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Natural Resource Program Center

Mojave Desert Network Vital Signs Monitoring Plan

Natural Resources Report NPS/MOJN/NRR—2008/057

ON THE COVER

From upper left to bottom right: Eureka Dunes, Death Valley National Park; Bighorn Sheep on Wheeler Peak, Great Basin National Park; Bear Poppy, Lake Mead National Recreation Area; Desert Tortoise, Joshua Tree National Park; Cholla Cactus Garden, Joshua Tree National Park; Photos taken by NPS Staff

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Natural Resource Report NPS/MOJN/NRR—2008/057

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Acronyms

AARWP	Annual Administrative Report and Work Plan
ARD	Air Resources Division
ATB	Across the Board
BLM	Bureau of Land Management
BOD	Board of Directors
BSC	Biological Soil Crusts
CAA	Clean Air Act
CESU	Cooperative Ecosystem Studies Unit
DEVA	Death Valley National Park
DOD	Department of Defense
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FTE	Full-time Equivalent
FY	Fiscal Year
GIS	Geographical Information System
GRBA	Great Basin National Park
GPRA	Government Performance and Results Act
GRTS	Generalized Random-Tessellation Stratified
GSA	General Services Administration
I&M	Inventory and Monitoring
JOTR	Joshua Tree National Park
LAME	Lake Mead National Recreation Area
MANZ	Manzanar National Historic Site
MOJA	Mojave National Preserve
MOJN	Mojave Desert Network
NPS	National Park Service
NRAC	Natural Resource Advisory Committee
NRPC	Natural Resources Program Center
PARA	Grand Canyon-Parashant National Monument
PDO	Pacific Decadal Oscillation
PDS	Protocol Development Summary
PWR	Pacific West Region
SOP	Standard Operating Procedure
TC	Technical Committee
USGS	United States Geological Survey
VSMP	Vital Signs Monitoring Plan
WASO	Washington Support Office
WRD	Water Resources Division

Executive Summary

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's (NPS) mission to manage park resources "unimpaired for the enjoyment of future generations." Thus, NPS has implemented the "Vital Signs Monitoring Program," a long-term ecological monitoring program that will provide rigorous, scientifically-based information on the status and trends of park ecosystems. With this information, park managers will be better able to evaluate complex and challenging resource issues and make sound decisions that result in long-term protection of park ecosystems. This information on park resource condition will also be useful towards park planning, research, education, and public awareness.

Cemetery monument at Manzanar National Historic Site, one of the seven parks in Mojave Desert Network. Photo courtesy Alice Chung-MacCoubrey.

Under the Vital Signs Monitoring Program, 270 park units were organized into 32 networks that linked parks with similar geographic and natural resource characteristics. The program created and funded Mojave Desert Network (MOJN) to assess ecosystem condition in six park units in Arizona, California, and Nevada, including Death Valley National Park, Great Basin National Park, Joshua Tree National Park, Lake Mead National Recreation Area, Manzanar National Historic Site, and Mojave National Preserve. After Grand Canyon-Parashant National Monument (PARA) was created in 2000, it was informally included in the set of parks addressed by the MOJN Inventory & Monitoring (I&M) Program. The MOJN encompasses the largest total park area of all the networks in the lower 48 states (combined acreage of 3.3 million hectares or 9.7 percent of the total land area managed by NPS).

The network monitoring program is intended to provide the minimum infrastructure needed to track the condition of park resources and is designed to complement, not replace, existing park monitoring and other agency monitoring programs. Funding for the MOJN supports a core, professional staff who perform network duties and collaborate with park staff and other programs and agencies to implement an integrated and long-term program to monitor the network's highest-priority Vital Signs. No additional funds were allocated from the National I&M Program after the inclusion of PARA within the network, thus making partnerships and cost-sharing paramount to the program's success.

Claret cup hedgehog (*Echinocereus triglochidatus*), Grand Canyon-Parashant National Monument. Photo courtesy Kari Yanskey.

The MOJN Vital Signs Monitoring Plan (VSMP) provides a framework for MOJN's long-term natural resource monitoring program. The result of an extensive, multi-year planning process, the VSMP addresses all aspects of the planned monitoring program, from program goals and administration to sampling design, data analysis, and reporting. Specifically, the MOJN VSMP provides background information about the network parks, describes conceptual models used to guide and support program development, identifies the network's 20 final Vital Signs, the process for selecting them, and their grouping into protocols, discusses sampling concepts and preliminary sampling designs, describes how data will be managed, analyzed, and reported, proposes a staffing plan, implementation schedule, and budget, and outlines the administrative framework and

Leconte's barrel cactus (*Ferocactus cylindraceus* var. *lecontei*), Grand Canyon-Parashant National Monument. Photo courtesy Kari Yanskey.

mechanisms for program oversight. The MOJN VSMP (or Phase III plan) represents the culmination of 5 years of planning and is built upon previous versions of this plan developed during Phase I (2005) and Phase II (2006).

During Phase I of development, the network compiled background information about park resources, threats, and management concerns and current and historic monitoring efforts. This information is presented in Chapter 1, along with an ecological overview of network parks. Also described in Chapter 1 are the policy and management contexts for the monitoring program, including the goals and objectives for the MOJN monitoring effort. Appendixes A to F contain additional information used in program development.

Beavertail pricklypear (*Opuntia basilaris* var. *basilaris*), Grand Canyon-Parashant National Monument. Photo courtesy Kari Yanskey.

During Phase II, the network collaborated with park staff and scientists from multiple agencies and universities to develop conceptual ecological models for park ecosystems and to produce a final list of network Vital Signs. Chapter 2 presents an overview of the conceptual models, which contain four levels of increasing complexity and detail. Described in Chapter 2 are the major concepts underlying the overarching model, a short synopsis of the dry and wet system models, and short descriptions of biomes and components within dry and wet systems. The conceptual models are presented in their entirety in Appendix G.

Using the results of the early planning and design work, the network hosted a series of park- and network-level workshops to produce a final list of Vital Signs (Chapter 3). Workshop participants included park and network staff and individuals from other federal and state agencies, academic and research institutions, and non-profit organizations. Workshops were conducted over the course of 3 years (2003-2005) and culminated in a final list of 20 Vital Signs. The network proposes to address 17 of these Vital Signs through 10 protocols and to postpone development of the remaining 3 Vital Signs until the first set are complete. The final report from the 2004 Network-Level Vital Signs Scoping Workshop describes the process for prioritizing and ranking Vital Signs, presents the resulting prioritized list of candidate Vital Signs, provides justifications for rankings, and identifies potential monitoring questions, partners, and funding sources (Appendix H).

During Phase III, network staff developed strategies for monitoring Vital Signs, identified procedures for managing, analyzing, and reporting data, identified necessary staff and cooperators for developing and implementing monitoring protocols, and devised a schedule and budget for implementation. The results of these planning efforts are summarized in Chapters 4-10 and Appendix I.

In Chapter 4, we describe sampling

Vital Signs and monitoring protocols for the Mojave Desert Network: This table identifies protocols planned (or postponed) for development, Vital Signs addressed, and their primary funding source. Protocol names in bold are those funded primarily by the network.

PROTOCOL NAME	PRIMARY VITAL SIGNS ADDRESSED	FUNDING SOURCE
Air Quality	Ozone Wet and Dry Deposition Visibility & Particulate Matter	Funded by another program
Climate	Basic Meteorology	Funded by another program
Integrated Upland	Soil Erosion & Deposition Soil Disturbance Soil Chemistry & Nutrient Cycling Soil Hydrologic Function Vegetation Change Biological Soil Crusts	MOJN-funded
Riparian Vegetation	Vegetation Change	MOJN-funded
Riparian Birds	Riparian Bird Communities	MOJN-funded
Invasive/Exotic Plants	Invasive/Exotic Plants	Combination of MOJN and other program funding
Fire and Fuel Dynamics	Fire and Fuel Dynamics	Funded by another program
Groundwater and Springs	Groundwater Dynamics & Chemistry Surface Water Dynamics Surface Water Chemistry	MOJN-funded
Streams and Lakes	Surface Water Dynamics Surface Water Chemistry	MOJN-funded
Landscape Dynamics	Landscape Dynamics	MOJN-funded
Small Mammals	Small Mammal Communities	Development is postponed
Reptile Communities	Reptile Communities	Development is postponed
At-Risk Populations	At-Risk Populations	Development is postponed

concepts, steps, and considerations for developing sampling designs and summarize the spatial and temporal sampling designs proposed for each protocol. The network will use a combination of random and nonrandom sampling designs, depending on the monitoring objectives. For random sampling designs, we will consider the generalized random-tessellation stratified approach, which assigns a random sample of sites to panels that are visited on a rotational basis. In other cases, protocols will require the use of hand-picked, nonrandom, judgment samples (or index sites) based on management priorities. Where possible, sampling for Vital Signs will be co-located in space and time to improve efficiency and depth of ecological understanding.

Monitoring protocols are detailed study plans that explain how data are to be collected, managed, analyzed, and reported. Well-developed monitoring protocols ensure standardization of methods among individuals and successive staff, allow documentation of changes in methods, and are a key component of quality assurance. Over the next 3-5 years, network staff and cooperators will develop 10 monitoring protocols to address Vital Signs for which MOJN staff will play a lead role in field data collection and/or analysis and reporting of the monitoring results. In Chapter 5, we describe the specific format and content of each protocol, identify the process for developing protocols, and summarize key elements of Protocol Development Summaries (PDSs; Appendix I). PDSs are short

The Mojave desert supports colorful biota at a variety of scales, including these lichens at Grand Canyon-Parashant National Monument. Photo courtesy Kari Yanskey.

summaries that provide specific information on how each protocol will be developed, by whom, using what methods, and according to what timeframe. In Chapter 9, we provide a schedule for development, testing, peer-review, and implementation of each of the monitoring protocols.

Data and information management are central to the MOJN I&M Program and a critical component of any successful long-term monitoring program. To assure and maintain data integrity, MOJN will follow procedures outlined in the MOJN Data Management Plan (DMP; Appendix J) and summarized in Chapter 6. The DMP documents our strategy for ensuring that data collected by the program are subjected to rigorous quality assurance and control procedures, and refers to other documents and resources for specific procedures. The plan also addresses how data and information will be made available to others for decision making, research, and education.

Data analysis, interpretation, and reporting are crucial components in the development and implementation of the MOJN I&M Program. Data compiled from monitoring projects will be used by diverse audiences – NPS park managers and superintendents, scientific collaborators, educators – who might have different requirements and needs. In Chapter 7, we summarize the network's plan for analysis and reporting, including types of analytical procedures, communication and reporting tools, responsible parties, and intended audiences.

Successful program implementation will also rely upon appropriate staffing and administrative oversight (Chapter 8). MOJN's long-term monitoring program will be developed and implemented through a combination of core network staff and additional personnel, which will vary with programmatic phase (Implementation Phase [FY 2009-11] or Monitoring Phase [FY 2012 and on]). The network receives general program guidance and direction through the National I&M Program Manager and the Regional I&M Coordinator. Local program oversight and direction is achieved through the MOJN Board of Directors (BOD) and Technical Committee. Specific roles and responsibilities of these oversight groups are described in Chapter 8 and the MOJN Network Charter (Appendix K).

In FY 2008, the network's annual operating budget included $860,000 from the NPS Vital Signs Monitoring Program and $76,900 from the NPS Water Resources Division. These funding levels are expected to remain relatively fixed, except for potential across-the-board rescissions and periodic cost-of-living increases. These funds are held in Washington Office base accounts and are transferred annually through the Pacific West Regional Office to Lake Mead NRA, the network's host park. All funds are managed by the MOJN Network Coordinator under the auspices of the BOD. Chapter 10 provides an expanded description of the network budget, major categories of expenses, allocations towards data management, and a detailed budget for the first year of implementation (FY 2009).

Acknowledgments

The Mojave Desert Network's (MOJN) Vital Signs Monitoring Plan could not have been completed without the commitment, hard work, and support of network staff, park staff, and external cooperators, and strong leadership at the national, regional, and local levels.

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Lastly, we thank Penny Latham, Pacific West Region I&M Coordinator, for her patient guidance, tireless contributions, and participation in the MOJN BOD and many other network activities, and Steve Fancy, NPS National Monitoring Program Leader, who is largely responsible for the success of the NPS I&M Program.

Chapter 1: Introduction and Background

1.1 Guidance

The National Park Service (NPS) is implementing a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. The effort was undertaken to ensure that the approximately 270 park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. The national strategy consists of a framework having three major components: (1) completion of basic resource inventories upon which monitoring efforts can be based; (2) creation of experimental Prototype Monitoring Programs to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters ("Vital Signs") in all natural resource parks (NPS 2005a).

1.1.1 Legislation

NPS managers are directed by federal law and NPS policies to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission (NPS 1916) of leaving these resources "unimpaired for the enjoyment of future generations." Congress strengthened the NPS's protective function, and provided language important to recent decisions about resource impairment, when it amended the Organic Act in 1978. Along with national legislation, enabling legislation (Appendix A) and mission statements (Table 1.1) for Mojave Desert Network (MOJN) parks ("park" hereafter is used in a general sense to refer to national parks, monuments, preserves, and national historic sites, all of which occur in the MOJN) provide justification, guidance, and context for natural resource management programs, including inventory and monitoring.

More recently, the National Parks Omnibus Management Act of 1998 (NPS 1998) established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. Section 5934 of the Act requires the Secretary of the Interior to develop a program of "inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources." A summary of federal legislation and policy related to the inventory and monitoring efforts can be found in Appendix B.

The 2001 NPS Management Policies (NPS 2001a) updated previous policy and specifically directed that "natural systems in the National Park System, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions."

The Government Performance and Results Act (GPRA) is central to NPS operations, including the Inventory and Monitoring (I&M) Program. The NPS has developed a national strategic plan identifying key goals to be met (NPS 2001a). A list of the national GPRA goals relevant to MOJN parks is located in Table 1.2. In addition to the national strategic goals, each park unit has a 5-year plan that includes specific park GPRA goals. Many of these park specific goals are directly related to natural resource monitoring needs.

The NPS Water Resources Division provides explicit guidance and funding for the water quality component of each of the 32 network's monitoring programs. Design and implementation of water quality monitoring is fully integrated with the network Vital Signs monitoring design process (including staffing, planning, design, etc.) to facilitate integration within the context of a comprehensive network monitoring program. The NPS goal is to rely on its own uniform monitoring data and use it to protect water resources. Monitoring of water quality also is supported through legislation, policy, and guidance described above, including the 1916 Organic Act (NPS 1916), National Parks

Monitoring is a central component of natural resource stewardship in the National Park Service, and in conjunction with natural resource inventories and research, provides the information needed for effective, science-based decision-making and resource protection.

Table 1.1. Mission Statements[a] for Mojave Desert Network parks.

PARK NAME	PARK MISSION STATEMENT
Death Valley National Park (DEVA)	Death Valley National Park dedicates itself to protecting significant desert features that provide world class scenic, scientific, and educational opportunities for visitors and academics to explore and study.
Great Basin National Park (GRBA)	The mission of Great Basin National Park is to preserve for the benefit, inspiration, and enjoyment of present and future generations a representative segment of the Great Basin of the western United States and to promote an understanding of the natural and cultural heritage of the entire physiographic region.
Joshua Tree National Park (JOTR)	The National Park Service at Joshua Tree National Park preserves and protects a representative area of the Colorado and Mojave deserts and the natural and cultural resources for the benefit and enjoyment of present and future generations. The park includes rich biological and geological diversity, cultural history, recreational resources, and outstanding opportunities for scientific study.
Lake Mead National Recreation Area (LAME)	We provide diverse inland water recreational opportunities in a spectacular desert setting for present and future generations.
Manzanar National Historic Site (MANZ)	Manzanar National Historic Site dedicates itself to protecting the physical remnants of the internment camp and telling the story of the internment of over 110,000 individuals of Japanese ancestry during World War II in an accurate and balanced way that represents diverse viewpoints and beliefs.
Mojave National Preserve (MOJA)	Mojave National Preserve was established to preserve outstanding natural, cultural, and scenic resources while providing for scientific, educational, and recreational interests.
Grand Canyon-Parashant National Monument (PARA)	Grand Canyon-Parashant is a model of land management for the BLM and NPS that conserves its natural, scientific, and historic resources and includes ecological restoration and protection in a broad ecosystem context, while honoring the history and living traditions of the people who came before us: "the place where the west stays wild."

[a] Mission statements obtained from park General Management Plans (NPS 1992a; 1995; 1996; 1999b; 2000; 2001b; 2005b).

Omnibus Management Act (NPS 1998), and Natural Resource Challenge (NPS 1999a). Each network, as part of the Vital Signs Monitoring Program, is required to: (1) determine priorities for impaired water and pristine water monitoring; (2) define site-specific monitoring objectives; and (3) develop detailed water quality monitoring plans.

1.1.2 Justification for Natural Resource Monitoring

The intent of the NPS I&M Program is to track a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values or resource significance, known as "Vital Signs." This subset of resources and processes is part of the total suite of natural resources that park managers are directed to preserve. NPS managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a foundation for making decisions, working with other agencies, and the public for the benefit of those resources.

