney, V. Andres, and R.M. Featherstone**. 1961. A new and rapid colorimetric determination of acetylcholinesterase activity. Biochem. Pharmacol. 7:88-95.

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## Metabolites of Xenobiotic Chemicals

**APPLICATION:** The identification of certain metabolites of xenobiotic chemicals in animals confirms that toxicants have entered cells and interacted with molecular targets; in this way, supporting evidence can be provided that a population response is attributable to biochemical stress from xenobiotic compounds. These metabolite biomarkers can be used to assist in such diagnoses since the nature and proportions of metabolites of xenobiotic chemicals in various tissues have been extensively studied (Creaven et al., 1965; Lee et al., 1972; Melancon and Lech, 1976; Krahn and Malins, 1982).

The feasibility of using xenobiotic metabolite formation as a biomarker depends on the sensitivity of the analytical methods employed for their detection and quantitation. The presence of such metabolites may be assessed by detection and quantitation of free and conjugated metabolites in tissues, body fluids, or excreta. Determination of the metabolites of polycyclic aromatic hydrocarbons (PAHs) in tissues and of PAHs and chlorinated phenols in bile of fish as a biomonitoring method is currently ready for use in environmental monitoring (Lee et al., 1972; Krahn and Malins, 1982).

**INDEX PERIOD:** If measurements of metabolites are to be undertaken in wild populations of organisms, initial sampling efforts must be designed so that temporal variability throughout the year can be tested. Also, variability in feeding times (e.g., in the case of biliary metabolites), sex, maturity, and environmental temperatures are ancillary factors that must be considered, any of which may dictate a stratified sampling program. Several treatments of environmental sampling design are available that can be used to help in design of a statistically sound sampling strategy.

**MEASUREMENTS:** Most of the analytical procedures used for measuring free and conjugated metabolites involve chromatographic techniques including gas chromatography and high-pressure liquid chromatography (with or without enzymatic hydrolysis). A limitation of many of these procedures is the lengthy preparation time required before the sample is subjected to analysis. Thus, the efficiency and cost-effectiveness of metabolite biomarkers could be significantly improved by developing procedures such as an immunoassay for sensitive, rapid measurement of metabolites in a large number of samples.

A variety of factors, including reproductive state, temperature, and dietary status, can influence metabolite production. The influence of various factors on metabolite proportions has been the

focus of more limited studies. For example, during feeding, the bile and its associated metabolites are discharged from the gall bladder. In females during egg production, a number of biochemical changes occur that can affect production of metabolites. These include steroid-synthesizing cytochrome P-450 isozymes that can affect oxidation rates of xenobiotics and types of metabolites produced. Also, there is increased lipid synthesis needed for egg production, which may facilitate metabolite production. Eggs may sequester certain types of metabolites. Ancillary measures of these influential factors must be made to account for their effects on metabolite production.

Sample collection times for a set of biomarker indicators are from 0.5 to1.0 day for each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for metabolite measures is $25 to 75 a sample.

**VARIABILITY:** The expected spatial variability of metabolite measures within a resource sampling unit was not estimated. The expected temporal variability of metabolites was not estimated because the index period was not defined; however, the temporal variability could be significant because of the relatively rapid

pharmacodynamics of many metabolites. Nevertheless, field trials have demonstrated clear statistical differences between exposed and unexposed populations (Melancon and Lech, 1976; Krahn and Malins, 1982).

**PRIMARY PROBLEMS:** Species-specific information is needed to expand the utilization of metabolites as biomarkers beyond fish and the aquatic environment. In addition, if metabolites are to be used as biomarkers of effect, more information is needed to relate the presence of specific metabolites of xenobiotics in organisms to toxic effect.

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# APPENDIX B

## SITE LOCATION MAPS

The maps contained in this Appendix provide site locations for the various monitoring and sampling programs discussed in Chapter 6.

# APPENDIX C

## Analytical Capabilities

TABLE C1. ANALYTICAL CAPABILITIES FOR ORGANIC COMPOUNDS

| | |
|---|---|
| **Organochlorine Scan** | |
| o,p′ - DDE | cis-chlordane |
| o,p′ - DDD | trans-nonachlor |
| o,p′ - DDT | cis-nonachlor |
| p,p′ - DDE | trans-chlordane |
| p,p′ - DDD | Heptachlor Epoxide |
| p,p′ - DDT | Hexachlorobenzene |
| Lindane | Mirex |
| Dieldrin | BHC |
| Endrin | Toxaphene (estimated total) |
| Oxychlordane | PCBs (estimated total) |
| **Photomirex and Degradates** | |
| 8-monohydromirex | |
| 10-monohydromirex | |
| 2,8-dihydromirex | |
| cis-5,10-dihydromirex | |
| trans-5,10-dihydromix | |
| **Chlorophenoxy Acid Herbicides Scan** | |
| 2,4-D | Dicamba |
| 2,4-DB | Silvex |
| 2,4,5-T | Dichlorprop |
| **Other Individual Organic Analyses** | |
| Dicofol | PCB Aroclors: |
| Endosulfan (I, II) | PCB-1242 |
| Endosulfan Sulfate | PCB-1248 |
| Kepone | PCB-1254 |
| Oil and Grease | PCB-1260 |
| Octachlorostyrene | |

TABLE C1. (continued)

## Anti-cholinesterase Compounds

**Carbamate Scan**

Methiocarb
Methomyl
Aldicarb
Carbaryl
Carbofuran
Oxamyl

**Organophosphate Scan**

Acephate
Azinphos-methyl
Chlorpyrifos (Dursban)
Coumaphos
Demeton (two peaks)
Diazinon
Dichlorvos
Dichrotophos
Disulfoton
EPN
Ethoprop
Dimethoate
Fensulfothion
Famphur
Fenthion
Malathion
Methamidophos
Methyl Parathion
Mevinphos
Monocrotophos
Parathion
Phorate
Terbufos
Trichlorfon

TABLE C1. (continued)

| Petroleum Hydrocarbon Compounds | |
|---|---|
| **Aliphatic Hydrocarbon Scan** | **Polycyclic Aromatic Hydrocarbon (PAH) Scan** |
| n-dodecane | naphthalene |
| n-tridecane | fluorene |
| n-tetradecane | phenanthrene |
| octylcyclohexane | anthracene |
| n-pentadecane | fluoranthrene |
| noncylohexane | pyrene |
| n-hexadecane | 1,2-benzanthracene |
| n-heptadecane | chrysene |
| pristane | benzo (b) fluoranthene |
| n-octadecane | benzo (k) fluoranthene |
| phytane | benzo (e) pyrene |
| n-nonadecane | benzo (a) pyrene |
| n-eicosane | 1,2,5,6-dibenzanthracene |
| | benzo (g,h,i) perylene |

TABLE C2. GUIDELINES FOR ESTIMATING DETECTION LIMITS FOR SELECTED ELEMENTS ANALYZED BY INDUCTIVELY COUPLED PLASMA EMISSION SPECTROSCOPY (ICP)[1]

| ELEMENT | WATER | | SEDIMENT | | TISSUE | |
|---|---|---|---|---|---|---|
| | w/o Precon[2] | Precon | w/o Precon | Precon | w/o Precon | Precon |
| Ag | 0.05 | 0.01 | 8 | 2.5 | 20 | 4 |
| Al | 0.1 | 0.02 | 20 | 5 | 40 | 8 |
| As | 0.7 | NA | 20 | NA | 30 | NA |
| B | 0.06 | 0.01 | 10 | 2.5 | 20 | 4 |
| Ba | 0.05 | 0.01 | 5 | 2.5 | 20 | 4 |
| Be | 0.005 | 0.001 | 0.5 | 0.01 | 2 | 0.4 |
| Cd | 0.006 | 0.001 | 1 | 0.25 | 2 | 0.4 |
| Cr | 0.03 | 0.003 | 5 | 0.5 | 4 | 0.8 |
| Cu | 0.025 | 0.005 | 2.5 | 1.25 | 10 | 2 |
| Fe | 0.1 | 0.02 | 10 | 5 | 40 | 8 |
| Mg | 1 | 0.2 | 100 | 50 | 400 | 80 |
| Mn | 0.015 | 0.003 | 1.7 | 0.75 | 6 | 1.2 |
| Mo | 0.05 | 0.01 | 8 | 2.5 | 20 | 4 |
| Ni | 0.04 | 0.008 | 6 | 2 | 16 | 3.2 |
| Pb | 0.06 | 0.02 | 12 | 5 | 40 | 8 |
| Sb | 0.05 | 0.01 | 30 | NA | 15 | 2 |
| Se | 0.5 | 0.05 | 50 | NA | 50 | 2 |
| Sn | 0.05 | 0.009 | 30 | 2.5 | 20 | 4 |
| Sr | 0.01 | 0.002 | 2 | 0.5 | 4 | 0.8 |
| Tl | 0.5 | 0.05 | 50 | 5 | 50 | 0.5 |
| V | 0.05 | 0.01 | 5 | 2.5 | 20 | 4 |
| Zn | 0.02 | 0.004 | 10 | 1 | 4 | 1.6 |

Sample Weights:

water - minimum 200 ml, standard 500 ml
tissue - minimum 7.5 g, standard 25 g
sediment - minimum 10 g, standard 50 g

[1] Concentrations are reported as μg/g dry weight for tissue and sediment or μg/ml for water. Detection limits are also greatly affected by sample size.

[2] Precon = Preconcentration, an acid digestion (pH 3 or 6) to decrease the lower limit of detection.

TABLE C3. GUIDELINES FOR ESTIMATING DETECTION LIMITS FOR SELECTED ELEMENTS ANALYZED USING GRAPHITE FURNACE ATOMIC ABSORPTION SPECTROSCOPY*

| ELEMENT | WATER | TISSUE | SOIL/SEDIMENT |
|---|---|---|---|
| Ag | 0.001 | 0.40 | 0.2 |
| Al | 0.10 | 10 | 5.0 |
| As | 0.005 | 0.5 | 0.7 |
| Be | 0.002 | 0.05 | 0.2 |
| Cd | 0.001 | 0.4 | 0.2 |
| Cr | 0.003 | 0.3 | 0.5 |
| Cu | 0.01 | 1.0 | 0.5 |
| Fe | 0.002 | 0.2 | 0.4 |
| Mn | 0.001 | 0.1 | 0.2 |
| Mo | 0.002 | 0.3 | 0.8 |
| Ni | 0.003 | 0.5 | 0.6 |
| Pb | 0.001 | 0.4 | 0.5 |
| Sb | 0.004 | 0.4 | 0.5 |
| Se | 0.004 | 0.6 | 1.0 |
| Sn | 0.01 | 1.0 | 2.0 |
| Tl | 0.004 | 0.4 | 0.6 |
| V | 0.003 | 0.3 | 0.6 |

Sample Weights:

water - minimum 10 ml, standard 500 ml

tissue - minimum 0.1 g, standard 25 g

soil/sediment - minimum 0.2 g, standard 50 g

*NOTE: Concentrations are reported as μg/g dry weight for tissue and sediment or μg/ml for water. Detection limits are also greatly affected by sample size.

TABLE C4. GUIDELINES FOR ESTIMATING DETECTION LIMITS FOR SELECTED ELEMENTS ANALYZED USING HYDRIDE GENERATION ATOMIC ABSORPTION SPECTROSCOPY*

| ELEMENT | WATER | TISSUE | SOIL/SEDIMENT |
|---|---|---|---|
| As | 0.002 | 0.8 | 0.3 |
| Sb | 0.002 | 0.8 | 1.0 |
| Se | 0.002 | 0.2 | 0.3 |

Sample Weights:

water - minimum 10 ml, standard 50 ml

tissue - minimum 1 g, standard 1 g

soil/sediment - minimum 0.5 g, standard 1 g

*NOTE: Concentrations are reported as ug/g dry weight for tissue and sediment or ug/ml for water. Detection limits are also greatly affected by sample size.