The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because parks are open systems, with threats such as air and water pollution, or invasive species, originating outside of the park's boundaries. No single spatial or temporal scale is appropriate for all system components and processes. The appropriate scale for understanding and effectively managing a resource might be at the species, population, community, or

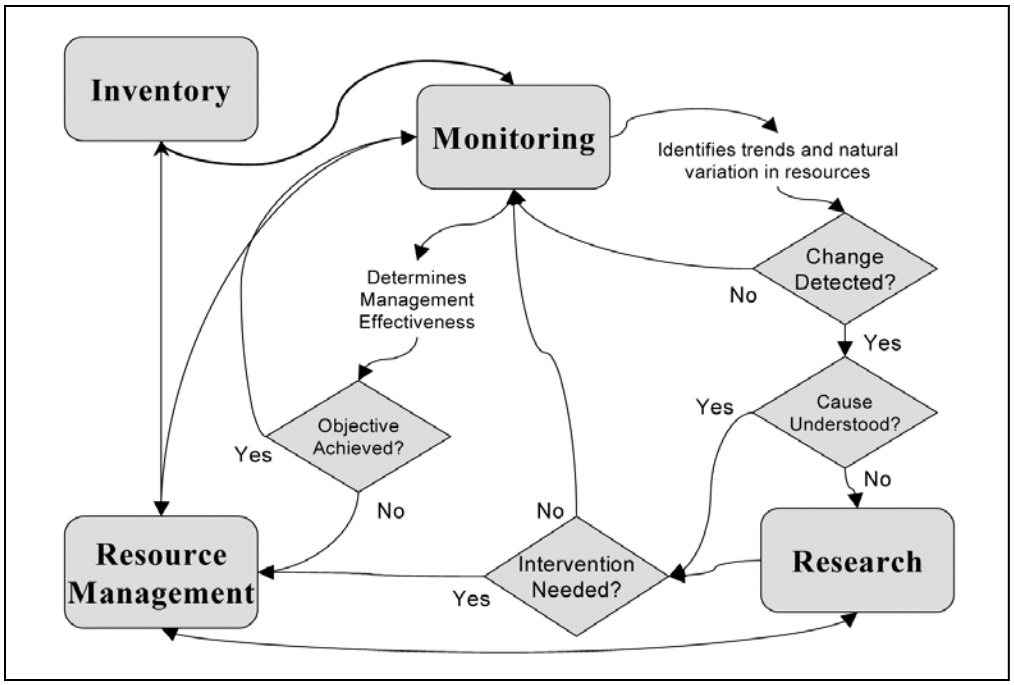


Figure 1.1. Relationships among inventories, monitoring, research, and natural resource management activities in national parks (modified from Jenkins et al. 2002).

landscape level. This reality may require a regional, national, or international effort to understand the resource.

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource inventories and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.1). Ecological monitoring establishes reference conditions for natural resources from which future changes can be detected. Site-specific information provided through natural resource monitoring is needed to identify change in complex, variable, and imperfectly understood ecosystems and to determine whether observed changes are within historic levels of variability or may indicate unwanted influences. Thus, monitoring data help define the typical limits of variation in park resources by augmenting historic data, and when put into a landscape context, monitoring provides the basis for determining meaningful change in ecosystems. Monitoring results may also be used to determine what constitutes impairment and to identify the need to initiate or change management practices.

Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

1.1.3 Goals of Vital Signs Monitoring in the Mojave Desert Network

The NPS Servicewide (or National) I&M Program has defined long-term goals to comply with legal requirements, to fully implement NPS policy, and to provide park managers with the data they need to understand and manage park resources.

The National and MOJN goals for Vital Signs Monitoring are:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation

Table 1.2. GPRA goals specific to parks [a] and relevant to development of a monitoring plan for the Mojave Desert Network.

GPRA GOAL	GOAL #	DEVA	GRBA	JOTR	LAME	MANZ	MOJA
Category 1a: Natural and cultural resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem context.							
Disturbed Lands Restored	Ia1A	X	X	X	X		X
Exotic Plant Species	Ia1B	X	X	X	X		X
Land Health – Wetlands[b]	Ia1C		X				
Land Health – Riparian and Stream Areas[b]	Ia1D		X				
Land Health – Upland[b]	Ia1E		X				
Land Health – Mined Lands[b]	Ia1G		X		X		
Threatened and Endangered Species	Ia2	X	X	X	X		X
Species of Management Concern	Ia(0)2B		X	X	X		X
Exotic Animals	Ia2C	X	X		X		X
Air Quality and Wilderness Values	Ia3	X	X	X			
Surface Water Quality	Ia4	X	X	X	X		X
Water Quantity	Ia4B						X
Cultural Landscapes on the CLI	Ia7	X	X			X	X
Paleontological Resources	Ia9	X		X	X		X
Category 1b: The NPS contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.							
Park Natural Resource Data Sets	Ib01	X	X	X	X	X	X
Cultural Landscapes Baseline	Ib2B	X	X	X	X	X	X
Vital Signs Identified	Ib3A	X	X	X	X	X	X
Vital Signs Monitored	Ib3B	X	X	X	X	X	X

[a] As of September 1, 2008, PARA was still developing their park strategic and planning documents.
[b] Goal targets will be established after parks have completed baseline and status determinations. It is expected that several MOJN parks will adopt one or more of the land health goals.

measures and reduce costs of management.

3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress toward performance goals.

The defined goals drive action in conceptual design and monitoring protocol development. Monitoring data are intended to detect long-term environmental change, provide insights into the ecological consequences of change, and help decision-makers determine if observed changes suggest a change in management practices. Clearly articulated goals and objectives help define all aspects of a program including the choice of Vital Signs to be monitored. MOJN objectives will be developed for each individual vital sign.

1.2 Mojave Desert Network Overview

In 1999, the NPS launched the Natural Resource Challenge, a nationwide program designed to strengthen natural resource management and to guide and fund inventory and monitoring efforts in

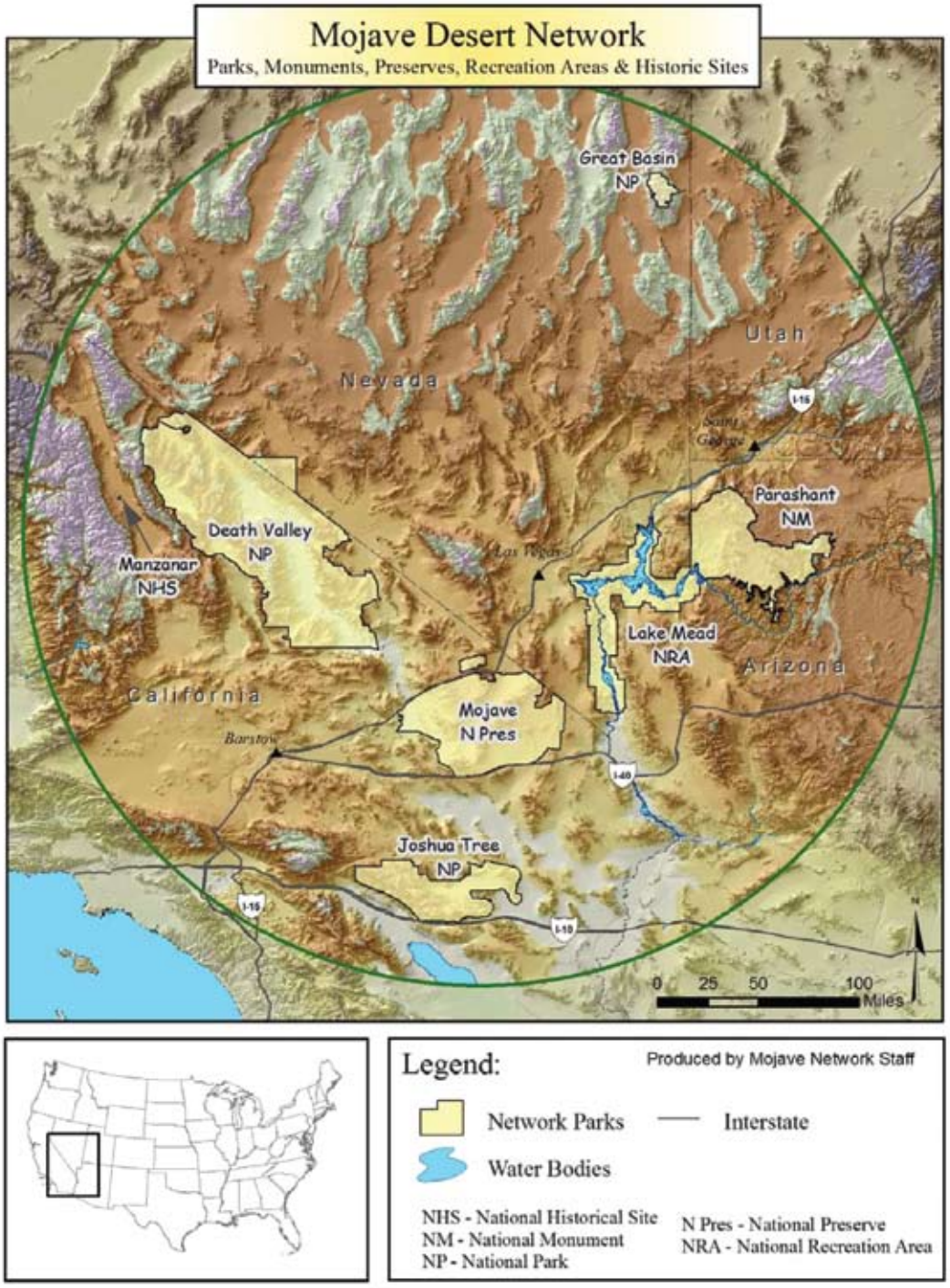


Figure 1.2. Parks of the Mojave Desert Network.

our nation's parks (NPS 1999a). Under the program, approximately 270 park units were organized into 32 networks, with individual networks comprised of parks that share similar geographic and natural resource characteristics. The program created and funded the MOJN to assess ecosystem condition in six parks in Arizona, California, and Nevada, including Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAME), Manzanar National Historic Site (MANZ), and Mojave National Preserve (MOJA) (Figure 1.2). After Grand Canyon-Parashant National Monument (PARA) was created in 2000, it was informally included in the set of parks addressed by the MOJN I&M Program. No additional funds were allocated from the National program to the network following the inclusion of PARA in the MOJN.

Table 1.3. Area and elevation of Mojave Desert Network parks.

PARK NAME	ABBREVIATION	AREA (ha)	ELEVATION RANGE (m)
Death Valley National Park	DEVA	1,374,420	-86 to 3,368
Great Basin National Park	GRBA	31,194	1,615 to 3,981
Joshua Tree National Park	JOTR	321,327	0 to 1,772
Lake Mead National Recreation Area	LAME	521,346[a]	152 to 1,719
Manzanar National Historic Site	MANZ	329	1,158
Mojave National Preserve	MOJA	619,923	274 to 2,438
Grand Canyon-Parashant National Monument	PARA	424,242[b]	366 to 2,447
	Total	3,292,781	-86 to 3,981

[a] Excludes 84,358 hectares of NPS-owned land currently within LAME boundary that is now part of PARA; total park acreage for LAME including NPS-owned land within PARA is 605,704 hectares.

[b] Total size of PARA includes 84,358 hectares of NPS-owned land, 327,288 hectares of BLM-managed lands, and 12,595 hectares of non-federal lands.

The seven NPS parks in the MOJN network encompass a total of nearly 3.3 million hectares of land and include vertical relief that ranges from the lowest point in North America in DEVA (-86 m a.s.l.) to the alpine peaks of GRBA (3,981 m a.s.l.) (Table 1.3). A majority of the MOJN parks sit between the Sierra Nevada to the west (MANZ, DEVA), the north-south trending Basin and Range province to the north and east (MOJA, DEVA, LAME, PARA), the Transverse ranges to the south (JOTR), and the South Snake range (GRBA) in the north (Brussard et al. 1998).

The MOJN is predominantly semi-arid to arid, comprised of three contiguous desert ecosystems (Great Basin, Mojave, and Sonoran deserts), which exhibit a southward gradient of increasing temperature and decreasing average elevation. Because of its intermediate position along this climatic and elevational gradient, the Mojave desert is considered to be the transitional zone between the Great Basin and Sonoran deserts. Three of the MOJN parks (GRBA, MANZ, and portions of PARA) are located in the northern part of the MOJN, which is considered "high (elevation) or cold (climate) desert" environment. The remaining parks (DEVA, JOTR, LAME, MOJA, and portions of PARA) are located in the southern part of the MOJN, in a "hot desert" environment.

As the northern-most MOJN park, GRBA lies entirely within the Great Basin desert region and the South Snake Range in east-central Nevada. GRBA has a rugged landscape exhibiting high elevation, snow-covered peaks (nearly 10% of its land is above 3,000 meters) separated by low desert basins and valley floors. It is a temperate desert with hot summers and cold, snowy winters due to greater volumes of summer rains and winter snows. Due in part to its distance from urban centers, GRBA contains many relatively pristine natural resources, and often has some of the best visibility in the nation. GRBA is known for its glacial formations and karst geology, which include at least 42 natural caverns that harbor a variety of biological and physical resources. One of the most decorated caves in the nation is Lehman Caves, which is the longest cave in Nevada. Ten perennial stream systems and six subalpine lakes support riparian habitats and greater biological productivity than surrounding, more arid areas and thus have local and regional ecological significance. The combination of a diverse moisture gradient, geologic history, and the isolation of higher alpine/subalpine areas in GRBA produce endemic plant and animal species that occur nowhere else.

DEVA lies southwest of GRBA, near the southern boundary of the Great Basin desert and the northern boundary

of the Mojave desert. Two mountain ranges flank DEVA to the west and east, producing dramatic topographic relief and landscape views. Renowned for its exposed, complex, and diverse geology and tectonics, DEVA contains one of only two active rift faults known in the world. DEVA includes the lowest point in North America (Badwater, -86 m b.s.l.), receives the least precipitation in the U.S., and claims the nation's highest and world's second highest recorded temperature. In addition, the park is one of the only places on earth where all five major dune types occur in close proximity. Because "hot desert" species are found at lower elevations and "cold desert" species are found at higher elevations, DEVA supports diverse assemblages of plant and animal life and has one of the nation's most significant fossil records. Various habitats such as springs, drainages, playas, sand dunes, and subterranean pools are home to a plethora of endemic species that have adapted to DEVA's unique and harsh environment (e.g., Devils Hole pupfish, [*Cyprinodon diabolis*]).

To the west of DEVA, MANZ is located at the northwestern edge of the Mojave desert, adjacent to the Great Basin and Sierran montane area. The park is shielded from moist ocean air masses by the Sierras and predominantly experiences a high-desert type climate. Originally established as a cultural historic site, MANZ has significant biological diversity that is highest along a natural, but intermittent creek, which flows west to east through the park. Natural vegetation at MANZ is primarily Great Basin sagebrush scrub (*Artemisia* spp.), saltbush (*Atriplex* spp.), rabbitbrush (*Ericameria* spp.), and a variety of forbs, cacti, and grasses.

A recent addition to the MOJN, PARA was created by presidential proclamation on 11 January 2000 and is jointly managed by the NPS and Bureau of Land Management (BLM). PARA lies on the northeast edge of the Mojave desert, at the boundary between floristic provinces, with low elevations represented by classic, "hot desert," Mojave desertscrub, and upper elevations represented by "cold desert," Colorado Plateau vegetation. The intersection of these biomes is a distinctive feature giving rise to elevated biological diversity in this park (Stevens 2001). Geologically, the monument is exemplary, providing exceptional insights into the geologic history of the Colorado Plateau. The most prominent topographic feature within the monument is the Shivwits Plateau, which is physiographically and stratigraphically typical of the Grand Canyon region. PARA offers impressive landscapes, remote and open spaces, natural caves

Aspen and talus slopes in Baker Canyon, Great Basin National Park. Photo courtesy Erik Beever, USGS.

Dune complex near Furnace Creek, Death Valley National Park. NPS Photo.

Pinyon/Juniper woodland at Grand Canyon-Parashant National Monument. NPS Photo.

The Sierra Nevada Mountains from Manzanar National Historic Site. NPS Photo.

and sinkholes, volcanic cinder cones and basalt flows, and significant fossil resources (e.g., invertebrates, sponges).

Adjacent to and south of PARA is LAME, which encompasses 229 km of the Colorado River and is centered on two artificial lakes, Lake Mead and Lake Mohave. It is the premier inland water-recreation area in the West and primary source of drinking water for southern Nevada. LAME lies along the northeast boundary of the Mojave desert. Approximately 87% of LAME consists of terrestrial habitat representing elements of the Mojave, Sonoran, and Great Basin deserts (NPS 1999b). A smaller portion of the recreational area falls within the Colorado Plateau Province. The Colorado River's former channel and associated lake shoreline, in combination with the park's desert springs, provide important opportunities to preserve one of the Southwest's most threatened habitats—the desert riparian community. Due in large part to these rare, riparian communities, the park supports significant populations of approximately 100 species of special concern and species at the limits of their distributional range.