TABLE C5. GUIDELINES FOR ESTIMATING DETECTION LIMITS FOR MERCURY ANALYZED BY COLD VAPOR REDUCTION ATOMIC ABSORPTION SPECTROCOPY*

| ELEMENT | WATER | TISSUE | SOIL/SEDIMENT |
|---|---|---|---|
| Hg | 0.0004 | 0.1 | 0.2 |

Sample Weights:

water - minimum 25 ml, standard 100 ml

tissue - minimum 5 g, standard 15 g

soil/sediment - minimum 1 g, standard 5 g

*NOTE: Concentrations are reported as ug/g dry weight for tissue and sediment or ug/ml for water. Detection limits are also greatly affected by sample size.

TABLE C6. DETECTION LIMITS AND SAMPLE WEIGHT REQUIREMENTS FOR ORGANIC ANALYSES*

| MATRIX | COMPOUNDS | Detection Limit ppm, wet weight | Sample Wt. (g) Minimum | Sample Wt. (g) Optimal |
|---|---|---|---|---|
| TISSUE/ SEDIMENTS | Pesticides(1) | 0.01 | 10 | 100 |
| | PCBs | 0.05 | 10 | 100 |
| | Toxaphene | 0.05 | 10 | 100 |
| | Aromatics (PAHs) | 0.01 | 10 | 100 |
| | Aliphatics | 0.01 | 10 | 100 |
| | Kepone | 0.01 | 10 | 100 |
| | Oil and Grease | 500 | 20 | 100 |
| | Chlorophenoxy Acid Herbicides | 0.01 | 50 | 100 |
| | Organophosphates | 0.10 | 10 | 20 |
| | Carbamates | 0.10 | 10 | 20 |
| WATER | Pesticides(1) | 0.005 | 100 | 1000 |
| | PCBs | 0.100 | 100 | 1000 |
| | Toxaphene | 0.100 | 100 | 1000 |
| | Aromatics (PAHs) | 0.005 | 500 | 1000 |
| | Aliphatics | 0.005 | 500 | 1000 |
| | Kepone | 0.005 | 100 | 1000 |
| | Chlorophenoxy Acid Herbicides | 0.005 | 200 | 1000 |
| | Organophosphates | 0.001 | 500 | 1000 |
| | Carbamates | 0.001 | 500 | 1000 |

(1) Includes organochlorines, kepone, dicofol, endosulfans, photomirex, and octachlorostyrene.

*NOTE: Detection limits are determined, to a large extent, by sample weights. The detection limits given are based on optimal sample weights.

TABLE C7. DETECTION LIMITS FOR POLYCHLORINATED DIBENZO-P-DIOXINS AND DIBENZOFURANS (PCDD/PCDF)*

| ANALYTE | DETECTION LIMIT (pg/p) |
|---|---|
| TCDD, TCDF | 1 |
| PeCDD, PeCDF | 2 |
| HxCDD, HxCDF | 4 |
| HpCDD, HpCDF | 10 |
| OCDD, OCDF | 40 |

* T = Tetra
Pe = Penta
Hx = Hexa
Hp = Hepta
Oc = Octa

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## Porphyrin Accumulation

**APPLICATION:** Heme biosynthesis is a vital process for animals to maintain an adequate blood cell count, because the heme molecule is the building block for blood cells. When a chemical is known to have a specific effect on heme biosynthesis, abnormalities of porphyrin metabolism may provide a method for assessing exposure (Elder and Urquhart, 1987). Conversely, patterns of porphyrin accumulation in tissues and excreta may be used to predict the sites of action of chemicals within the pathway of heme biosynthesis (Marks, 1985). Thus the analyses of porphyrins may be used in a diagnostic manner.

Chlorinated aromatics such as polychlorinated biphenyls (PCBs) and heavy metals such as Pb may disturb porphyrin metabolism in mammals and birds. In chemically induced porphyrias, these chemicals or their metabolites modify the activity of one or more of the enzymes involved in heme biosynthesis, resulting in an alteration in the size and/or composition of the porphyrin pool (Goldstein et al., 1973; Strik, 1979). Available evidence in birds suggests that porphyrins are promising as a biomarker in field studies. This biomarker is currently accepted as a biomarker in human studies.

**INDEX PERIOD:** No temporal limitations are known to exist; however, no index period during the year is known to have minimum temporal variability.

**MEASUREMENTS:** Analysis involves homogenizing the liver in 3 N HCl to extract the porphyrins and determining individual protoporphyrins by their fluorescence. Uroporphyrin can be determined directly on the HCl extract by its specific fluorescence. The spectrum of protoporphyrins present can be determined by high-pressure liquid chromatography with fluorescence detection.

An example of the use of porphyrins in ecological studies is exposure of mallard ducks to Pb. Pb inhibits the activity of heme synthetase, the enzyme responsible for incorporating Fe into protoporphyrin IX to form heme. As a result, protoporphyrin accumulates in the peripheral blood, where it can be measured by a simple fluorescence technique. Using a hematofluorometer, Roscoe et al. (1979) reported increased levels of protoporphyrin in a single drop of untreated blood following administration of Pb shot to mallard ducks. Following the administration of 1 to 18 number 4 Pb shot, the blood concentrations of protoporphyrin IX were related to clinical signs of Pb poisoning. Although death corresponded to protoporphyrin IX concentrations >800 g/dL in penned ducks, lesser concentrations would probably lead to death in the wild. For a study of Pb

exposure in two types of pen-reared and wild ducks, toxicity and lethality corresponding to much less elevated blood protoporphyrin IX concentrations (<800 g/dL) are reported (Rattner et al. 1989).

Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day for each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for porphyrin measures is $25 to $75 a sample.

**VARIABILITY:** A study of herring gulls from the Great Lakes may serve as an example of the spatial variability of porphyrin measures within a resource sampling unit. Fox et al. (1988) have shown that gulls from contaminated areas have considerably higher concentrations of highly carboxylated porphyrins in liver than gulls from "clean" areas. In the areas studied, the frequency of levels >10 times the median of the control (clean) values ranged from 22 to 100%. The expected temporal variability for porphyrin in animal liver throughout the year was not estimated.

**PRIMARY PROBLEMS:** Information on species other than birds will enable further utilization of porphyrins in ecological monitoring programs.