South of both LAME and DEVA is MOJA, which lies in the south-central Mojave desert and has strong floristic influences from the Sonoran desert along its southern boundary. MOJA encompasses a vast expanse of "hot desert" set among a landscape of mountain ranges, high elevation sand dunes (Kelso Dunes), great mesas, and extinct volcanoes (NPS 2000). Similar to DEVA, the dunes in MOJA constitute unique environments with specially adapted endemic plants and animals. In addition to far-reaching vistas, MOJA offers the densest population of Joshua trees (*Yucca brevifolia*) in the world. With an extensive variety of habitats, including species and landforms only found in the Mojave desert, MOJA provides opportunities for scientists and visitors alike to conduct research and view the diverse wealth of resources within this unique desert preserve. Also, approximately half of the lands within the preserve have been designated Critical Habitat for the desert tortoise, *Gopherus agassizii*, a species federally listed as threatened (NPS 2000).

The southern-most park in the MOJN, JOTR, lies at the transition between the Mojave and Sonoran deserts, and within the west-east oriented Southern California Mountains. In this compressed transition zone between three ecosystems, the park supports a unique diversity of desert flora and fauna. Providing major habitat for its namesake, JOTR supports extensive stands of Joshua trees, prickly pear cacti (*Opuntia* spp.), California juniper (*Juniperus californica*), and pinyon pine (*Pinus monophylla*). The park

showcases exposed granite monoliths and rugged canyons, which reveal the powerful tectonic and erosional forces that shaped the landscape. Five of North America's 158 desert fan palm oases occur in JOTR, where fault lines that run through igneous and metamorphic rocks force water to the surface. A diverse and unique assemblage of species, especially reptiles, are dependent on these water sources. Currently, species that are actively managed within the park include the federally threatened desert tortoise, desert bighorn sheep (*Ovis canadensis nelsoni*), Mojave fringe-toed lizard (*Uma scoparia*), and sensitive bat species.

1.3 General Ecological Overview

In recent years, ecoregion classification systems have emerged as one of the most useful land classification systems for understanding relationships between ecologically similar land units and for supporting sustainable resource management practices (Bailey 1995, 1998). Developed by the USDA Forest Service, ecological land types are defined, classified, and mapped into progressively smaller areas of increasingly uniform ecological potential (U.S Forest Service 1993; McNab and Avers 1994; Bailey 1995). Based on a hierarchical framework, the four levels of ecological units are Domain, Division, Province, and Section (from broadest to finest spatial scale). These ecological units are designated based on similarity of: 1) potential natural communities, 2) soils, 3) hydrologic function, 4) topography and landforms, 5) lithology, 6) climate, 7) air quality, and 8) ecological processes such as nutrient cycling and natural disturbance regimes (Cleland et al. 1997).

The MOJN parks fall within five Ecoregion Provinces (Figure 1.3) located within the Dry Domain of the National Hierarchical Framework of Ecological Units (U.S. Forest Service 1993; McNab and Avers 1994; Bailey 1995). The predominant province is the American Semi-Desert and Desert Province, which includes the Mojave and Sonoran deserts and a majority of the "hot climate" parks. Two of the four ecoregion provinces are similar climatically and floristically, and include the "cold climate" parks: Nevada-Utah Mountains-Semi-Desert-Coniferous Forest-Alpine Meadow Province and the Colorado Plateau Semi-Desert Province. A small portion of the MOJN (<5%) is contained within the last two provinces: the California Coastal Range Province and the Intermountain Semi-Desert and Desert Province. Where ecologically distinct units lie adjacent to each other, a transition zone having unique selective pressures often generates endemic species that are specially adapted to this narrow range of environmental conditions and exist nowhere else. It is apparent from the MOJN ecoregion map (refer to boundary between different

Lake Mead National Recreation Area, the only National Recreation Area in the Network. NPS Photo.

Kelso Dunes, a unique and isolated sand dunes system, Mojave National Preserve. NPS Photo.

Joshua Tree National Park, near Barker Dam. Photo courtesy Stacy Manson.

colors in Figure 1.3) that environmental transition zones are present in several of the MOJN parks (DEVA, JOTR, PARA).

In the following subsections, we describe key abiotic and biotic characteristics of the MOJN as a preface to the ecological conceptual models presented in Chapter 2. More detailed information for each subsection can be found in Appendix C.

1.3.1 Landforms and Geology

The United States has been divided into physiographic or geomorphic regions based on common topography, rock types and structure, and geologic and geomorphic history. Here, we describe the distinctive landforms and geological features of the Basin and Range physiographic province, within which lie a majority of the MOJN parks.

The Basin and Range Province is the largest physiographic province in the U.S. and is the product of geological forces stretching the earth's crust. Over time, compressional and extensional tectonic activity along fault lines, volcanic extrusions, igneous intrusions, glaciation, and continuous erosion and deposition have modified the distribution and thickness of these rocks. Presently, the Basin and Range is characterized by uplifted and tilted mountain ranges consisting primarily of thick Paleozoic and Mesozoic rock abruptly separated by broad, elongate, alluvium-filled valleys or basins. The overall configuration of these alternating mountain ranges and valleys is generally northwest-southeast trending. Basins consist of either piedmont slopes, regions of active erosion and deposition, and/or basin floors characterized by slow runoff, restricted drainage, and an accumulation of soluble salts. Both GRBA and DEVA lie in the mountainous, western portion of the Basin and Range and exhibit the most extreme relief of the province. MANZ lies on its western edge, in the Owens Valley, directly in the rain shadow formed by the Sierra Nevada mountains. LAME, MOJA, and JOTR also lie within the Basin and Range, while PARA is located on the Shivwits Plateau, the westernmost plateau of the Colorado Plateau physiographic province, adjacent to the Basin and Range.

In the Basin and Range, soils are primarily aridisols, with mollisols and alfisols found at higher elevations in the mountains and entisols found on older alluvial fans and terraces. These soils vary widely in their properties (e.g., age, parent material, pedogenic process, size, and texture). Across a range of climatic conditions and topography (see section 1.3.2), the effective moisture of soils with different properties varies, which determines or limits vegetation types and productivity.

1.3.2 Regional Climate and the Role of Topography

Ecosystem distribution is largely determined by climate (i.e., temperature and precipitation) (Bailey 1995, 1998). Within the MOJN, climatic patterns and transitional zones are influenced by landscape position, latitude, and topography. As a result, regional climatic conditions across the MOJN are some of the most extreme and variable in the world (Bailey 1995). In this section, we describe the temperature and precipitation regimes in the MOJN, the dominant role of topography in determining regional climate, water availability, and ultimately, the distribution of plant and animal communities across the region.

Moist air masses originating in the Pacific Ocean, travel eastward, meet

the Sierra Nevada and the Transverse Ranges, rise, cool, and drop the bulk of their moisture load (as rain or snow) before they enter the MOJN. The effect of this rain shadow is a scarcity of water across the MOJN resulting in a semi-arid to arid desert environment. On the western side of the MOJN, drier conditions occur with limited precipitation from winter storms coming from the North Pacific Ocean. From west to east across the MOJN, precipitation gradually increases and occurs bimodally, especially during the summer and fall monsoon seasons. Thus, long periods of drought, with relatively high temperatures, are followed by short bursts of annual or bi-annual rain/snow precipitation events. This produces short, warm to hot growing seasons in which vegetation and wildlife compete strongly for food and water resources. The "hot desert" parks have average annual temperatures between 16-24 °C (7.1-32.6 °C range). Winters are mild and summers are very hot, and limited precipitation ranges from 5-25 cm in the valleys to 65 cm in the mountains. The "cold desert" parks have lower average annual temperatures between 3-10°C (2.1-16 °C range) and precipitation ranges from 13-20 cm in the valleys to 65-90 cm in the mountains.

Mountainous regions, with their broad elevational range and diverse topography have more complex weather patterns. Increasing altitude has a similar effect on weather as increasing geographic latitude, resulting in altitudinal zonation. In the MOJN, altitudinal zonation occurs along the slope of large mountains (e.g., Wheeler Peak in GRBA) and within deep canyons and valleys, creating local microclimates and supporting specialized vegetation zones. In the higher-elevation mountains, regional climate varies dramatically, characterized by longer, cold winters and relatively short, hot summers. In desert basins and canyons, thermal energy and humidity increases during the hotter summer months, which causes thermal updrafts and temperature fluctuations that create opportunities for plants to exceed their normal elevational limits (e.g., ponderosa pines or firs found at lower elevations in canyons). Closed basins, which are characteristic of the Basin and Range physiographic province, often experience temperature inversions, (i.e., cold air descends from mountains and accumulates in valleys) which can also affect the elevational distribution of plants (Grayson 1993).

Regional, episodic climate effects, such as El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and even the Atlantic Multi-decadal

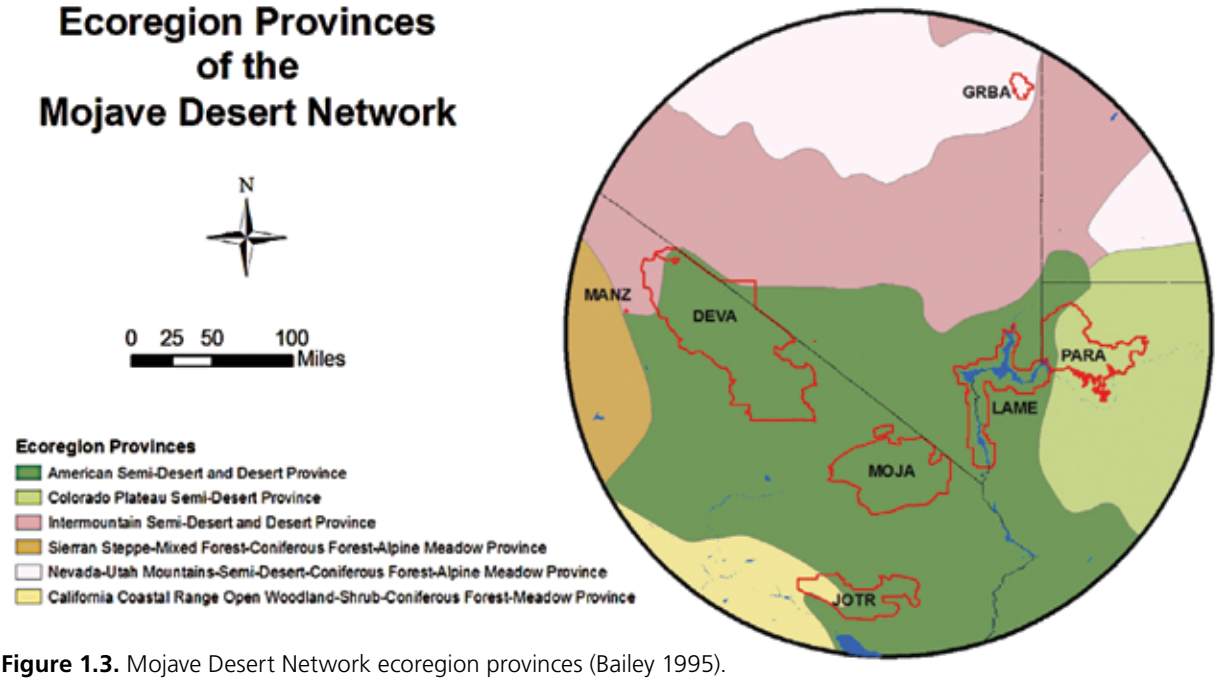


Figure 1.3. Mojave Desert Network ecoregion provinces (Bailey 1995).

The limited aquatic and hydrologic resources in MOJN are disproportionately important due to their critical role in supporting endemic biota, riparian plants and animals, and animals from adjacent uplands.

Oscillation (AMO) are also known to impact temperature regime, drought frequency, and precipitation in the Southwest (McCabe et al. 2004). ENSO is an ocean-atmospheric phenomenon that brings inter-annual variability to weather and climate and occurs with a frequency ranging from 3-8 years. Typically ENSO manifests itself by producing wetter, colder winters, which can have a profound effect on MOJN parks. Total seasonal precipitation is also correlated with ENSO and the PDO, with generally wetter years occurring during El Niño events and the positive phase of the PDO (Hereford et al. 2004). In arid and semi-arid environments, increases in precipitation trigger an increase in plant growth, which in turn results in more herbivores and ultimately more carnivores (Holmgren et al. 2006). Extended drought produces severe impacts on arid ecosystems including die back of perennial vegetation (Webb et al. 2001) and declines in animal populations (e.g., threatened desert tortoise) (Longshore et al. 2003). More than half of the spatial and temporal variance in multi-decadal drought frequency over the conterminous United States can be attributed to the PDO and AMO (McCabe et al. 2004).

1.3.3 Hydrology

Aquatic or hydrologic resources represent a very small portion of total land cover in the MOJN (excluding LAME), however they are disproportionately important from an ecological perspective (Appendix D). This is because they often host endemic biota and riparian species that rely on aquatic habitats during part of their life cycle. Wet features embedded in dry desert ecosystems produce biological hotspots where biodiversity is concentrated in relatively small areas such as riparian habitats (e.g., springs, oases, stream corridors), and montane islands. For example, more than 75% of terrestrial species, including 80% of birds and 70% of butterflies, are strongly associated with riparian vegetation in the Mojave-Great Basin region (Brussard et al. 1998).

Surface water resources in MOJN parks include both lotic (flowing) and lentic (non-flowing) environments. Major lotic environments are the Colorado, Virgin, and Muddy Rivers, while minor sources are perennial streams and springs, seasonal and ephemeral springs, and streams and seeps. Lentic environments in the MOJN include springs, wetlands, streams, lakes and ponds, playas, and oases/springs. These surface waters harbor biological diversity, provide an important source of drinking water for humans and wildlife, and are associated with important cultural sites.

Groundwater is fundamental to the function of desert hydrological systems and alteration to the groundwater flow system directly impacts aquatic and riparian systems. Groundwater hydrology (discharge at springs, seeps, and storage in groundwater aquifers) is controlled by factors affecting recharge through the unsaturated zone. Much of the present-day recharge in the MOJN is discharged to the atmosphere by evapotranspiration from plants, soil, and surface water sources. In the absence of any human development, the groundwater systems in the MOJN are in dynamic equilibrium with long-term climatic patterns. Rain and snow provide recharge to the groundwater system, which is balanced by an equal amount of discharge plus short-term changes in groundwater storage.

1.3.4 Flora

Water is the single most important resource for the survival of biota in desert ecosystems, and its availability governs the abundance and distribution of flora and fauna (Noy-Meir 1973; Reynolds et al. 2004). Current vegetation communities in the MOJN parks are the result of species adaptation and evolution, in addition to migration in response to departures from long-term climatic conditions (Thompson and Anderson 2000). Unique flora exist around desert riparian habitats (springs, streams, ponds, seeps), many of which have limited geographic distribution, are endemic, and are often classified as threatened or endangered. As a result, the Mojave desert has the highest frequency of endemic species in the western U.S. (McLaughlin 1989), which is indicative of its high ecological value. Plants provide a variety of necessary services for ecological

function such as primary productivity, organic matter for decomposition, protection of soil from wind and water erosion, and cover for animals ranging from micro-invertebrates to large mammals. Disturbance that results in change to the composition, cover, or structure of plant communities is likely to alter ecosystem function. In DEVA and LAME, aquatic and riparian plant species are sensitive to environmental variations and are highly important indicators of ecosystem status and health. Riparian habitats are potentially the most significant to the long-term maintenance of biological diversity and potentially the most threatened habitats across parks in the MOJN.

In a majority of the 'hot desert' parks (DEVA, JOTR, MANZ, MOJA), scrub/shrubland vegetation is the dominant vegetation type (88-95% of land cover), with the remaining portion covered by barren land (rock, sand, clay). Within LAME, 16% of the land-cover type is open water (Lakes Mead and Mohave), while 80% is scrub/shrubland (based on U.S. Geological Survey [USGS] National Land Cover Dataset, 2001). Two distinct floristic subregions, western and eastern, occur in the Mojave desert as a result of a strong west-east precipitation gradient. Across the western Mojave subregion, three native vegetation communities contribute 75% of shrubland cover: creosote bush (*Larrea tridentata*) scrub, mixed woody scrub, and desert saltbush scrub. In the eastern Mojave subregion, plant communities are comprised of desert dunes, Mojave mixed steppe, big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*) scrub, and native grassland. At higher elevations, a belt dominated by Joshua trees is present (JOTR, MOJA), and at slightly higher elevations, pinyon-juniper exists (DEVA, JOTR, MOJA). At even higher elevations (>3,048 m a.s.l.), especially within DEVA, a montane zone occurs, supporting ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), and bristlecone pine (*Pinus longaeva*).

GRBA and eastern PARA represent the "cold desert" MOJN parks that are similar climatically and floristically to each other. Distinct from the "hot desert" MOJN parks, the major land-cover type is evergreen forest representing 81% of GRBA land and 27% of PARA land (USGS National Land Cover Dataset 2001). Vegetation exhibits altitudinal zonation, with lower elevations dominated by large, continuous expanses of sagebrush-steppe, and slightly higher elevations dominated by pinyon-juniper woodland. At still higher elevations, there is a subalpine montane zone dominated by mountain mahogany (*Cercocarpus betuloides*), Douglas fir, spruce, and

Cactus garden in Joshua Tree National Park. Photo courtesy Alice Chung-MacCoubrey

Bear Poppy (*Arctomecon humillis*) in Lake Mead National Recreation Area. Photo courtesy NPS staff.