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## Histopathologic Alterations

**APPLICATION:** Histopathological alterations are most valuable as an indicator of exposure to a variety of anthropogenic pollutants. Because the alterations occur after physiologic or biochemical

perturbation, the responses may be thought of as integration of molecular changes at the cell, tissue, and organism level. This indicator is distinguished from (response) indicators of gross pathology in that its measures are not highly perceptible to the unaided eye. The utility of histopathological alterations as biomarkers is most studied in teleost fish, but changes in tissues and cells occur in all vertebrates and invertebrates, and laboratory studies of histopathological consequences of toxic exposure are well documented. No resource specificity or geographic limitations are apparent.

The techniques used to monitor this indicator are ready for field use. Considerable testing has been completed in the laboratory, but an inadequate application to field studies is the major cause of lack of historical data. The Status and Trends Program (mussel watch) of the U.S. National Oceanographic and Atmospheric Administration (NOAA) and limited monitoring efforts attest to the utility of these approaches.

**INDEX PERIOD:** Although season-related variation exists, no specific sampling window during the year was proposed.

**MEASUREMENTS:** Extensive methodology exists for the determination of tissue, cellular and subcellular responses. New plastic embedment procedures improve resolution without appreciably increasing cost. Histopathologic measures demonstrated to be useful as biomarkers include the following.

(1) **Hepatocellular necrosis and sequelae:** This includes coagulative necrosis associated with exposure to anthropogenic environmental toxicants in both mammals and fish (Wyllie et al. ,1980; Meyers and Hendricks, 1985; Popper, 1988), regenerative hyperplasia indicative of extensive prior necrosis, and bile ductular/ductal hyperplasia, a lesion of chronic duration consistently found in wild fish from impacted sites (May et al., 1987).

(2) **Spongiosis hepatis:** this results from fibroblastic transformation of Ito cells (Yamamoto et al., 1986) and observed in winter flounder of coastal New England, English sole in Puget Sound, and in fishes collected from impacted sites in the Kanawha River of West Virginia.

(3) **Hepatocytomegaly:** enlarged hepatocytes seen as an early change in English sole of Puget Sound, Washington (Myers et al., 1987), in sea pen cultures of Atlantic salmon in Puget Sound (Kent et al., 1988), and in livers of pond-cultured fingerling striped bass (Groff, 1989), or as a rare form of chronic swelling of endoplasmic reticulum cisternae encountered in high prevalence in winter flounder of Boston Harbor and nearby estuaries (Murchelano and Wolke, 1985).

(4) **Foci of staining alteration:** an early stage in the spectrum of lesions seen between normal and tumor-bearing liver that have been associated with eventual tumor formation (Hendricks et al., 1984).

(5) **Liver neoplastic lesions:** examples are hepatic adenoma, hepatocellular carcinoma, cholangioma, and cholangiocarcinoma.

Although somewhat subjective, user-oriented computer software for the quantification of lesions exists. When applied to characterize magnitude of response, data amenable to statistical

evaluation are obtainable. Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day for each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for histopathologic measures is $50 to $100 a sample.

**VARIABILITY:** Responses are easily recognized provided that proper reference and control data are available. Physiologic and sex-related variation exists and must be taken into account, but should not prevent the immediate application of histopathologic biomarkers because normal variation is at cell and subcellular level of organization, whereas effective biomarkers involve tissue components. The expected spatial variability of hispathologic alterations within a resource sampling unit and the expected temporal variability of these alterations during the index period were not estimated.

**PRIMARY PROBLEMS:** An experienced histologist is required for proper interpretations of slides.

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## Macrophage Phagocytotic Activity

**APPLICATION:** The immune system, in its capacity to destroy foreign material and protect the host against disease, can serve as a useful sentinel of the health status of environmentally stressed organisms. Several responses have been used as measures of immune function and status, including lymphocyte mitogenesis (Laudenslager et al., 1983; Spitsbergen et al., 1986), antibody-producing cell formation (Anderson et al., 1983), antibody production (O'Neill, 1981), and nonspecific macrophage activity (Weeks et al., 1986, 1987, 1988; Weeks and Warinner, 1984; Wishovsky et al., 1990). These and other elements of the immune system have been shown to be affected (depressed or stimulated) by exposure to toxicants. The nonspecific macrophage activity assays have been extensively field tested, primarily in fish, and are suited to a screening-level evaluation of an important component of the immune system.

This indicator has been tested in fish specimens obtained from contaminated and uncontaminated estuarine waters and in experimentally exposed animals; it is considered ready for regional evaluation.

**INDEX PERIOD:** Although field experience with this assay has been limited to fish specimens sampled during the late spring through autumn months (these fish species are unavailable during the winter months), the assay method is believed to be applicable during all seasons.

**MEASUREMENTS:** Macrophage activity is evaluated by isolating macrophages and measuring either directly by microscopically observing the active uptake of foreign particulate matter (phagocytosis), or indirectly by measuring the chemiluminescence resulting from the production of reactive oxygen intermediates that accompanies macrophage ingestion of foreign matter. The macrophage phagocytosis assay measures the percentage of macrophages capable of ingesting formalin-killed Escherichia coli during an incubation period of 90 to 120 min at 15C. The macrophage suspension is washed and placed on microscope slides, which are differentially stained and examined under oil immersion microscopy. It is easily and inexpensively carried out, requiring only standard laboratory equipment and techniques. In the chemiluminescence assay, macrophages are stimulated by using soluble (phorbol myristate acetate) or particulate (zymosan or bacteria) stimuli in the presence of luminol, which enhances the emitted luminescence. Photon emission is measured with a liquid scintillation counter or luminometer. The procedure is rapid (30 to 60 min), inexpensive, and easily performed.

Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day for each resource sampling unit for two to three technicians. The estimated laboratory analysis cost for phagocytotic activity measures is $25 to $75 per sample.

**VARIABILITY:** The variability of phagocytotic activity among replicates from fish populations maintained in the laboratory has been minimal (approximate coefficient of variation was 25 to 30%). The expected spatial variability of phagocytotic activity within a resource sampling unit and its expected temporal variability throughout the year were not estimated.