Desert tortoise are found only in the Mojave and Sonoran deserts. NPS Photo taken at Lake Mead National Recreation Area.

ponderosa, limber, and bristlecone pines. At the highest elevations, the alpine zone begins at treeline, interspersed with alpine tundra and meadows, and supports nearly 600 documented alpine plant species and ancient stands of bristlecone pine (>5,000 yrs old). Nearly as diverse as either the Rocky Mountains or Sierra Nevada at equivalent latitudes, the alpine and subalpine zones add greatly to the biological diversity of the region and to the potential resilience of the region in response to climatic change (Brussard et al. 1998). At GRBA, 55% of rare and sensitive plant species documented within the park occur in alpine or subalpine habitats.

1.3.5 Fauna

Invertebrates comprise approximately 95% of all animals (individuals) on earth (Mason 1995) and similarly comprise most of the animal biomass in deserts. Invertebrates and microorganisms, though often unnoticed, are important inhabitants in desert ecosystems because of their influence on a wide range of community- and ecosystem-level processes (see 7.1 Terrestrial Invertebrates, Appendix C). Two conspicuous and particularly influential inhabitants of the desert Southwest are ants and termites. These small, unrelated, social organisms have profound effects on desert ecosystems. They are important as, among other things, consumers of both living and dead plant material and other insects; as prey for a suite of specialist predators that include both birds and lizards; as seed dispersers and seed predators; as decomposers; and, as nutrient cyclers, mainly through their nesting activities (Whitford 1996; MacMahon et al. 2000). Due to the low volume of free surface water in the Great Basin and Mojave deserts, aquatic invertebrates are often overlooked, but aridland springs support diverse aquatic invertebrate communities. Each spring is distinctive due to its unique combination of water chemistry, discharge, temperature, elevation, morphology, and disturbance. Thus, most aquatic habitats are distinctive, isolated and relictual, resulting in high rates of endemism. In addition, because aquatic invertebrate communities experience the environment on much smaller temporal and spatial scales than larger animals, they can function as indicators of water quality or ecosystem health (Brussard et al. 1998).

Vertebrates contribute significantly to ecosystem function in desert shrublands and represent an important component of the biodiversity present in the Great Basin, Mojave, and Sonoran deserts (Whitford 2002). In general, vertebrates affect species diversity and trophic structure through competition and predation, while granivory (seed eating) and herbivory (vegetation eating) have strong effects on soil processes and plant community dynamics. As desert inhabitants, large herbivores (mule deer, bighorn sheep) impact vegetation and sensitive habitats (e.g., soil crusts on gypsum dunes), either individually or in groups, by their feeding and herding behavior. Granivores (rodents, birds) consume seeds, influence seed dispersal, and store excess seeds in caches for leaner times (Pulliam and Brand 1975; Reichman 1977). These seed caches appear to serve as important sites of germination for some plant species (Longland et al. 2001). In addition, seed-caching behavior may play an important role in the success of vegetation recovery in burned areas following wildfire.
In the MOJN, carnivores include the mountain lion (*Felis concolor*), coyote (*Canis latrans*), the desert kit fox (*Vulpes macrotis*), ringtails (*Bassariscus astutus*), and raptors (hawks, owls, eagles),

while omnivores or scavengers include skunks, and various avian species (e.g., ravens [*Corvus corax*], turkey vultures [*Cathartes aura*]). Reptiles of significant interest include the desert tortoise (*Gopherus agassizii*), gila monsters (*Heloderma suspectum*), sidewinders (*Crotalus cerastes*), and a high diversity of rattlesnakes (*Crotalus* spp.).

1.3.6 Resources of Special Ecological Significance

Biological soil crusts refer to a diverse community of cyanobacteria, bacteria, lichens, mosses and metabolic by-products that are cemented into a semi-permeable soil surface. Intact biological soil crusts protect soils from both wind and water erosion, relative to bare soil, thus providing soil stabilization, which is important for, among other processes, seed establishment and germination (Belnap 2003; Warren 2003). The biotic components of the soil crust fix carbon and nitrogen and decompose and recycle organic matter, which contribute to the nutrient content and cycling processes important for plant growth and survival. Unfortunately, crusts are susceptible to trampling from large animals (feral equids, livestock, recreationists) and disturbances from vehicles. Biological soil crusts can be found in all network parks and are essential components and indicators of the status and health of desert ecosystems (Belnap et al. 2001).

Riparian habitats or communities occur along major watercourses, lakeshores, isolated springs, seeps, ponds, and streams. Aquatic, riparian and terrestrial species as well as a significant number of species of special concern rely on riparian areas because of the available water, associated species diversity (i.e., greater potential prey diversity), and structural diversity, which provides cover, food, migration pathways, and other habitat components (Lohman 2004). Unfortunately, riparian habitats comprise one of the most dramatically altered community types over the last 150 years in the western United States. Obligate riparian bird species may be particularly good indicators of change in riparian communities, the most threatened habitat in the MOJN. For example, the Least Bell's vireo (*Vireo bellii pusillus*), an obligate-riparian breeder (Kus 1998), locate the vast majority of their nests in riparian vegetation. Change in the abundance or nesting behavior of this species may indicate compromised ecosystem health.

Eureka Valley Sand Dunes, Death Valley National Park. NPS Photo.

Eolian dune and sand sheet systems are also home to endemic flora and fauna in the MOJN parks. Eolian sand deposits occur near locations with abundant sand supply, such as downwind of disturbed desert areas, major rivers and washes, and playas. These dunes are composed of well-sorted fine- to medium-grained sand, which result in deep water infiltration, rapid evaporation, and hence relatively short periods of near-surface water availability. Dunes are inhabited by distinctive plants that are able to colonize unstable materials; this plant cover is crucial to dune stability. Both active and stabilized parts of eolian sand systems present challenges in the form of moisture-deficient, unstable substrates; however many plants, insects, and reptiles have adapted to these sites.

Playas are complex valley bottom systems that have self-contained drainage systems and are inundated on a nearly annual basis forming temporary shallow lakes. Wet playas have shallow groundwater and discharge, resulting in abundant salts, soft and unstable surfaces, and under certain conditions,

adjacent, associated springs. Dry playas have deeper water tables and are periodically inundated by surface water, but have less salt buildup than wet playas. Dry playas experience deposition from distal piedmont alluvial processes, from shallow ephemeral lakes, and from eolian dust and sand. Playas can be found throughout the MOJN, with numerous playas occurring at DEVA, JOTR, LAME, and MOJA. The Death Valley playa, nearly 128,000 acres, is one of the world's largest salt pans. As with aeolian systems, playas support unique, highly variable, environments and biota that challenge categorization and are particularly sensitive to disturbance.

All MOJN parks contain natural caves except MANZ. One of the primary reasons for establishment of GRBA, Lehman Cave is famous throughout the world for an unusual concentration of cave formations and abundance of shields (NPS 1992a). GRBA contains over 30,000 acres of karst geology and over 40 natural or 'wild' caves. Caves are generally stable environments when compared with surface ecosystems, often showing remarkable consistency in temperature and humidity. Unique, cool microclimates near cave mouths may be important for several plant and animal species (e.g., bats). Cave and karst systems are sensitive to many environmental factors including changes in hydrology and water quality, atmospheric changes (CO_2), and altered geologic processes (erosion). Cave environments, including unique cave invertebrates, may provide a sensitive indicator of environmental change.

Cultural resources (e.g., landscapes, historic sites) are an important component of the MOJN parks. A cultural landscape is a geographic area that includes cultural and natural resources associated with an historic event, activity, person, or group of people. They reveal our relationship with land over time, help individuals and groups understand themselves, and provide a sense of local and national heritage. MANZ represents the most notable cultural landscape and historic site within the MOJN where 110,000 Japanese American were interned in World War II (1942-1945). As the best preserved internment site (NPS 1996), thousands of people visit MANZ each year. In addition, the primary 'industries' of early Euro-American settlements in the MOJN were located near available water resources and associated with agriculture, ranching, and mining (DEVA, JOTR, MOJA). Similar to natural resources, these cultural landscapes are affected by natural forces, development (commercial, residential), vandalism, and neglect. While cultural landscapes represent a relatively small proportion of total land area in the network, they are disproportionately important to park mission, NPS management, and visitor experience. Spring sites associated with cultural landscapes tend to be highly altered areas and often serve as a starting point for non-native plant and animal invasion (American bullfrogs [*Rana catesbeiana*], tamarisk [*Tamarix* spp.]), thus affecting the structure and function of surrounding ecosystems.

1.4 Natural Resource Threats and Management Concerns

Because many of the MOJN parks share similar natural resource threats and issues, a set of network-level threats were identified during previous phases of the I&M process (see Appendixes E and H). In conjunction with this process, MOJN staff gathered park-specific information on key natural resources, natural resource threats, and other significant concerns facing parks. In order to narrow the focus, ensure relevance to several network parks, and increase efficiencies in the planning process, priorities were established among focal resources and resource concerns. Examples of resources used by network staff to identify common priorities included: General Management Plans, Resource Management Plans, Strategic Plans, and interviews with park resource managers. Appendix E provides a summary of threats and management concerns for all Vital Signs prioritized by the MOJN.

In the following section, we discuss these network-level threats, with emphasis on the high- and medium-priority stressors. Threats considered the highest priority at the network-level include: (1) invasive

Table 1.4. Relative importance of Mojave Desert Network ecosystem stressors (from the Mojave Desert Network Park-Level Vital Signs Monitoring Workshop in 2003).

STRESSOR	MOJN ORDER/OVERALL	DEVA	GRBA	JOTR	LAME	MANZ	MOJA	PARA*
Invasive Species	1/High	H	H	H	H	H	H	N/A
Water Quantity Alteration	2/High	H	H	H	H	H	H	N/A
Land Use Change/ Development	3/High	H	M	H	H	H	H	N/A
Air Quality Degradation	4/High	H	H	H	M	M	H	N/A
Altered Disturbance Regime	5/Medium	M	H	H	M	H	H	N/A
Recreation/Visitation	6/Medium	H	M	M	H	H	M	N/A
Climate Change	7/Medium	M	M	H	L	M	M	N/A
Water Quality Degradation	8/Medium	M	H	M	M	M	L	N/A
Soil Alteration	9/Medium	L	L	M	H	H	M	N/A
Grazing	10/Low	M	H	N/A	M	L	M	N/A
Resource Extraction	11/Low	M	L	L	L	H	M	N/A
Increased Native Wildlife Pops	12/Low	L	M	M	L	H	L	N/A
Habitat Fragmentation	13/Low	L	L	M	M	M	L	N/A
Nutrient Availability	14/Low	L	L	L	L	L	L	N/A
Disease	15/Low	L	L	L	L	L	L	N/A

*PARA did not participate in workshop.

species; (2) water quantity alteration; (3) land use change/development; and (4) air quality degradation (Table 1.4). Threats considered a medium priority include: (5) altered disturbance regime; (6) recreation/visitation; (7) climate change; (8) water quality degradation; and (9) soil alteration. Livestock grazing, although ranked as a low-priority threat (Table 1.4), is briefly discussed in this section because of the significant historic impacts of grazing within the MOJN.

1.4.1 Invasive Species

Network-wide scoping sessions concluded that invasive species are the greatest stressor to terrestrial (dry) systems in the MOJN parks. Deserts are considered one of the least invaded ecosystems by plants, possibly due to naturally low levels of soil nitrogen (Brooks and Esque 2003). However, at least 66 non-native plant species have been identified in two or more park units within the MOJN. Similar to other arid systems in the western U.S., invasive annual grasses are particularly widespread and abundant, with species in the Mojave desert dominated by grasses in the genera *Bromus spp.* and *Schismus spp.* (Brooks 1999).

Only 7 non-native terrestrial vertebrate species have been identified in two or more park units, including several common bird species and feral burro. Non-native aquatic species are common, particularly in the reservoirs at LAME (bull frogs, game fish, quagga mussels). Although significant amounts of staff time is dedicated to the management of these non-native fauna, they are considered less important (as a resource threat) than non-native invasive plants.

Park management concerns are primarily related to invasive, non-native plant species and include: (1) the ability of invasive, non-native plant species to compete with native plant communities for limited resources, reducing native plant density, biomass, and diversity (Brooks 2000); (2) potential impacts of non-native plant species on native fauna, particularly special status species (e.g., desert tortoise), through the alteration of native plant communities (e.g., food source, shelter); (3) potential for permanent alteration of ecosystem processes, such as fire, which are critical to maintaining ecosystem structure and function; and (4) potential impacts of invasive plants, such as tamarisk, on

The landscape of the MOJN parks has been significantly altered through historic and current patterns of land use and continues to be threatened by competing human interests.

groundwater and surface water resources.

1.4.2 Water Quantity Alteration

The importance of water to desert ecology cannot be overstated. The availability of surface water is directly related to the availability of subsurface or groundwater, which is slowly recharged through precipitation events and which feeds scattered springs and wetland habitats across network parks. In places around Las Vegas, groundwater levels have declined 90 m since 1907 due to human demands (Bawden et al. 2003). Continued up-gradient pumping of groundwater may potentially lower the water table and dry up critical surface water resources within the MOJN parks. Primary threats to surface and subsurface water quantity identified by park managers are groundwater withdrawal by surrounding communities/commercial use, diversion of surface waters (e.g., through pipeline), and invasion by non-native plant species such as tamarisk.

Park management concerns related to alteration of water quantity are primarily focused on the future ability of parks to protect this critical resource in the face of burgeoning population growth. Reductions in already scarce water resources will likely impact biodiversity, the potential for extinction of aquatic- and riparian-dependent species, and resources available to other fauna (e.g., bighorn sheep). Further investigations are needed to better understand the complex relationships between groundwater withdrawal, available surface water, and plant and wildlife populations.

1.4.3 Land Use Change/Development

The landscape of the MOJN parks has been significantly altered through historic and current patterns of land use and continues to be threatened by competing human interests. Since WWII, human population across the desert southwest has increased from approximately 8 million to over 40 million human inhabitants today (Wilkerson 2004). In Clark County, Nevada, human population increased 8200% between 1940 and 2000, with over 1.7 million inhabitants by 2000 (U.S. Census Bureau 2005). As human population continues to increase in areas surrounding parks, the associated impacts of urbanization on fragile desert resources (e.g., air pollution, increased groundwater withdrawal, nitrogen deposition, noise/light pollution, invasive species introduction) will increase. Impacts as a result of the myriad of human activities and development include: 1) physical alteration of the landscape surface (e.g., road-building, building construction, agriculture and grazing), 2) modification of plant and animal communities (from cats and dogs, invasive plants and animals, habitat fragmentation), and 3) multiplicative effects such as enhanced dust generation from gravel roads and effects of visitation and recreation.

1.4.4 Air Quality Degradation

Threats to air quality in and around network parks are primarily associated with adjacent urbanization and include both point and non-point sources. Air quality in the network is affected primarily by air pollutants (e.g., ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter) from densely populated urban centers in California, Arizona, and Nevada. Other sources of air quality degradation within and outside park boundaries include increased fire frequency in areas not naturally prone to fires, off-road vehicular traffic, mining activities (particulates), cogeneration power plants, landfills, vehicular emissions, and watercraft emissions (nitrogen and sulfur deposition). Potential future threats to air quality are primarily related to proposed commercial development on lands adjacent to parks (e.g., Eagle Mountain Landfill near JOTR, coal-fired power plants near GRBA).

Park management concerns related to declining air quality are associated with potential or actual negative impacts to visitor experience and human health, impacts on park natural and cultural resources (e.g., petroglyphs), and alteration of ecological processes (e.g., nutrient cycling). Maintenance of viewsheds and night sky vistas is a key management goal for several network parks, and reduced visibility may have a significant negative impact on visitor experience. Some park natural resources are particularly sensitive to specific pollutants. For example,

alpine lakes at GRBA have a very low buffering capability, thus the ecology (e.g., soil and water chemistry, species composition, predator-prey relations) could be significantly altered through deposition of acid rain and other air-borne contaminants.

1.4.5 Altered Disturbance Regime

Natural disturbance regimes that are of primary interest in the MOJN are drought, fire, and flood events. Although these disturbances are considered part of, and critical to, the maintenance of natural ecological processes, they may also be considered ecosystem stressors or threats when natural disturbance regimes become altered by human activities. Changes in disturbance regimes that concern park managers generally involve change in frequency (e.g., fire frequency), intensity (e.g., flood events), or duration (e.g., drought events). Examples of specific threats to natural disturbance regimes in network parks include: (1) spread of invasive annual grasses leading to increased fuel continuity, fire frequency, and fire intensity; (2) historic and current fire suppression activities leading to increased fuel loading and changes in plant community structure and composition that increase the frequency and intensity of fires; and (3) climate change that may alter the amount or pattern of precipitation leading to extended drought periods or increased frequency and intensity of floods.

1.4.6 Recreation/Visitation

Natural resources within parks are impacted not only by land use and development outside park boundaries, but also by increased visitation within parks. Increased human population (see section 1.4.3) surrounding parks is reflected in an increasing trend in park visitation. The longest period of visitation records at DEVA indicates an increase from 9,970 visitors per year in 1933 to 890,375 visitors per year in 2003 (Figure 1.4). In 2003, four of six network parks (DEVA, JOTR, LAME, MOJA) were in the top 30% of NPS units (N=353) with the highest percent of total visitors. LAME experiences the highest visitation in the network and, in 2003, ranked 5th in the nation with 7,915,581 recreation visits per year. In 1995, LAME had its highest visitation of 9,838,702 total recreation visits (NPS 2005c). Direct effects of increased park visitation include soil compaction in sensitive habitats (e.g., gypsum dunes and riparian corridors), light pollution, illegal collecting, and introduction and spread of invasive plant and animal species. Indirect effects of increased visitation are related to changes in land use, infrastructure development within park boundaries (e.g., increased number of developed roads, bathrooms, interpretive buildings), use of park resources (e.g., increased water consumption), and additional staff to manage visitation and provide a high quality visitor experience (Wittemyer et al. 2008).

Recreation and visitation levels among Mojave Desert Network parks are highest at Lake Mead National Recreation Area. NPS Photo.

1.4.7 Climate Change

The modern distribution and ecology of plant and animal communities is linked on a broad temporal scale to the climatic history of the Great Basin-Mojave desert region (Brussard et al. 1998). In response to climate change over time, both the distribution and composition of biotic communities have been altered as species sought more favorable conditions, adapted to existing conditions, were extirpated locally, or became globally extinct. Many studies of future climate conditions predict global

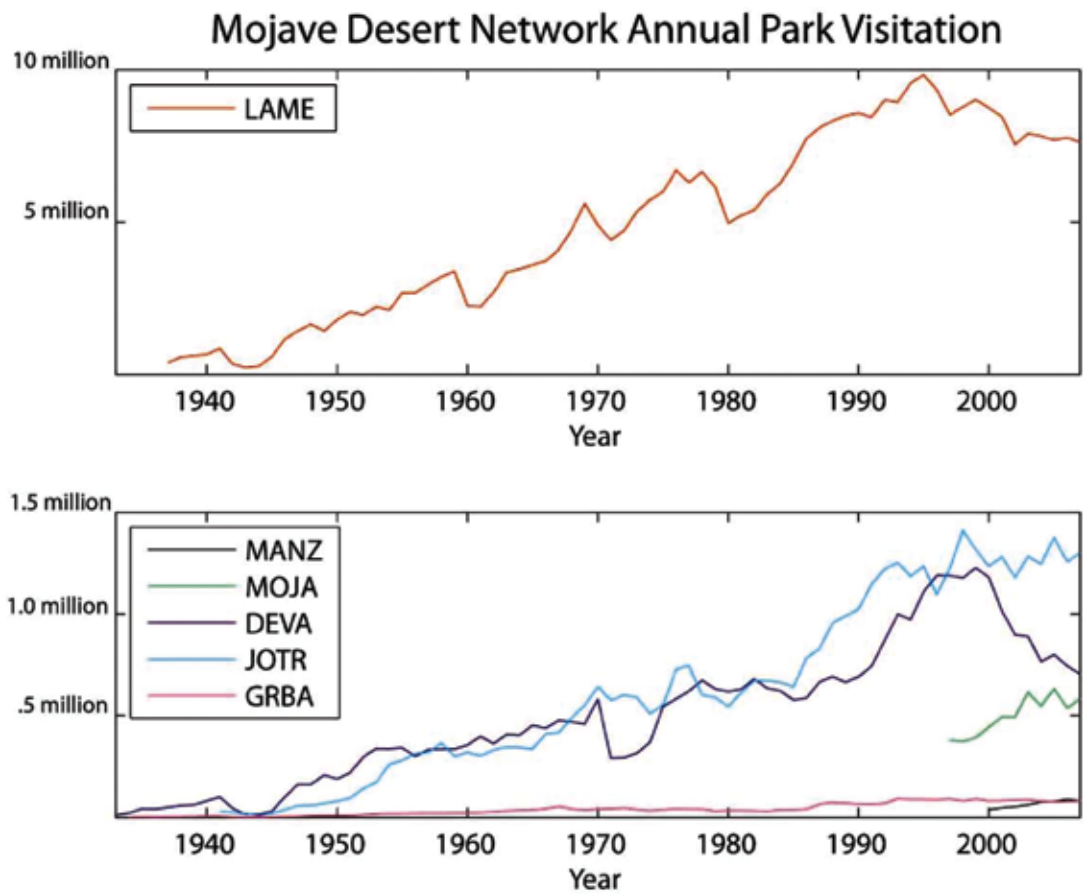


Figure 1.4. Trends in visitation at Mojave Desert Network parks. Note that the y-axis scales differ for the two panels in the figure.

warming of unprecedented rate resulting in increased temperatures, more variable weather patterns, more extreme weather events, and generally drier conditions in the southwestern U.S. (Giorgi et al. 2001; IPCC 2007). Human-induced changes in weather/climate may result from increased emission of greenhouse gases, increased atmospheric particulates, change in solar radiation and surface reflectance, and change in water vapor and other parameters associated with urbanization at a regional to global scale. Thus, on top of the background of climate variability is superimposed the short- and long-term effects of climate change caused by anthropogenic factors.

Network and park management concerns are related to the potential effects of altered weather patterns and climate on ecosystem processes and biotic and abiotic resources. Specific concerns include associated change in ambient temperature and amount of precipitation (fewer storms, decreased snowpack, decreased flow in rivers and streams), surface water quantity, soil moisture and temperature, dust mobility, rate of soil erosion and deposition, change in the distribution and species composition of plant and animal communities, length of growing season, and fire fuel loading. Other potential concerns relate to human responses to weather/climate change, including increased reliance on groundwater supply and construction of dams and pipelines. Controlling anthropogenic factors that alter weather/climate are considered outside the scope of management of the network or individual park unit. Effective monitoring will provide a basis for establishing the natural variability and human-induced change components of climate and help generate a database for projecting and interpreting hydrologic and biologic health of the desert ecosystem.

1.4.8 Water Quality Degradation

Threats to groundwater and surface

water quality vary in significance depending on the specific type and location of the water resource. For example, the chemical constituents or groundwater signature are determined by groundwater source, age, flow through different types of rock, and general movement. Alteration in groundwater chemistry can provide information on changes in water flow paths, changes in groundwater recharge, and presence of contaminants, all of which may indicate environmental change. General threats to water quality across network parks include: atmospheric pollutants, and pollutants from communities, mining, and commercial operations; more frequent, high-intensity fire events; concentrated recreational activities; and livestock grazing. There may be a link between water quantity and water quality, thus groundwater depletion/ lowered water tables also represent a potential threat to water quality in network parks. Acid rain is also considered a potentially significant threat to alpine lakes at GRBA.

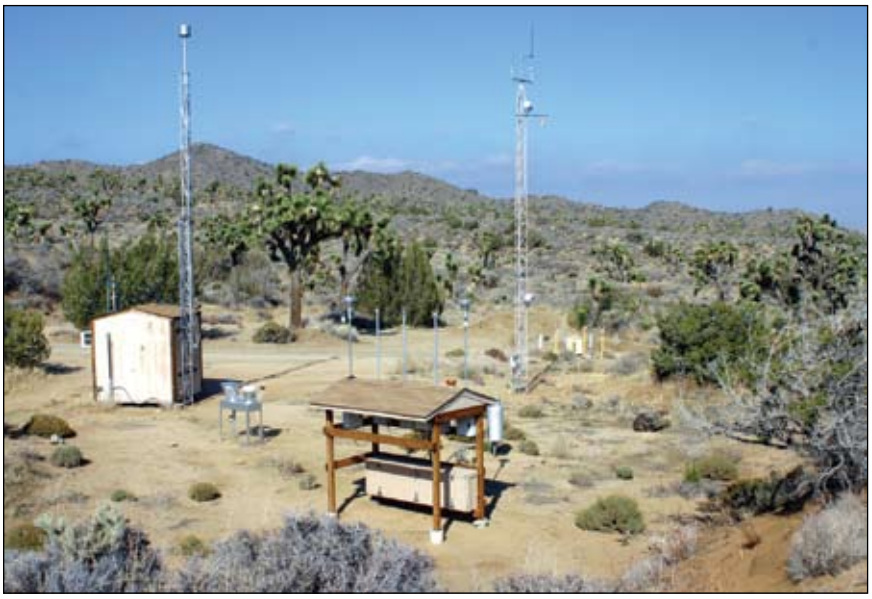
Park management is primarily concerned about the impact of decreased water quality on aquatic and terrestrial species and communities, public health and safety, and visitor experience. Wildlife, especially endemic and special-status species that depend on these relatively rare aquatic habitats for food, water, shelter, and breeding, may be particularly vulnerable. LAME provides drinking water for 18 million people in Nevada and California, thus human health issues related to alteration of water quality are a primary management concern. In addition, network parks obtain a portion of their drinking water from local springs, and the availability of clean water is considered a critical element of visitor experience. Lastly, the NPS is required to manage water resources in accordance with applicable laws, regulations, and NPS policy related to surface water quality/ impaired waters.

1.4.9 Soil Alteration

In arid systems, any disturbance or alteration to the top soil layer (top 3-20 mm), especially those areas with well-developed biological soil crusts (see section 1.3.6), is of particular concern. Threats to soil resources in the MOJN parks include any change that unnaturally accelerates geomorphic processes or significantly alters the physical or chemical properties of soils and ability of soils to function. Park management concerns vary depending on the specific threat but are generally related to potential impacts of degraded soil quality on desert ecosystems. Specific concerns include: (1) altered soil nutrient cycling leading to broad scale changes in plant communities (e.g., spread of invasive annual grasses); (2) increased atmospheric particulates (e.g., dust) leading to alteration of soil pedogenic processes; (3) compaction of soils in high visitor use areas (e.g., trails, riparian habitats), livestock grazing and off-highway vehicle use leading to long-term changes in soil-water-plant interactions, runoff, and rate of soil erosion; (4) alteration in the location and/or rate of soil erosion leading to changes in surface hydrology, loss of cultural resources, and change in plant distributions; (5) destruction of biological soil crusts and associated changes in soil stability and erosion rate; (6) development of hydrophobic soils in association with intense, stand replacing fires; and (7) potential contamination of soils (e.g., cyanide, lead, mercury, arsenic, uranium) associated with mining and commercial activities.

1.4.10 Grazing

Livestock grazing has occurred across extensive areas, and at varied intensities, in MOJN parks for over 150 years. Today, limited livestock grazing continues in DEVA, GRBA, LAME, MOJA, and PARA. Though few studies have documented grazing impacts in the Mojave desert and Colorado Plateau, research from other areas of the Southwest indicates that livestock grazing can impact and alter the species composition, function, and structure of ecosystems (Jones 2000); however, effects are context dependent (Milchunas and Lauenroth 1993). Of particular concern for park managers in the MOJN is the potential impact of livestock grazing on riparian habitats and the fauna associated with them (Carothers et al. 1974; Mosconi



Air Quality monitoring equipment, Joshua Tree National Park. NPS Photo.

and Hutto 1982, Chaney et al. 1990). Again, while grazing currently is not considered a high-priority threat within all MOJN parks, some monitoring of grazing impacts may be included in the MOJN monitoring program.

1.5 Summary of Current and Past Monitoring

An understanding of current and past monitoring activities in and around network parks is an important foundation for development of the MOJN Vital Signs monitoring program. Such information allows the network to identify where monitoring is adequate, and might only need to be expanded (or abandoned), and where additional inventory, monitoring, or protocol development is needed. Monitoring of Vital Signs identified through scoping workshops at the park and network-levels should complement existing monitoring programs already in place in network parks.

Park Resource Management Plans and the NPS Natural Resource Inventory and Monitoring Guidelines (NPS-75) guide current and past monitoring activities at the network parks (NPS 1992b). Each park's monitoring activities are also guided by GPRA management goals and are often focused on special status species, non-native plant and animal species, and riparian communities. Monitoring activities within network parks falls into two general categories: 1) monitoring conducted only within park boundaries (Appendix F, section 2.0); and 2) monitoring conducted within or near park boundaries that is part of a larger (e.g., state-wide, regional, national) monitoring program, which attempts to make inferences beyond park boundaries (Appendix F, section 3.0). Thorough analysis of current and past monitoring projects and data (Table 1.5) can serve as the basis for long-term monitoring in parks related to high-priority MOJN Vital Signs.

1.5.1 Air Quality Monitoring

Although most of the MOJN parks are some distance from large urban areas, many experience poor air quality from pollutants. In 2004, the American Lung Association, State of the Air Report (American Lung Association 2004) declared San Bernardino County, CA (adjacent to JOTR, non-attainment Class I airshed; and MOJA, Class II airshed) to have the unhealthiest air (e.g., visibility, ozone) in the nation. Recent data indicate that JOTR, MANZ, and MOJA are at high risk for foliar injury to plants from elevated ozone levels (NPS 2004a). Under the Clean Air Act (CAA) and GPRA mandate, Class I park managers have a special responsibility to monitor and protect air quality and related resources from the adverse effects of air pollution, and to provide recommendations to protect park natural and cultural resources. At the network-level, monitoring air quality conditions and understanding their interactions with physical and biological components of the ecosystem is vitally important to effectively evaluate the effects of these hazards on ecosystem health.

In the MOJN, climate and air quality data are monitored at a variety of stations located within ('on-site') or adjacent to the seven park units (Table 1.6). Many of the climate and air quality stations in the MOJN were installed and funded by non-NPS national agencies, inter-agency collaborations, and external partnerships. DEVA, GRBA, and JOTR have long-term, on-site, climate and air quality monitoring stations supported by NPS park staff and the NPS Air Resources Division. Three of the other MOJN parks (LAME, MANZ, MOJA) have climate and air quality stations within 170 km of park boundaries

Table 1.5. Record of historic (H, > 5 years ago) or current (C) monitoring data for the Mojave Desert Network Vital Signs across park units. "Level 1" refers to the NPS Ecological Monitoring Framework.

LEVEL 1	MOJN VITAL SIGN	DEVA	GRBA	JOTR	LAME	MANZ	MOJA	PARA
Air and Climate	Air Chemistry – Ozone	H/C	H/C	H/C	H/C	C		C
	Air Chemistry – Wet and Dry Deposition	H/C	H/C	H/C			C	
	Air Quality – Visibility and Particulates	H/C	H/C	H/C				
	Weather and Climate – Basic Meteorology	H/C	H/C	H/C	C		H/C	
Geology and Soils	Soil Hydrologic Function							
	Soil Chemistry and Nutrient Cycling			C				
	Biological Soil Crust Dynamics			C				C
	Soil Erosion and Deposition				C[d]			
	Soil Disturbance				C[d]			
Water	Groundwater Dynamics and Chemistry	H/C		H/C	C		H/C	H
	Surface Water Dynamics	H/C	C		C		H/C	
	Surface Water Chemistry	H/C	C		H/C			
Biological Integrity	Invasive/Exotic Plants[a]	C		C	C			C
	Vegetation Change	C[e]	C	H/C[e]	C[e]		C[e]	
	Reptile Communities		C	H/C			C	
	Riparian Birds	C[c]	C[c]	H	H/C[bc]		C[c]	
	Small Mammal Communities	C	H/C	H			H	
	At-Risk Populations	H/C		H/C	C		C	
Landscapes	Fire and Fuel Dynamics	H/C	H/C	H/C	H/C		H/C	H/C
	Landscape Dynamics					C		

a All parks report the number of acres of invasive species 'contained' related to GPRA Goal Ia1B.
b Associated with spring restoration.
c Landbird monitoring primarily conducted in parks through the Great Basin Bird Observatory, Point Reyes Bird Observatory, U. S. Geological Survey (N. Am. Breeding Bird Survey), or state wildlife agencies (NV raptor surveys) – some focus on riparian habitats. LAME is the only network park with a MAPS (Monitoring Avian Productivity and Survivorship Program) station.
d Represents a project approved for funding titled, "Monitoring protocols for soil stability at Lake Mead National Recreation Area."
e A total of 921 long-term vegetation monitoring plots associated with the U. S. Forest Service, Forest Inventory and Analysis program are contained within DEVA (N=553), JOTR (N=127), and MOJA (N=241) and it is assumed some plots are located within LAME. It is unknown how many of these plots have associated data.

(Table 1.6). Types of monitoring at these sites include ozone monitoring through the NPS Gaseous Pollutant Monitoring Network, wet deposition monitoring of atmospheric pollutants by the National Atmospheric Deposition Program (NADP), dry deposition monitoring of atmospheric pollutants by the Clean Air Status and Trends Network (CASTNet), and visibility monitoring through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. As new information is developed for the network, it will be added to the ARD's ARIS site at http://www2.nature.nps.gov/air/permits/aris/networks/index.cfm.

1.5.2 Water Resources Monitoring in Mojave Desert Network Parks

A review of water resources in individual network parks, baseline water-quality inventory data and analysis, clean water action plans (CWAP), water quality standards for states in the MOJN, and water monitoring projects in the MOJN are provided in Appendix D. Water quality at Lake Mead and Lake Mohave are monitored extensively by other agencies and programs (B. Moore, LAME *personal communication*) due to their importance as regional sources of drinking water, recreational value, and designation as critical habitat for several special-status species of fish.

Table 1.6 Weather and air quality (AQ) monitoring stations in ('on-site') or near Mojave Desert Network parks. Distance is from a given station to the boundary of park units.