**PRIMARY PROBLEMS:** Despite the considerable similarity in immune system functions across species, some development work is necessary to test and validate these assays for invertebrates and for mammals. Further research is needed to develop more quantitative relationships that may permit this assay to be considered a biomarker of potential adverse effects. To increase this biomarker's utility for diagnosing chemically induced disfunction of the immune system component, laboratory studies of fish exposed to selected contaminants should be performed to evaluate the immumodulatory effects of individual aquatic contaminants.

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## Blood Chemistry

**APPLICATION:** Blood chemistry assays basically evaluate performance of an animal's organ systems in vivo. Direct assessment of organ function is sometimes useful when other tests are ineffectual or cannot be performed. Circulating concentrations of biochemicals associated with the General Adaptation Syndrome are a function of their secretion into and clearance from the blood. Even though these indicators are representative of physiological functions in the organism, most are biochemical in nature and could serve in a restricted sense as screening indicators of exposure. Lag time between exposure to stress and biochemical response is typically short (within minutes to hours), and the response may persist for some time (days to months) following exposure.

Blood chemistry assays are simple to administer, objective, and in many cases interpretable. Many of these types of measurements have been taken on a wide variety of fish under a variety of environmental conditions and are basically ready for use in field situations. The underlying physiological bases for measurable changes are usually understood and can be traced in many instances to specific tissue and organ dysfunctions. For many of the cell/tissue/organ dysfunction indicators, however, use in routine monitoring is recommended provided that they are used in conjunction with other bioindicators at higher levels of biological organization (e.g., histopathological or bioenergetic parameters, growth) until the link between blood chemistry and organ dysfunction is better understood (see also "Cholinesterase Levels").

**INDEX PERIOD:** No index period is known to have minimal temporal variability. Although season may affect the absolute values of some parameters, comparisons can be made between animal data collected within the same season.

**MEASUREMENTS:** Indicators of cell/tissue/organ dysfunction represent a wide variety of assays including: (1) serum enzymes (i.e., lysosomal enzymes, transaminases), (2) electrolyte homeostasis (e.g., $Na^{2+}$, $K^{+}$), (3) carbohydrate and lipid metabolism (glucose, triglycerides), (4) endocrine-related hormones (i.e., corticosteriods, catecholamines), and (5) reproductive hormones (i.e., estradiol, testosterone). These five groups of circulating chemicals represent

myriad physiological processes and functions in the organism, and most groups should be chosen as indicators with care relative to the species, environmental conditions, state of development, and sex of the organism which is being monitored.

Because many of these variables are biochemical level indicators, they are short-lived in the blood and should be measured at discrete time periods of short intervals. Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day per resource sampling unit for two to three technicians. The estimated laboratory analysis cost for blood chemistry is $25 per sample.

**VARIABILITY:** Because of the short-lived nature of chemicals in the blood, the sample variability for most of these chemical parameters is relatively high. The independent variables which can influence the timing and magnitude of these variables in the blood are size, sex, age, and state of development of the organism and environmental factors such as season, temperature, food availability, habitat availability, and population density. Much information exists in the literature relative to the variability of many circulating blood parameters, particularly the more common commercial and sport species of fish (i.e., salmonids, centrachids) and domesticated animals (e.g., cattle, sheep, horses). The expected spatial variability of blood chemistry measures within a resource sampling unit and their temporal variability throughout the year were not estimated.

**PRIMARY PROBLEMS:** One major constraint is that normal or reference values for most species have not been statistically established for field situations. Before these types of measures serve as early warning signals of impending effects at the organism, population, or community level, some research is needed to establish the relationship between these types of assays and responses observed at higher levels of biological organization.

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## Cytochrome P-450 Monooxygenase System

**APPLICATION:** The cytochrome P-450 monooxygenase system is most valuable as a screening indicator of exposure to a variety of petroleum hydrocarbons (particularly polycyclic aromatic hydrocarbons [PAHs]) and halogenated hydrocarbons (dioxins, polychlorinated biphenyls [PCBs], PBBs). In some cases such as PAHs, it may be viewed as a diagnostic indicator because monooxygenase activity is required for activation to ultimate carcinogens. Lag time between exposure and response is typically short (within hours). Response generally persists throughout exposure and for some time thereafter (days to weeks), but method selection is important here (see Measurements). Its utility as a biomarker is most studied in teleost fish, but inductions of the system apparently occur in all vertebrates. No resource specificity or geographic limitations exist.

This technique is ready for field testing; in fact, considerable field testing has occurred in the case of petroleum-related contamination of aquatic systems with encouraging results. Considerable basic and applied research, however, is required for this approach to reach its potential as a biomarker for routine regional monitoring.

**INDEX PERIOD:** As with biochemical indicators in general, monooxygenase responses can be measured at discrete points in time. No temporal constraints are known, although active reproductive status may reduce baseline enzyme activity and/or the induction response to contaminants.

**MEASUREMENTS:** Several approaches are available; see Payne et al. (1987) and Stegeman and Kloepper-Sams (1987) and references therein. Simplest and least expensive, and often most sensitive, are associated enzyme activities such as ethoxyresorufin O-deethylase and aryl hydrocarbon hydroxlyase; these are measured spectrophotometrically, typically on microsomal fractions of hepatic or other (kidney, gut, heart, gill) tissues that are obtained by ultracentrifugation. However, chronic exposures sometimes can result in loss of activity following inductions. Considerably more involved, but quite powerful, techniques involve immunochemical assays for specific cytochrome P-450 isozymes and CDNA probes for messenger RNAs for specific isozymes. These have indicated inductions following losses of catalytic activity (as indicated by the enzyme assays mentioned earlier). Additionally, the greater specificity of these latter approaches can provide clues concerning the chemical compounds underlying an observed induction.

Most techniques available merit adaptations to make them simpler and more available for routine biomonitoring. Sample collection times for a set of biomarker indicators are from 0.5 to 1.0 day per resource sampling unit for two to three technicians. The estimated laboratory analysis cost for enzyme analysis is $25 to $75 per sample. Test responses are quite sensitive to petroleum

hydrocarbons and changes are relatively easy to discern provided proper reference or baseline data are available.

**VARIABILITY:** The expected spatial variability of this indicator within a resource sampling unit and its temporal variability throughout the year were not estimated.