PARK	AQ CLASS	WEATHER (RAWS OR COOP)	DRY DEPOSITION (CASTNET)	WET DEPOSITION (NADP/NTN)	VISIBILITY (IMPROVE)	OZONE (OZONE)
DEVA	II	On-site	On-site	On-site	On-site	On-site
GRBA	II	On-site	On-site	On-site	On-site	On-site
JOTR	I	On-site	On-site	On-site	On-site	On-site*
LAME	II	On-site	170 km	170 km	180 km	8 km*
MANZ	II	8-40 km	115 km	115 km	115 km	115 km
MOJA	II	On-site	100-150 km	100-150 km	100-150 km	35-50 km*
PARA	II	ND	ND+	ND+	ND+	ND

Air quality data for on-site monitoring stations can be obtained from the monitoring network's website listed below. Air quality estimates for parks without on-site monitoring are available from NPS Air Atlas at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm (Accessed 30 August 2005).
ND = Not determined.
RAWS = Remote Automated Weather Station Network
COOP = Cooperative Observer Program
NADP/NTN = National Atmospheric Deposition Program, data acquired from http://nadp.sws.uiuc.edu/
CASTNet = Clean Air Status and Trends Network at http://www.epa.gov/castnet/
IMPROVE = Interagency Monitoring of Protected Visual Environments at http://vista.cira.colostate.edu/views/
OZONE = EPA AirData at http://www.epa.gov/air/data/index.html or NPS AirWeb at http://www2.nature.nps.gov/air/data/index.htm
Passive ozone at http://www2.nature.nps.gov/air/studies/passives.htm
*Portable ozone (summer ozone season) at http://www2.nature.nps.gov/air/studies/portO3.htm
+ ARD plans to add PARA to its map of air quality monitoring in the MOJN (http://www2.nature.nps.gov/air/Permits/ARIS/networks/modn.cfm)

The MOJN will periodically review state 303(d) lists to determine the current regulatory status of these two reservoirs. Therefore, these reservoirs will not be directly sampled by the MOJN network nor addressed in the conceptual models presented in Chapter 2. For the rest of the MOJN parks, water monitoring is limited. In the April 2005 MOJN Water Resources Monitoring Workshop, the MOJN developed and prioritized monitoring objectives for water-related Vital Signs (Chapter 3).

Each state has developed its own list of Outstanding National Resource Waters (ONRW) under Environmental Protection Agency (EPA) guidance. Officially, there are no ONRWs in the MOJN, however, GBRA has four water bodies that have received a Class A designation by the state of Nevada, that state's highest level of protection (Baker, Lehman, Pine, and Ridge Creeks). Nevada defines Class A waters as waters or portions of waters located in areas of little human habitation, no industrial development or intensive agriculture, and where the watershed is relatively undisturbed by man's activity.

Under Section 305(b) of the Clean Water Act, each state is required to conduct water quality surveys to determine the overall health of the waters of the state, including whether or not designated uses are being met, and report to the EPA every two years. When impaired water bodies are identified, they are included in 303(d) priority lists in order to limit discharges of specific pollutants to that water body (Ledder 2003). LAME is the only network park that contains waters designated as 303(d) (Appendix D).

Chapter 2 Conceptual Ecological Models

2.1 Introduction

Conceptual models are critical elements in the design of scientific monitoring programs for the management of ecological systems. An ecological conceptual model is a visual or narrative summary that identifies and illustrates the connection between ecosystem components and their processes, important drivers and stressors that impact the ecosystem, and indicators of ecosystem health and status. A well-developed set of conceptual models helps us understand how physical, chemical, and biological elements of an ecosystem interact. This knowledge aids in the selection of potential indicators of ecologic condition and trend, prediction of potential responses to environmental change, analysis and interpretation of monitoring data, and communication of resulting information to park managers and the public.

The conceptual models for the MOJN do not attempt to explain all possible relationships or identify all possible components of the ecosystems. Instead, they simplify reality by organizing information for understanding these complex natural systems and help us make decisions regarding the preservation of our natural resources (Margoluis and Salafsky 1998). In addition to promoting integration and communication among scientists and managers from different disciplines (Gross 2003), the process of constructing conceptual models helps to clarify our thinking about system processes and monitoring program goals and aids in the identification of critical knowledge gaps and areas of uncertainty. Since human social systems are unpredictable and generate novel processes, not all components or consequences can be identified with current knowledge, thus these models should be viewed as "works in progress" that will be revisited and refined with emerging knowledge.

The objectives of the MOJN conceptual ecosystem models are to:

- Formalize current understanding of ecosystem components and processes in the MOJN across multiple scales.
- Identify major system drivers and stressors, the system attributes most affected by these drivers, and how they change through time.
- Identify indicators of ecological status and trend (Vital Signs) and link Vital Signs to key ecological components and processes.
- Aid in defining appropriate scales for monitoring in time and space.
- Aid in the development, interpretation, and presentation of monitoring data.
- Serve to communicate common understanding of the connections between management decisions and natural systems to NPS, other agencies, external scientists, and the general public (DeAngelis et al. 2003).

2.2 Mojave Desert Network Conceptual Model Approach

A wealth of conceptual models exists for semi-arid and arid parts of the American West, and we adapted many of these models for the MOJN. For the unique vegetation and desert processes found in the MOJN, we developed new models. Our general approach is to emphasize the role of water, a key limiting factor in the Mojave and Great Basin deserts, in structuring ecological communities. The amount of water, its availability, and its quality is controlled first by climate inputs and later by partitioning processes (e.g., runoff, infiltration, recharge) into saturated (e.g., lakes, streams, aquifers, and springs) and unsaturated (e.g., soil moisture) areas (Whitford 2002). Temperature fluctuations and pulses of water and nutrients superimposed upon a background of diverse geologic landforms and associated surficial deposits create a diversity of niches that shape biological communities (Chesson et al. 2004). Since water is such a limiting factor for MOJN desert biota, its role as a driver of plant and animal community structure and composition is emphasized in all our ecological conceptual models.

The MOJN developed a nested set of conceptual models with four levels of increasing complexity and detail (Figure

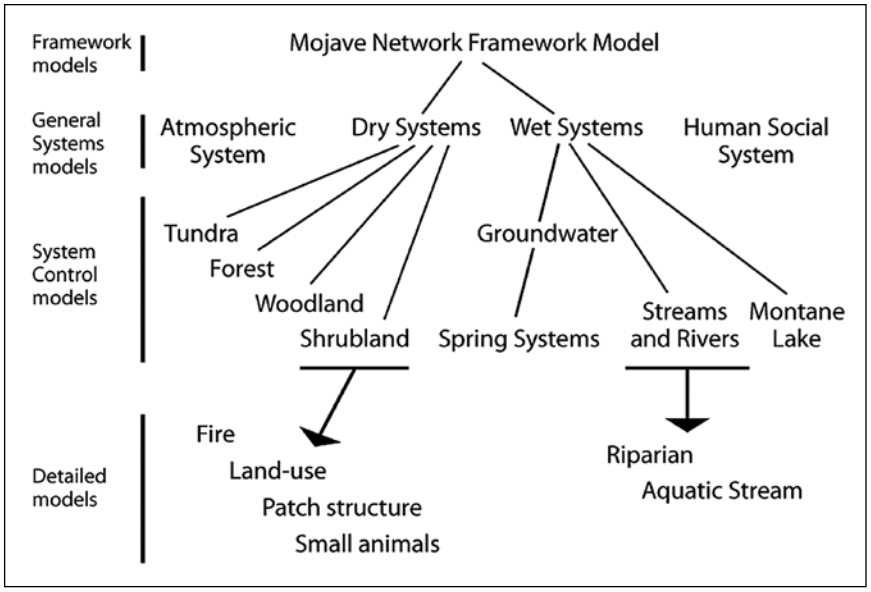


Figure 2.1. Hierarchy of models from framework description of ecosystems, to system and control models, and detailed models.

2.1). At the highest level, the MOJN Framework Model identifies four general systems: the **dry system (terrestrial), wet system (aquatic), atmospheric system, and human system**, and describes how these systems interact and affect the structure and function of one another on a broad-scale (Figure 2.2). At the next level, general systems models are developed for dry and wet systems, describing major components of each system (e.g., climate, soils, vegetation, and animals for dry systems), interactions and processes between components that influence the system structure, and means by which they are perturbed by stressors and drivers (dry system- Figure 2.3; wet system- Figure 2.4). More specific system control models describe specific biomes (e.g., shrubland or forest) or components (e.g., groundwater or springs) within the dry and wet systems. Lastly, detailed submodels illustrate important subsystems and disturbance effects, such as the shrubland fire and recovery model. Although we have described MOJN ecosystems with discrete models at different scales, we recognize that system components interact and respond at multiple temporal and spatial scales and have attempted to link components and processes across multiple scales and levels of complexity. The hierarchical relationships between major components of MOJN ecosystems, processes, drivers/stressors, and their interactions at multiple temporal and spatial scales are critical to understanding the selection of MOJN Vital Signs for monitoring.

In the following sections, we describe the major concepts underlying the overarching MOJN Framework model, the dry systems model, and the wet systems model and then briefly summarize biomes and components of dry and wet systems. All models are described in detail in Appendix G, the content of which overlaps closely with a publication by Belnap et al. (2008).

2.3 Mojave Desert Network Framework Model

We combined components of the Jenny-Chapin model (see Miller and Thomas 2004) to arrive at a simplified structure for the MOJN Framework model. We designed this highest level model to serve as the foundation for a series of more detailed ecological models. The Framework model identifies four General System Models (wet, dry, atmospheric, and human) and illustrates how wet and dry ecosystems in the MOJN, including the Mojave and Sonoran deserts, the southern part of Great Basin desert, and the western Colorado Plateau, are structured through interactions with the atmospheric system and human social systems (Figure 2.2). We briefly describe the four General Systems, summarize major interactions among them, and emphasize aspects of atmospheric and human social systems that act as drivers and stressors on components and processes of wet and dry systems.

The atmospheric system determines climate, which can change rapidly, and which creates the boundary conditions for weather. The atmospheric system conducts the most mass and energy, including pollution, to and from parks of the MOJN. Processes mediating interactions between the atmosphere and wet and dry systems include evaporation and transpiration, reflected radiation, precipitation, wind, and heat exchange. Climate of the Great Basin and Mojave deserts varies due to latitudinal and elevational effects on temperature, the rain shadow of the Sierra Nevada and Transverse

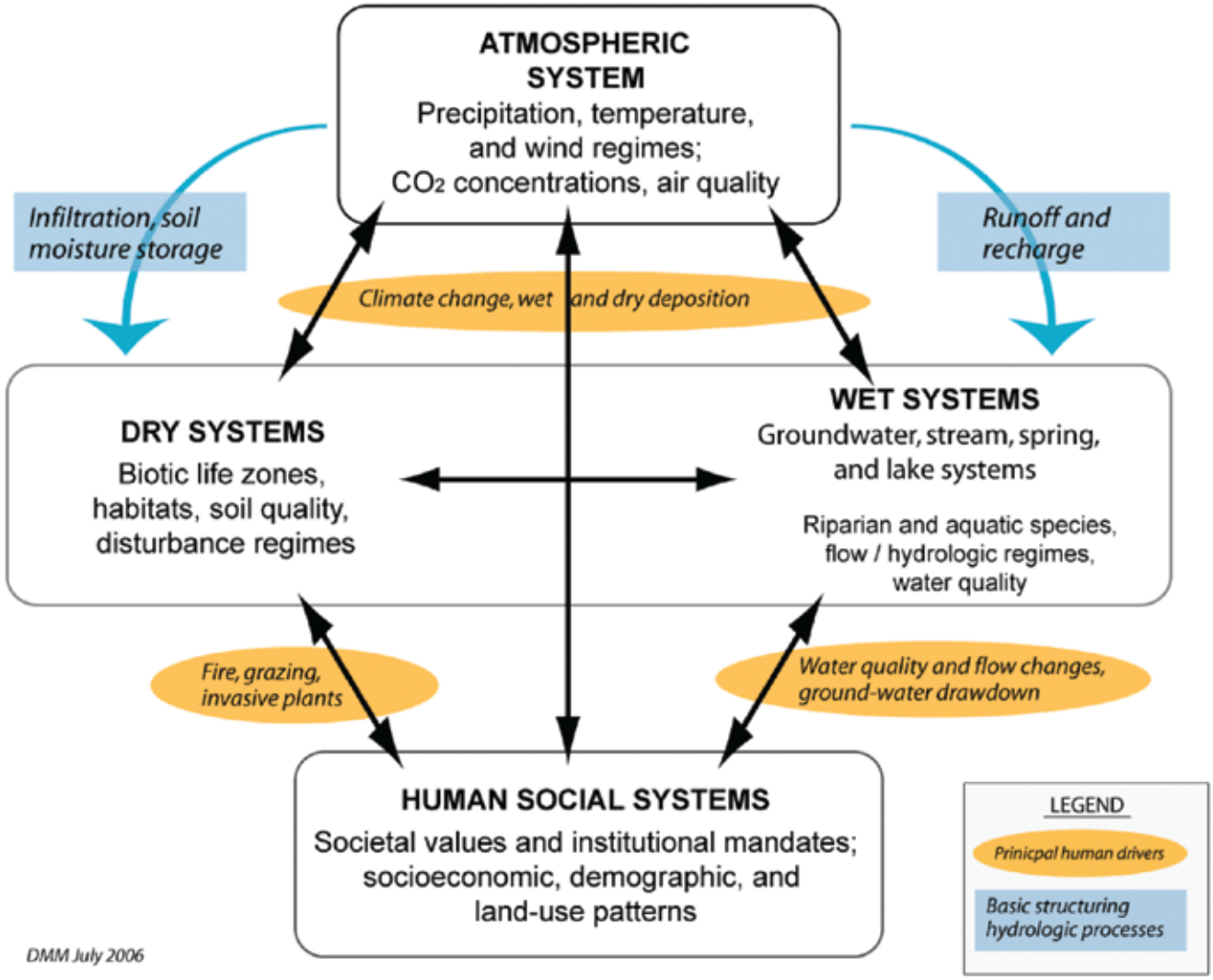


Figure 2.2. Mojave Desert Network framework model, showing the four principal systems, their components, interactions, and processes.

Ranges, which sharply reduce winter storm precipitation (see Chapter 1), and the influence of monsoonal systems from southern water bodies during summer. The result is a spatial and temporal mosaic of temperature and precipitation that interacts with geologic characteristics and elevation to determine plant community patterns across the landscape (vegetation zones). Biological communities are remarkably well- adapted to the harsh and variable desert climate, but nonetheless are ultimately limited by temperature extremes and long periods of drought. Climatic variability creates a complex framework for understanding past, current, and future features in the desert that are dependent on weather patterns (e.g., plant viability, plant-animal interactions, soil moisture availability, and persistence of ephemeral and perennial streams).

Climatic inputs of precipitation from the atmospheric system are partitioned into wet and dry systems. The dry system is best defined by what it is not and thus includes areas without standing or flowing "free" water. The division between wet and dry systems is logical for the MOJN because the transition between saturated, "free" water entities (e.g., springs, streams, lakes) and unsaturated substrates (e.g., soil or fractured rock) is rapid and distinct. Flora and fauna exhibit distinct transitions between wet and dry systems in direct response to the availability of water.

Dry systems comprise virtually all of the landscape within MOJN parks and are represented by a wide range of biomes (biotic communities) that are characterized by distinctive vegetation,

ranging from alpine tundra (*Salix* spp.) and adjacent conifer forests in GRBA to dry, sparsely vegetated shrubland valleys in lower elevation parks. Dry systems have been subdivided into system control models by these vegetation zones, or biomes. Within dry systems, soil characteristics and processes are linked to landscape-level characteristics and processes, and these components combine to structure plant communities and animal habitat. Precipitation inputs from the atmospheric system are partitioned into runoff, groundwater recharge (recharge of aquifers), and infiltration into soil moisture, which is the primary water source used by biotic systems. These same partitioning processes strongly affect many geomorphic processes, such as erosion, and soil processes (e.g., nutrient cycling). Particularly important for MOJN desert ecosystems are the near-surface soil moisture dynamics in which the available moisture is driven by spatial and temporal interactions with climate, soil, and vegetation (Noy-Meir 1973; Rodriguez-Iturbe 2000; Reynolds et al. 2004). Differences in soil moisture, along with temperature and elevation, result in the major dry system biomes (tundra, forest, woodland, shrubland), described in detail in the system control models.

Wet systems comprise a tiny fraction of the landscape within MOJN park units, but are a disproportionately important fraction in terms of virtually any ecological measure. The wet system is defined by areas with standing or flowing water such as lakes, streams, springs, and wetlands, and thus wet systems support plant communities that do not rely solely on direct precipitation. These areas have high biodiversity, displaying dense plant communities and supporting many terrestrial animals and diverse aquatic species. Most are isolated relics of formerly connected waterways, and support local obligate and endemic species. Climate (precipitation and temperature) is the main driver of the groundwater systems that maintain streams, lakes and springs in the network. Within a reference range of climate variability, recharge, storage, and discharge are approximately in a state of dynamic equilibrium.

Basins and ranges of the northern Mojave desert, Death Valley National Park. Photo courtesy D.M. Miller, USGS.

Natural and human-induced changes to the atmospheric system are expected to be major future drivers and stressors to wet and dry systems. Altered atmosphere and climate created by anthropogenic increases in CO_2, particulates, aerosols, ozone, and other pollutants have potential to drive many ecosystem processes outside the reference range of variability. Regional storm and air flow from coastal areas partition most of the air pollution, haze, and particulate matter from central and southern California, as well as from Reno and Las Vegas, into patterns of wet and dry deposition, reduced visibility, and pollutants that can be monitored on a regional scale. Climate models predict that drier and warmer conditions will prevail in the Great Basin during the next couple of decades, suggesting that forest and alpine tundra systems in the region may shrink, move upslope, or disappear from the landscape entirely. This loss of forest will impact associated wildlife and highlights the need for a more complete picture of forest ecosystem dynamics in the region.

Ecosystem condition cannot be understood without considering human impacts. Human social systems account for a majority of stressors and drivers influencing MOJN parks at scales from global to site-specific, and many of these influences are not directly in the control of the NPS. Natural resource threats

Table 2.1. Anthropogenic drivers and stressors, their potential ecological effects, and relevant Vital Signs for the Mojave Desert Network. Refer to Chapter 1 (Table 1.4) for the relative importance of these natural resource threats to each of the network parks.

DRIVER/STRESSOR	ECOLOGICAL EFFECTS	RELEVANT MOJN VITAL SIGN
Invasive Species	Increased fire frequency Community shifts and biodiversity loss Altered groundwater dynamics Altered soil nutrient cycling	Invasive/Exotic Plants Fire and Fuel Dynamics Vegetation Change
Water Quantity Alteration	Decreased surface water levels Altered riparian communities Loss of aquatic habitats Loss of biodiversity	Basic Meteorology Surface Water Dynamics & Quality Groundwater Dynamics At-Risk Populations, Riparian Birds
Land Use Change/ Development	Increased groundwater extraction Soil disturbance Habitat loss or fragmentation Altered surface water	Groundwater Dynamics & Chemistry Vegetation Change Landscape Dynamics, Riparian Birds At-Risk Populations, Small Mammals, Reptiles
Air Quality Degradation	Nitrogen deposition Establishment of invasive plants Lake acidification, foliar injury, vegetation growth loss	Wet/Dry Deposition, Ozone, Particulates Soil Chemistry/Nutrient Cycling Surface Water Quality
Altered Disturbance Regime (dry systems)	Altered nutrient dynamics Increased soil erosion and deposition Altered fire regime Increases in exotic species	Soil Chemistry/Nutrient Cycling Soil Disturbance, Erosion/Deposition Fire and Fuel Dynamics Invasive/Exotic Plants
Recreation/Visitation	Increased trampling and soil erosion Spread of invasive plants Disturbance/collection of wildlife	Soil Disturbance, Erosion/Deposition Biological Soil Crusts Invasive/Exotic Plants, Reptiles
Climate Change	Altered temperature, precipitation, deposition, and flow regimes	Basic Meteorology Vegetation Change
Water Quality Degradation	Impacts to wet and dry system flora and fauna	Surface Water Quality & Dynamics At-Risk Species
Soil Alteration	Increased soil erosion & deposition Loss of protective soil crusts Reduced infiltration and increased runoff Habitat loss	Soil Erosion/Deposition, Disturbance Biological Soil Crusts Soil Hydrologic Function Small Mammals

and management concerns identified by MOJN park staff (Chapter 1) form the list of key anthropogenic drivers and stressors listed in Table 2.1, which also includes their potential ecological effects and relevant MOJN Vital Signs (see Chapter 3).

2.4 Dry Systems Model

Dry systems comprise virtually all of the landscape within MOJN parks. It has long been established that water is the single most important component for the survival of biota in terrestrial desert ecosystems (dry systems), controlling production and the sequestration of carbon and nitrogen for plant production (Noy-Meir 1973; Reynolds et al. 2004). The availability of water is largely controlled by soils, a geologic characteristic. Thus, geology and climate are the first-order template upon which dry systems are structured.

In the dry systems model (Figure 2.3), climate drives many soils processes and influences characteristics for a given parent material (e.g., soil moisture regime). Across the landscape, a soil-geomorphic mosaic is created by variation in the magnitude, frequency, and timing of precipitation events and the interaction of precipitation with soil. For example, precipitation dynamics determine patterns of erosion, transport, and deposition of sediment. The soils-geomorphic mosaic in turn strongly governs the distribution and abundance of vegetation and other biota in desert systems (Juhren et al. 1956; Beatley 1969, 1976; Schwinning and Sala 2004). The abiotic matrix (e.g., soil, water, air) supplies the resources and supports the biota (e.g., flora, fauna) that together form the foundation of all dry ecosystems.

Plant and soil crust communities are

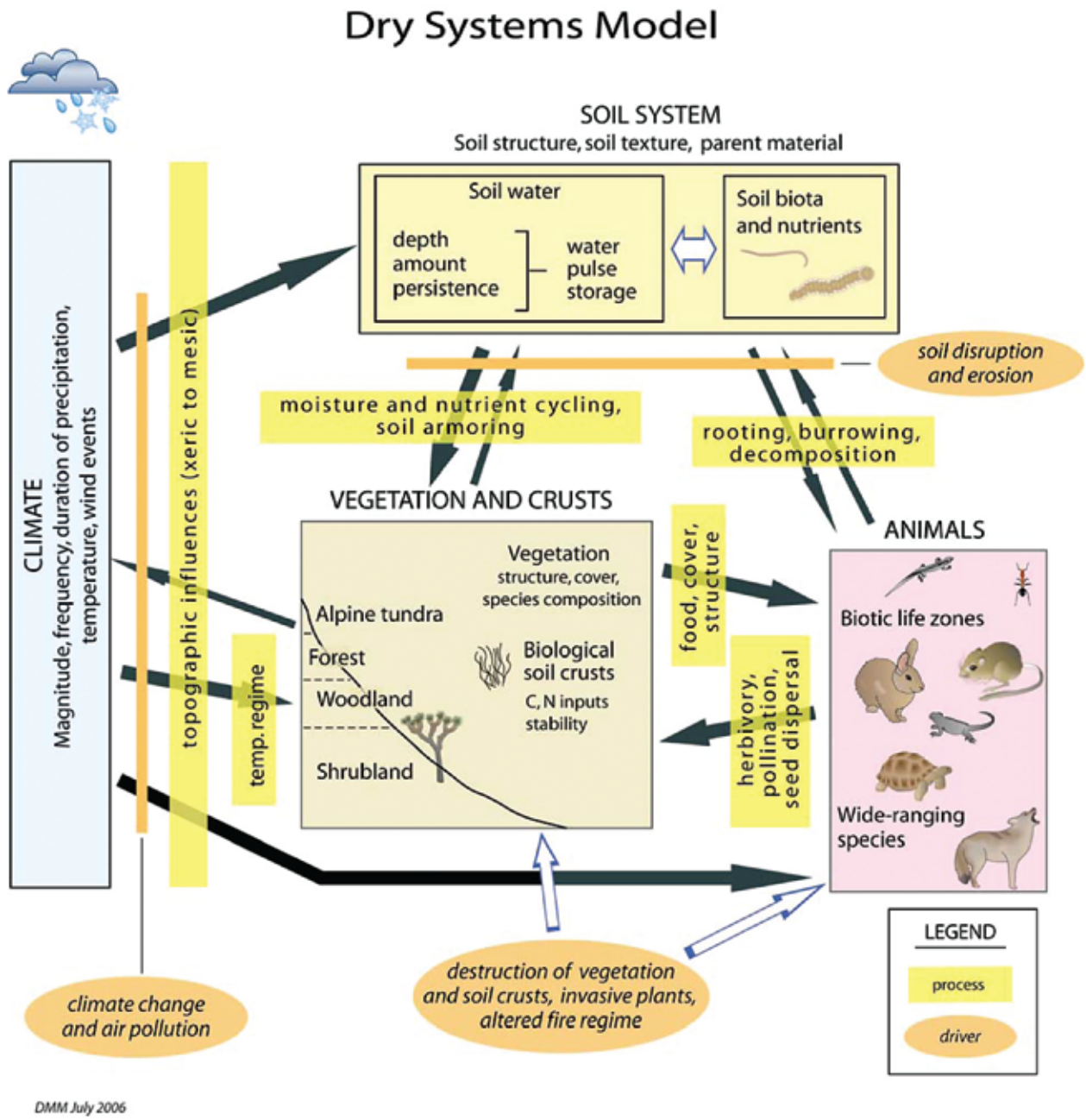


Figure 2.3. Mojave Desert Network conceptual model for dry systems.

largely structured by soil properties and processes, which in turn, influence soils through nutrient cycling, soil stabilization and armoring, and their role in natural and altered disturbance regimes. Vegetation structure and composition influence animal communities by providing food, cover, and other resources. Animal communities in turn modify the abiotic and biotic environment (soils and vegetation) through herbivory, seed dispersal, digging, burrowing, and other activities. The model incorporates natural and human drivers and stressors by identifying the model components they most strongly affect (Figure 2.3).

Elevation and aspect influence temperature, soil moisture, and ultimately soil morphology, and these abiotic influences have long been known as correlates of different vegetation zones (Figure 2.4). As latitude increases, vegetation zones descend in elevation due to decreasing temperature and increasing available moisture (Merriam 1890, 1898). Degree of plant cover generally increases with latitude and elevation, except at very high elevations. MOJN parks comprise a wide range of distinct vegetation zones, or biomes,

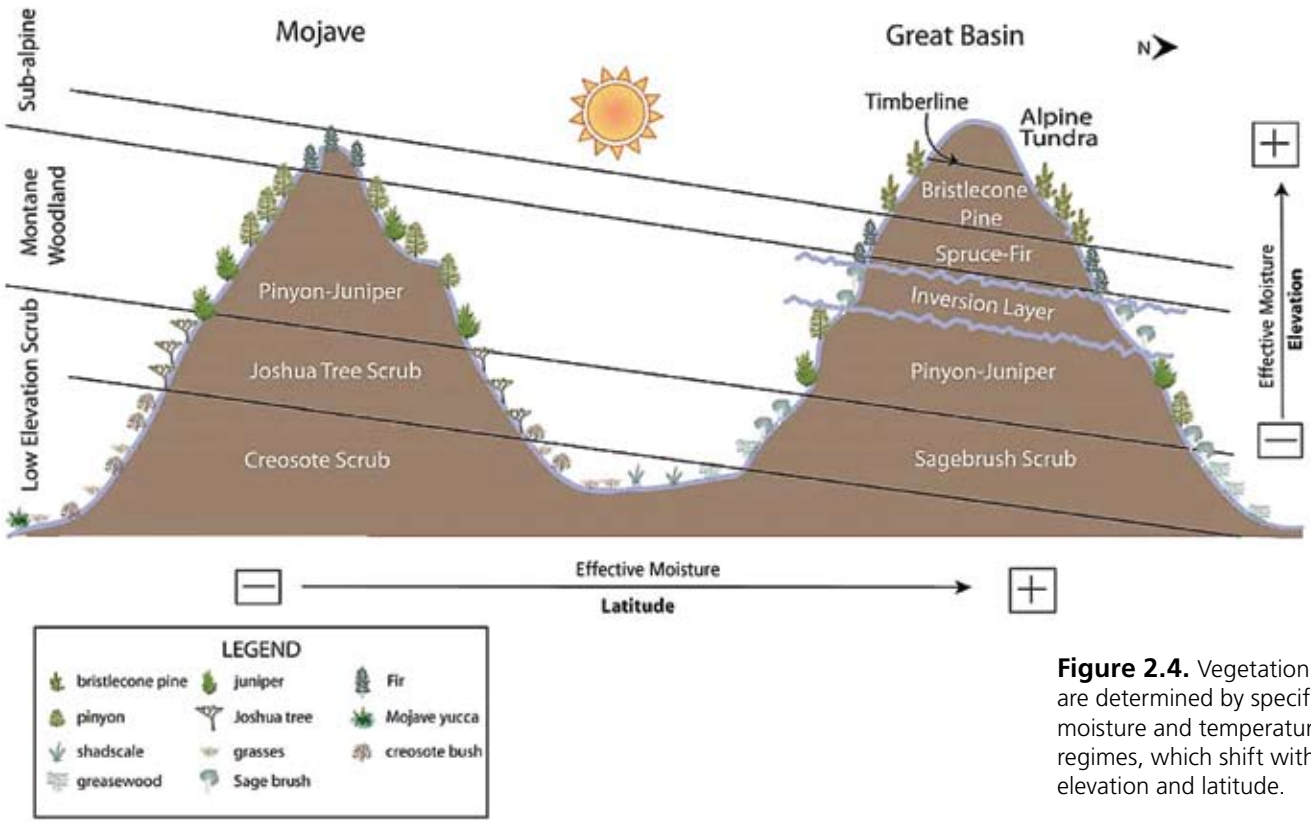


Figure 2.4. Vegetation zones are determined by specific moisture and temperature regimes, which shift with elevation and latitude.

ranging from shrublands at low elevations (e.g., sagebrush, creosote bush, pinyon-juniper woodlands at intermediate elevations, mixed conifer forests at higher elevations (e.g., spruce [*Picea* spp.], fir [*Abies spp.*], pine [*Pinus* spp.]), and alpine tundra above timberline (Figure 2.4).

MOJN dry systems also include a variety of unique environments such as dunes, dry lake beds, salt flats, lava flows, and caves, for which specific models were not developed. The shrubland biome covers a majority of the landscape and is the site of the majority of human and other disturbances; thus, we have placed the greatest emphasis and detail in the shrubland system control model and associated detailed models. Full system control and detailed models for all biomes are presented in Appendix G. We briefly summarize each biome in the following sections.

2.4.1 Shrubland Biome

Shrubland and desertscrub biomes generally lie in the lowest altitude and most arid part of the landscape, the piedmonts and valley bottoms. These areas are typically composed of thick alluvial deposits, which are commonly rocky in the Mojave desert and finer textured in the Great Basin.

Desertscrub biomes in the Great Basin and Mojave deserts are comprised of different plant communities. Great Basin shrubland (desertscrub of Turner 1994a) consists of major plant dominants with cold temperature affinities and species associated with warmer temperatures such as rabbitbrush, blackbrush (*Coleogyne ramosissima*), hopsage (*Grayia* spp.), and horsebrush (*Tetradymia* spp.). These species are soft-wooded, highly branched and evergreen, and generally form open to dense stands, with perennial grasses as important understory elements. Sagebrush shrubland has been subjected to grazing, which increases woody species by selective herbivory. Invasions by grasses and forbs have increased the fire fuel load, enhancing fire cycles that disfavor the non-sprouting shrubs (D'Antonio and Vitousek 1992; Brooks et al. 2004). These disturbances are treated in more detail in the land-use and fire submodels (Appendix G).

Creosote-dominated shrubland, with Kelso Dunes in background, Mojave National Preserve. NPS Photo.

In contrast, Mojave desert shrubland (desertscrub of Turner 1994b) consists of major plant dominants with warm temperature affinities. Cacti are common in the southeast Mojave desert (due to greater summer rainfall), but present throughout the Mojave and include hedgehogs, several prickly pear cacti, barrel cacti (*Ferocactus* spp.), and two tall-statured yuccas (*Mojave yucca* [*Yucca schidigera*] and Joshua Tree). Annual and biennial plants of the Mojave Desert shrubland are mainly winter germinators, although late summer germinators also occur. Creosote bush shrubland is the most widespread of the Mojave desert shrublands and often occurs with white bursage (*Ambrosia dumosa*) as a co-dominant. Mojave yucca and Joshua tree stands are common at higher altitudes, and in the case of the former, strongly associated with desert pavements and strong pedogenic soils. Studies of Joshua tree "woodlands" indicate that typically, the Joshua tree is dominant only in stature and the wide range of shrubs and grasses are of greater ecological importance (Rowlands 1978). Salt desert shrubland (Saltbush series of Turner 1994b) is typified by one or more *Atriplex* species along with halophytic chenopods. The shrubs are generally widely spaced, and occupy environments such as fringes of playas. Saline playas represent groundwater discharge environments, supporting mostly phreatophytic species, and thus are treated in the wet systems models.

Several detailed submodels in Appendix G describe patch-scale dynamics, the roles of small mammals and reptiles, the influence of natural disturbance regimes, and anthropogenic disturbance effects on shrubland ecosystems. One of the anthropogenic disturbance submodels, the shrubland fire and recovery model, describes the establishment of the grass/fire cycle in native shrublands (Appendix G, Section 7.3.4). The grass/fire cycle is an alteration of fire regime that may occur where alien annual grass species come to dominate the herbaceous layer in a plant community (D'Antonio and Vitousek 1992; Brooks et al. 2004). After colonizing, the alien annual grasses provide a continuous fine fuel that is readily ignited and facilitates fire spread where significant spread may not otherwise occur. Following these grass-fueled fires, alien annual grasses typically recover more rapidly than native species, further increasing the probability, size, and intensity of fires and the further decline of native species (Brooks and Minnich 2006). This cycle may be exacerbated by pollution and climate change. In parts of the MOJN, atmospheric nitrogen deposition may lead to increases in invasive annual grasses and decreases in the native annual vegetation (Brooks 2003). Climate variation resulting in temperature fluctuations, and the amount and seasonality of precipitation, could increase or decrease the relative importance of these disturbance processes.

The land disturbance model describes the effects of soil compaction, grazing, plowing, and water diversion on shrubland ecosystem function (Appendix G, Section 7.3.5). Each of these anthropogenic disturbances can directly or indirectly affect soil properties and plant communities, thus leading to effects on animal communities. For example, these activities cause soil disturbance and compaction, which leads to the loss of soil crusts, reduces water infiltration and nutrient cycling, and increases water and wind erosion. These effects on soils alter water and nutrient availability, which lead to changes in plant community composition and distribution, increasing the likelihood of invasive species establishment or spread, altered fire regimes, and fragmentation or loss of

wildlife habitat. Other biomes (tundra, forest, woodland) likely experience many analogous disturbance processes as those described for shrublands.