**PRIMARY PROBLEMS:** The types of compounds these responses are useful for appear to be somewhat limited, particularly in fish, but considerable species (across vertebrate taxa) variation occurs, and research in this area is needed. It is also important to note that some compounds (some solvents and metals) can inhibit these responses and could lead to "false negatives" in cases where inducers co-occur with such inhibitors. A constraint here is the lack of adequate historical data for establishing baseline values for most species of potential interest. Considerable research is needed in the area of chemical interactions before this technique is relied upon in situations evaluating highly complex mixtures.

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## Enzyme-Altered Foci

**APPLICATION:** Enzyme-altered foci (EAF) refer to the appearance of hepatocytes (identifed by histochemical changes) that are an early stage in a spectrum of lesions in the progressive development of neoplasia. With histochemical procedures to localize selected enzymes, altered phenotypes of "carcinogen-initiated" cells are demonstrated. EAF are most valuable as an indicator of prior exposure of the host to one of a variety of chemical carcinogens. First described in rodent liver, EAF have been shown to increase in a dose-dependent fashion with application of compounds to promote liver tumors (Pitot, 1988; Hinton et al., 1988; Hendricks et al., 1984; Nakazawa et al., 1985). Lag time between exposure and effect is likely to be weeks in duration. Because growth of foci occurs with application of promoters, focal volume may indicate both initiation and promotion. Care in method selection is important because negative and positive markers exist (Peraino et al., 1983).

This technique is ready for field testing, although developmental research (species specific) is required to bring this approach to its full potential as a biomarker for routine regional monitoring.

**INDEX PERIOD:** No optimal sampling window was recommended; however, no apparent temporal constraints exist.

**MEASUREMENTS:** Field samples can be quenched in liquid N and stored indefinitely. Processing includes routine cryostat sectioning of frozen tissue (livers of large fish) or freeze-drying and

embedment in glycol methacrylate using nonexothermic polymerization steps (small fish or early life forms). With the latter processing, nine enzyme reactions (Hinton and Lauren, 1989) have been proven useful. Several approaches are available (see Pretlow et al., 1987; Peraino et al., 1983).

**VARIABILITY:** The spatial and temporal variability needs to be assessed in various species of feral fish. The expected spatial variability of this indicator within a resource sampling unit and its temporal variability throughout the year were not estimated, because no proper reference or baseline data are available.

**PRIMARY PROBLEMS:** The constraints to field implementation is the lack of adequate historical data for establishing baseline values and no prior field application. Increasing volume of foci and appearance of enzyme-altered nodules may signify incipient promotion of carcinogen-initiated tissue.

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**INDICATOR:** Chemical Contaminants in Wood

**LINKAGE:** Exposure, Habitat

**ENDPOINT:** Sustainability

**APPLICATION:** Trees and woody shrubs may have recognizable annual growth layers that can be exactly dated to the year in which they were formed. Samples of wood representing individual years, or intervals of years such as 5 years or decades, can be analyzed by various physical-chemical techniques to determine elemental concentrations with potential environmental exposure and dose information. For example, changes in elemental concentrations may be related to anthropogenic impacts such as air pollution. By constructing a contaminant record, a natural or baseline contaminant dose can be determined for any plant community from which to judge current or future trends in exposure. This indicator is applicable to shrubland and woodland resource classes.

**INDEX PERIOD:** An optimal sampling window during the year is based only on logistical constraints.

**MEASUREMENTS:** (1) Sampling procedure: usually two cores a tree, obtained from 30 to 60 trees of a particular species at a given location. (2) After radial cores are mounted and surfaced so that growth increments can be discerned, each core is cross-dated. The cross-dating procedure assigns each ring in each specimen to the exact calendar year in which it was formed. This procedure is different from simple ring counting, which does not result in an exact chronological placement. (3) After each specimen is dated, wood samples associated with each time increment are removed (e.g., 5 years, decade). (4) The wood can then be subjected to various types of physiochemical analyses. The most common are inductively coupled plasma (ICP) optical emission spectroscopy and neutron activation analysis (NAA). ICP analysis typically yields information on the following elements: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Vu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Si, Sn, Sr, Ti, Tl, V, and Zn. NAA can be used to obtain concentrations of elements such as As, Au, Ca, K, Mo, Na, Ba, Fe, Hg, Sr, and Zn.

**VARIABILITY:** The expected spatial and temporal variabilities within a resource sampling unit and during an index period would produce ranges that deviate 50 to 100% from their respective mean values.

**PRIMARY PROBLEMS:** It is difficult to determine and separate trends for anatomical distribution of elemental concentrations that are caused by changes in the environment from those for concentrations due to the normal physiological processes of a tree.

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## REFERENCE/CANARY SITES

**INDICATOR:** Soil Erosion

**LINKAGE:** Response

**ENDPOINTS:** Biodiversity, Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** Accelerated erosion is one of the primary indicators of desertification (FAO, 1979) and is closely linked to vegetation loss and surface soil disturbances (Webb and Wilshire, 1983). Structural characteristics of natural shrubland and grassland soils are extremely sensitive to disturbance. Structural degradation initially manifests itself by destruction of soil crusts ("Abundance and Species Composition of Lichens and Crytogamic Crusts") and changes (generally a decrease) in infiltration rates. The destruction of soil crusts and loss of vegetation in disturbed areas can result in increased wind erosion. Decreases in soil infiltration rates are associated with increased runoff, which accelerates sheet, rill, and gully erosion.

Water erosion consists of particle detachment (interrill or sheet erosion) followed by particle transport (rill and gully erosion). A landscape in nominal condition would be characterized by a naturally established drainage density, a standard ratio of interrill to rill area, and a stable erosion rate. Disturbance of native soil structural characteristics would result in an alteration of the interrill/rill ratio and an accelerated erosion rate. If continued, the drainage pattern for an impacted area becomes more dense and more linear in outline.

The rate of wind erosion is controlled by wind speed and physical properties of the soil. Shrubland soils are commonly protected from wind erosion by vegetation, which breaks the wind speed at ground level and holds soil in place with its roots. Soil crusts (including cryptogamic crusts) also serve to resist wind erosion. Areas which have lost vegetation and the protective soil crusts are subjected to wind erosion during episodes of strong winds. This indicator would track a series of parameters linked to or resulting from accelerated erosion, and would be applicable to all arid resource classes.

**INDEX PERIOD:** There is no optimal sampling window for this indicator. However, because of high seasonal variation, it must be sampled during the same season on repeat field visits.

### MEASUREMENTS:

(1) **Integration of Factors Linked to Water Erosion Susceptibility:** These factors include information on soil characteristics, slopes, rate and timing of annual precipitation, vegetation cover, and mechanical disturbance. These factors would be obtained from products of the EMAP-Characterization group (soil information and slopes), meteorological data, and the vegetation biomass and mechanical disturbance indicators. The Food and Agriculture

Organization (FAO, 1979) provides an example of the development of the integration of factors to estimate water erosion susceptibility on a regional basis. The estimated cost is $500 a resource sampling unit.

(2) **Indicators of Accelerated Water Erosion:** The interrill/rill ratio, gully density, and alterations in drainage density and drainage pattern would be measured for appropriate soil and landform units by using low-altitude aerial photography or videography. The total cost of aerial data acquisition ($100) and analysis ($500) is $600 for each resource sampling unit.

(3) **Integration of Factors Linked to Wind Erosion:** Measures of vegetation cover, mechanical disturbance, and high wind events would be obtained by monitoring other indicators and meteorological data. These data would be integrated to identify areas at risk of accelerated erosion by wind. The FAO (1979) provides an example of this style of integrated index for wind erosion. The estimated cost is $500 a resource sampling unit.

**VARIABILITY:** The expected temporal variability of erosion-related measurements derived from airborne data during the index period would produce a range that deviates 5 to 50% from the mean value. This variability is induced primarily by seasonal and diurnal alterations in illumination conditions and can be largely eliminated by acquiring data with standardized illumination conditions. Because the remote sensing data will census the entire resource sampling unit, the spatial variability of measurements is inconsequential.

**PRIMARY PROBLEMS:** Measurement procedures must be standardized. The integration of factors to obtain indices for wind and water erosion would require some effort but is achievable.

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**Webb, R.H., and H.G. Wilshire, eds.** 1983. Environmental Effects of Off-Road Vehicles: Impacts and Management in Arid Regions. Springer-Verlag, New York.

**INDICATOR:** Abundance and Species Composition of Lichens and Cryptogramic Crusts

**LINKAGE:** Response

**ENDPOINT:** Biodiversity

**STATUS:** Moderate Priority Research

**APPLICATION:** Lichens, fungal, and algal crusts are widespread on rock and soil surfaces of arid lands (Cameron, 1969). In chaparral and woodlands, these organisms occur on the outer bark of plants, as well as on rocks and soils. They are important locally to preserving the stability of soils. Cryptogamic crusts stabilize soil by binding it with their thallial filaments, by armoring the surface, and by increasing surface roughness (Cameron and Blank, 1966). These cryptogamic crusts are strong enough to protect underlying soil from raindrop impacts and wind erosion. Cryptogamic crusts are known to be quite sensitive to mechanical disturbance of soil surfaces (Wilshire, 1983). Once they have been disrupted, the forces of wind and water are able to accelerate erosion. Lichens in forests are known to be sensitive indicators of air pollution damage (Ferry et al., 1973; Anderson and Treshow, 1984), and it may be possible to use cryptogamic crusts as an indicator of air pollution exposure in arid ecosystems. This indicator would be applicable to all arid resource classes.

**INDEX PERIOD:** The optimal sampling window would be during the growing season from late spring to early autumn.

**MEASUREMENTS:** The measurement of lichens and cryptogamic crusts requires field work. Techniques which may be amenable to the measurement of abundance and species composition for these organisms include permanent photo plots, species richness, and density and areal cover by species. Methods for these measurements are available (U.S. BLM, 1985). Estimated cost of measurement is $200 a resource sampling unit.

**VARIABILITY:** These organisms expand during moist times and contract during dry times; therefore, the expected temporal variability of this indicator during the index period would produce a range that deviates 5 to 100% from the mean value. Spatial variability within a resource sampling unit would vary over a similar range.

**PRIMARY PROBLEMS:** Measurement of this indicator is labor intensive and requires a high degree of training to identify species and perform adequate sampling. The full value of this indicator for arid lands is not currently established.

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**INDICATOR:** Foliar Chemistry

**LINKAGE:** Exposure, Habitat

**ENDPOINT:** Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** Foliar analysis can be used as an indicator of elemental availability in soil or atmospheric deposition. The vector analysis described below can be used to determine if vegetation is experiencing increases in nutrient or toxin concentrations that are in turn causing either negative or positive growth effects. Through a combination of foliar concentration and content, a reliable estimate of probable growth response to changes in nutrient and toxin status can be obtained. This information can be combined with stressor indicator data to determine if external inputs of nutrients are causing changes in productivity of a given species over its natural range. In arid vegetation, foliar Si has been shown to be a good indicator of grazing pressure (Cid et al., 1989).

**INDEX PERIOD:** Sampling should occur during periods of peak stable biomass.

**MEASUREMENTS:** For dominant (by biomass) species on site, total tissue concentrations of N, P, K, Ca, Mg, Na, S, Fe, Mn, Zn, Cu, B, Ti, Al, Mo, Cl, Si, Ni, Pb (10 foliar samples per species per sampling unit) should be measured. Leaves should be washed (quickly) with mild nonphosphate detergent solution. Unwashed leaves could be included for comparison and to estimate dust accumulation on leaves (differences in Al, Si, and Ti, especially). Observations to be made include Mn/Mo ratio changes (which indicate soil pH changes: increased ratio, greater acidity).

For vector analysis, both foliar concentration and weight per leaf of new foliage are required. Samples are taken and analyzed as described above. Litter fall sampling is not recommended as a substitute for live foliage samples because the translocation of nutrients prior to litter fall to relatively constant concentrations (e.g., Turner, 1977) would greatly reduce the sensitivity of litter fall as an indicator of nutrient status and change.

Foliar concentrations and leaf weights are plotted on a generic nomograph (Weetman and Fournier, 1982), which depicts potential responses of first-year needle weight and elemental concentration to elemental input. This method has proven successful in predicting growth responses to fertilization in balsam fir (Timmer and Stone, 1978), jack pine (Timmer and Morrow, 1984), lodgepole pine (Weetman and Fournier, 1982), and loblolly pine (Johnson and Todd, 1988). The predictions from these nomographs should provide an early indication of plant response to changes in nutrient or toxin availability from atmospheric deposition or various site disturbances. The cost would range from $50 to $150 a sample.

**VARIABILITY:** The expected spatial variability of foliar elements within a resource sampling unit would produce a range that deviate <20% from the mean value. Temporal variability during the index period was not estimated.

**PRIMARY PROBLEMS:** Concerns include the lack of baseline data on many species and of understanding of optimum sampling time. The vector analysis has not been tested on several species and may not work well in nondeterminate species (e.g., species that initiate growth whenever conditions are favorable rather than during a specific season each year).

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**INDICATOR:** Physiochemical Soil Factors

**LINKAGE:** Exposure

**ENDPOINTS:** Sustainability

**STATUS:** High-Priority Research

**APPLICATION:** The application of this indicator to arid ecosystems is similar to indicators described for forests, but it is somewhat more intensive, especially with respect to soil physical properties. Quantitative pits (Hamburg, 1984) in conjunction with soil pedon descriptions would be made on each ground sampling plot on a one-time basis for the purpose of describing the soil type and obtaining data on soil bulk density and the proportion of gravel (the latter to be used in calculating soil elemental contents on an aerial [kg/ha] basis). The soil would be classified according to the U.S. Soil Conservation Service Great Group Level or to a finer degree (e.g., series), if possible.

Periodic measurements of soil chemical properties would be used to detect temporal changes in soils and to correlate such changes with measures of soil moisture, temperature, plant growth, nutrient use efficiency, and other indicators that may be relevant to soil change. This indicator provides a baseline against which future changes in soils may occur in response to long-term climate change (e.g., soil C and N content; Post et al., 1982, 1985). Soil salinity changes also would be identified in response to changes in ground-water levels and surface water movement patterns. Plant species composition or lack of plants would also reflect soil salinity status.

For grasslands, changes in climate or land use (e.g., cultivation) can strongly affect soil organic matter storage (Schimel et al., 1990). Soil organic carbon (SOC) levels represent the balance between net primary production and decomposition and are a sensitive indicator of ecosystem function and status. Decreases in grassland SOC from increasing decomposition rates are a likely consequence of global warming; as a result, these systems would become a net source of $CO_2$ and provide feedbacks to the climate system (Schimel et al., 1990). SOC response in shrubland or woodland systems may not be as important or detectable as in grassland because soil organic matter levels are low, but SOC responses in ecotones between forest and woodland would be a critical indicator of the desertification processes that may occur as a result of climatic change.

**INDEX PERIOD:** An optimal sampling time does not exist. However, because of the high seasonal variation, soil chemistry must be measured during the same season on repeat field visits.

**MEASUREMENTS:** Quantitative pits are soil sampling units in which the exact volume, weight, and particle size distribution of soil are measured by horizon (Hamburg, 1984). These parameters represent nutrient concentration data on an areal basis (e.g., kg/ha). A minimum of 10 quantitative pits would be measured initially at each resource sampling unit, and within each pit a pedon description would be obtained. Samples for determination of long-term change would be taken randomly from a permanently established grid (e.g., 10 samples taken randomly within a 20 by 20-m grid during each sampling period). All samples would be analyzed for total C (LECO), total N

(Kjeldahl), soluble salts (Rhoades, 1982), exchangeable cations (Al, K, Ca, Mg, Na, Zn, Cu, Mo), and cation exchange capacity (1 M $NH_4Cl$), extractable $SO_4^{-2}$ (0.016 M $NaH_2PO_4$), extractable P (bicarbonate), and extractable B (Bingham, 1982). Pedon samples would also be analyzed for total P, S, K, Ca, Mg, Na, Zn, Cu, and Mo. All samples would be archived for potential additional analyses.

Pedon analyses and determination of soil bulk density and gravel fraction would be conducted one time only; soil nutrients would be sampled at 5-year intervals. Costs of collection and analyses for soils would be approximately $150 to $200 a sample for periodic nutrient collections and $300 to $350 a sample for the quantitative pit samples. With a sufficient number of quantitative pits, measurement error (standard errors) can be maintained at <20%. Pedon analyses, soil bulk density, and gravel fraction would be sampled one time only. Soil nutrients would be sampled quarterly to allow an examination of seasonal variations, which can be significant with respect to certain extractable nutrients (e.g., extractable P).

**VARIABILITY:** The expected temporal variability of soil chemistry and structure in surface soil samples during the index period would produce a range that deviates <50% from the mean values. The spatial variability within a resource sampling unit ranges between 20 and 80%, depending upon depth and sampling unit size.

**PRIMARY PROBLEMS:** The high spatial variability of soil chemistry would be the greatest problem to be encountered, especially with respect to soil physical properties. This would necessitate more replication than is typical of most soil sampling protocols. Laboratory techniques for trace metals requires skill and care.

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16. ABSTRACT

In response to the growing concerns regarding the condition of the nation's ecological resources, the U.S. EPA has initiated the development of a national interagency program to determine the status of, and to monitor the changes in, ecological systems. This program is called the Environmental Monitoring and Assessment Program (EMAP). The Arid Ecosystem portion of EMAP includes grasslands, shrublands, woodlands, riparian zones, tundra and deserts in the arid (dryer) regions, primarily the central and western U.S.. This document outlines a strategy for the development and operation of the Arid Ecosystems portion of EMAP. Through workshops, with interagency cooperation and technical support from universities, indicators (measures of ecological parameters) will be evaluated, developed and tested in small scale pilot field studies, before being implemented at larger scales. Also discussed in the document are the sampling design; plans for the use of remote sensing and GIS; development of the information management system; a quality assurance program; means for implementation of a large scale field sampling operation; and the guidelines for statistics, assessment and reporting for the program.

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