2.4.2 Pinyon-juniper Woodland Biome

Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands are the only major vegetation type occurring throughout the entire MOJN and are comprised of various combinations of eight pinyon and juniper species. These woodlands occur at middle elevations (1500 – 2300 m) on upper piedmont and lower slopes of mountain ranges in an elevational band between shrubby vegetation below (e.g., chaparral, Sonoran desertscrub, Mojave desertscrub, or shrub steppe) and mixed conifer forests above. Pinyon-juniper woodlands typically exhibit broken canopies ranging from 25 to 50% tree cover, and trees are rarely more than 12 m tall. Habitat tends to be rocky, and soils are usually thin on the mesas, plateaus, piedmonts, slopes and ridges (Pase and Brown 1994). Depending on a variety of environmental factors and antecedent conditions, the vegetation under the tree canopy ranges from bare ground to a rich shrub and/or grass community hosting species representative of Mojave desertscrub, Sonoran desertscrub, interior chaparral, Great Basin shrub-steppe, and/or montane communities. Pinyon and juniper woodlands are important for wildlife habitat, and shifts in the distribution and density of pinyon and juniper woodlands can have large effects on the species composition, behavior, and population status of resident animals.

Livestock and other large herbivores have important effects on pinyon and juniper systems, and some MOJN parks have been historically or are currently grazed by commercial livestock and/or feral equids. Intense grazing by livestock reduces perennial grasses, which leads to a reduction in fine fuels. Reduced fine fuels and intentional fire suppression results in a cascade of effects; including reduced frequency of surface fires, increased canopy cover of pinyon and juniper, reduced understory moisture, and altered understory plant composition (Appendix G, Section 6.2). Although some effects of livestock grazing can lead to decreased fire frequency, other effects, such as the introduction and spread of invasive annual grasses by livestock, may lead to increased fire frequency and establishment of a grass/fire cycle (described in Section 2.2.1).

2.4.3 Mixed Conifer Biome

Coniferous forests (excluding pinyon and juniper woodlands) cover less than 1 percent of the Great Basin landscape, and even less of the Mojave desert landscape, where they represent scattered patches at high altitudes. There are 15 species of conifer in the Pinaceae in the Great Basin including ponderosa pine, white fir (*Abies concolor*), Engelmann spruce, Douglas fir, and limber pine (*Pinus flexilis*), which are found between 6,500 feet and timberline. Shrub understory in the forest is an important part of the forest ecosystem, and patches of mountain sage and mountain mahogany may play successional roles. Forest cover provides a unique environment for a host of plant and animal species that otherwise would not exist, adding great value to the diversity and stability of the ecoregion. The mixed conifer forest biome covers a substantial proportion of GRBA and is found between the woodland and shrubland biomes and alpine tundra.

As is the case throughout most of the intermountain west, upland forests of the Great Basin are disturbance-driven ecosystems (Peet 2000). Wildfire is the most widespread and significant disturbance agent in the region. Perhaps the result of fire suppression, insect pest outbreaks are becoming increasingly important to conifers, especially in combination with the stress of prolonged drought. Anthropogenic drivers include global climate change, selective grazing and trampling by livestock (Belsky and Blumenthal 1997), and motor vehicle use (primarily off-highway vehicles). Increased temperature due to climate change may reduce total area of forest cover, by differentially selecting for arid-tolerant species at the lower elevations, or as a result of some species migrating upslope

Bristlecone pine, Mt. Washington, Great Basin National Park. NPS photo.

where they will occupy smaller areas where more favorable climatic conditions occur. Motor vehicle use can lead to increases in soil compaction and erosion, opportunities for invasive species (Gelbard and Belknap 2003), higher incidence of human-caused fire, and a reduction in habitat quality due to increased fragmentation (Trombulak and Frissell 2000).

2.4.4 Alpine Tundra Biome

Alpine tundra occurs on rocky mountain tops above upper timberline, and is only present in the MOJN at GRBA. The short growing season due to cold, combined with intense radiation, wide temperature variation, extreme wind, thin air, and long-lasting snow, severely limit the productivity of flora and fauna in this zone (Scott and Billings 1964). The tundra environment is generally characterized by thin, rocky soils and plants with low, prostrate growth forms. Despite harsh environmental conditions, a diverse community of short-stemmed perennial herbs, lichens, and mosses are common, as are prostrate forms of woody shrubs (Pase 1994). At upper timberline, a transitional zone includes bristlecone (*Pinus aristata*) and limber pine with their characteristic stunted, krummholz growth.

Anthropogenic drivers include climate change, direct trampling and contamination, wet and dry deposition of air pollution, ozone, introduced fire, and plant harvesting. Alpine tundra may be affected by climate change as: 1) the increased variability in climate results in a greater intensity and frequency of wind storms, 2) increased CO_2 alters plant species composition by changing the need for photosynthetically efficient plants, and 3) timberline migrates upward due to increased temperatures. Reduced atmospheric ozone leads to increased solar radiation and incident UV radiation, damaging plants at these high elevations. Human trampling and harvesting of plants disturbs soils and plant mats, increasing wind and water erosion.

2.5 Wet Systems Model

The wet systems model describes the relationship and interactions among climate and four components: groundwater, lakes, streams, and springs (Figure 2.5). Hydrologic inputs to the wet system come from two predominantly abiotic systems: the atmosphere (through direct precipitation) and groundwater (through storage and transport of water). Water from these two sources is transported through biotic systems, then returned to the atmosphere through evaporative processes and returned to groundwater systems through deep infiltration. Water entering ecosystems from surface runoff and groundwater discharge support wet system habitats.

Stream and stream-bank (riparian) ecosystems consist of environments such as the floodplain, channel bank, channel bed, and channel, and are used by many ecosystem components such as plant communities, aquatic species, and wildlife. The function and distribution of these habitats are driven by the flow regime, particularly the pattern of flow of floods in space and time. Large streams and rivers are also complex networks in which the organization of channels and their tributaries uniquely shape flow characteristics and exchanges with floodplain and riparian habitats (Benda et al. 2004). The flow regime shapes habitats through disturbances, temperature and light variations, and water chemistry (including nutrient concentrations; Scott et al. 2004). The flow regime strongly influences

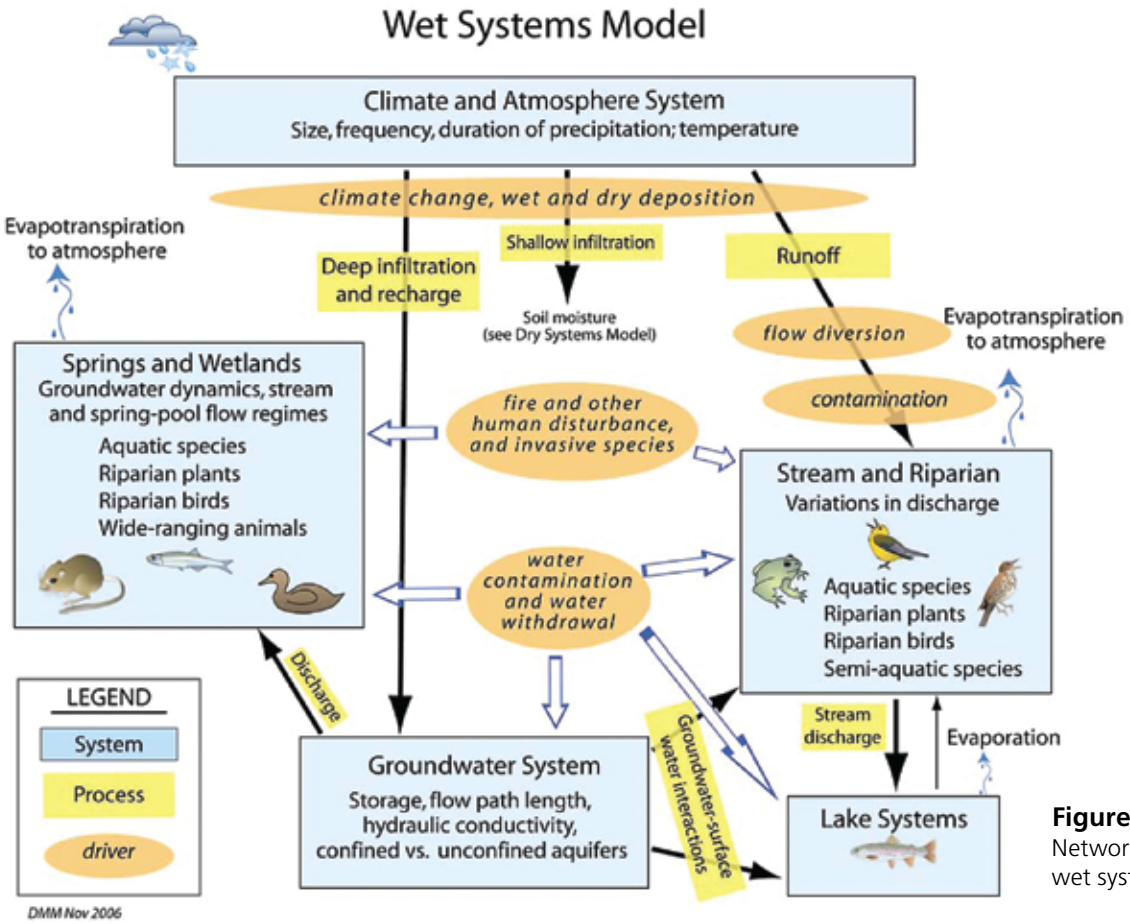


Figure 2.5. Mojave Desert Network conceptual model for wet systems.

aquatic species from fish to springsnails and amphibians, as well as riparian vegetation such as cottonwoods (*Populus* spp.), willows, seep willows (*Baccharus salicifolia*), arrowweed (*Pluchea sericea*), ash (*Fraxinus* spp.), cattails (*Typha* spp.), rushes, and sedges. Because streams and riparian zones are associated with available water, they are utilized by wide-ranging wildlife such as deer (*Odocoileus* spp.), bighorn sheep, and a wide variety of birds. Riparian zones are also susceptible to invasive species that alter the habitat and stream function, such as tamarisk, and can then act as corridors for other invasive species.

Shallow subalpine lakes at GRBA depend on snowmelt runoff and groundwater. These lakes undergo seasonal fluctuations in volume, resulting in barren rocky shores rather than vegetated riparian zones. The subalpine position of these lakes renders them highly vulnerable to climate change and air pollution, because small temperature and precipitation changes can disproportionately affect lakes dependent on snowmelt, and because airborne pollutants are carried rapidly into the lakes along short flowpaths. Another factor that makes the lakes particularly susceptible to change is their underlying geology, which consists of metamorphic rocks that provide low buffering capacity.

Desert spring-fed wetlands can be broadly characterized as pools, streams, and muddy or boggy areas. Extensive wetlands and multiple spring pools form where a regional carbonate aquifer system discharges, such as at Ash Meadows, NV, and at DEVA. However, most of the desert parks have isolated small springs and wetlands that exhibit variable discharge. In Joshua Tree National Park, fan palm (*Washingtonia* spp.) oases are important habitat and historical sites. Where springs occur in broad, sediment-filled valleys, short streams and riparian corridors form. The seeps and springs at the mouths of mountainous canyons are more

Rogers Spring, Lake Mead National Recreation Area. NPS photo.

common, but typically smaller than springs fed by regional aquifers.

Spring-fed wetlands form a wide variety of important riparian and aquatic habitat (Stevens and Springer 2004). In general, biological importance is correlated with the size of the wet area, brook length for flowing streams, and size of pools, which are in turn a function of spring discharge. Groundwater discharge at springs is thus a key indicator of riparian biologic health and integrity.

The major human stressors to wet systems affect both water quantity and quality. Groundwater is fundamental to the function of desert wet systems, and is described in terms of components and processes such as recharge, storage, and discharge of groundwater. Springs are affected by groundwater extraction, distribution of contaminants, and disturbance of recharge zones through paving and diversion (Figure 2.5). Water quantity can be indirectly altered in spring-fed wetlands and stream systems by invasive plants (e.g., tamarisk). Other human impacts include introduction of predators and parasites (e.g., mosquitofish [*Gambusia* spp.] and Asian tapeworm [*Cestoda* spp.]), direct human disturbance, and fire. Vital Signs reflect many of these drivers as well as the importance of wet systems for endemic and at-risk populations of pupfish (*Cyprinodon* spp.), chub, amphibians, riparian bird communities, and aquatic macroinvertebrates.

The major human stressor to streams and rivers is alteration of the flow regime through water withdrawal and damming. Other major stressors are the intentional or accidental introduction of exotic species, the degradation of water quality, effects of grazing and other land-use disturbances, impacts of recreational use, and indirect effects of human-induced climate change and alteration of groundwater dynamics. Major threats to subalpine lakes are atmospheric deposition of pollutants, introduced species, and alteration of climate and precipitation patterns.

2.5.1 Groundwater

Groundwater hydrology consists of three principal components: recharge, storage in groundwater aquifers, and discharge at springs, seeps, and other sites. Much of the present-day recharge in the MOJN occurs in mountains and the groundwater is discharged to the atmosphere by evapotranspiration from the plants, the soil, or open water (lakes, spring pools, and wet playas). In the absence of any human development, the groundwater systems in the MOJN are in dynamic equilibrium with long-term climatic patterns. Rain and snow provide recharge to the groundwater system, which is balanced by an equal amount of discharge plus short-term changes in groundwater storage. Storage and surface water discharges respond to long and short-term climatic changes. Large aquifers (regional carbonate) with long storage capacities respond slowly to climatic shifts, while small aquifers (perched mountainfront) with short residence time respond more quickly to periodic drought and flood cycles. An important consideration for groundwater systems is that water discharging in a spring within a given park may be recharged far away, so distant areas may be relevant for managing local hydrology.

The principal aquifer types within the MOJN are basin-fill deposits and regionally extensive carbonate rock (Harrill and Prudic 1998). Basin-fill

deposits consist of unconsolidated to consolidated clastic materials eroded from adjacent mountains. These deposits can be thousands of feet thick and form the most productive aquifers, especially in the Mojave and Sonoran deserts. Groundwater flowing through basin-fill aquifers typically remains within its originating basin, except for water that infiltrates downward into underlying rock that has hydrologic connections beneath other basins. Carbonate rocks form a regionally extensive aquifer within the Basin and Range and northern Mojave desert. This aquifer allows for interbasin flow, as groundwater flows beneath surface water divides of mountain ranges (Harrill and Prudic 1998). The carbonate aquifer recharges over a broad area of mountain tops near GRBA and discharges in many places, including springs and marshes of DEVA and LAME.

Recharge is derived from rain and snow. Climatic factors, partitioning of precipitation to runoff or infiltration, and spatial linkages of runoff, biotic use, evapotranspiration, and soil hydraulic properties all affect whether recharge occurs, and its locations and amounts. In low lying basins, where precipitation is low (5-15 cm/yr), rainfall provides moisture to the surface soils but is insufficient to saturate the underlying soils and to percolate into the groundwater system (Hevesi et al. 2003). Groundwater recharge occurs primarily in the mountains and upper piedmont areas where annual precipitation is from 15 to more than 75 cm (Hevesi et al. 2003) and elevations are greater than 1,500 m (Maxey and Eakin 1950; Rice 1984). In northern, colder regions (GRBA), or where mountains reach high altitudes (e.g., Spring Mountains), winter snow pack provides the dominant source of recharge to the groundwater system. In the southern regions (MOJA), rainfall is the dominant source of recharge. Most recharge occurs in the winter and spring, when precipitation is high and evapotranspiration is low. Diffuse recharge may reach the saturated zone (groundwater system) as deep infiltration of precipitation through fractured or porous rock in the mountain blocks. Alternatively, where bedrock is impermeable or topography is steep, snowmelt or rain may channel and flow down the mountain front onto the upper piedmont. Most channeled water infiltrates into the streambed and some recharges the underlying basin-fill aquifers as focused recharge. An extreme example of this is in the Mojave River basin, where 80 percent of the recharge to the basin is estimated to be from leakage of floodwater from the Mojave River into the underlying basin-fill aquifer (Stamos et al. 2001).

Saratoga Springs in southern Death Valley National Park consists of several spring mouths that provide water to three open-water ponds. Photo courtesy D.M. Miller, USGS.

2.5.2 Spring Systems

Spring systems are ecosystems formed where groundwater discharges at the earth's surface. Groundwater can move along complex and lengthy flow paths or along small aquifers with short pathways. The aquifer characteristics (residence time, lithology, chemistry) impart strong controls on groundwater discharge characteristics such as temperature, chemistry, and rates (Freeze and Cherry 1979; Domenico and Schwartz 1990; Fetter 1994), as depicted in the groundwater model. Springs are commonly the primary sources of water for small streams and riparian zones.

We group groundwater systems into three types of aquifers for the purposes of discussing spring systems: (1) small, commonly perched, aquifers;

Table 2.2. Characteristics of springs related to three kinds of aquifers common in the Mojave Desert Network.

AQUIFER TYPE	PERCHED	LOCAL	REGIONAL
Aquifer size	Very small	Small	Large
Water temperature	Cold	Cool	Warm
Solute concentration	Low	Low to moderate	Moderate to high
Total discharge	Very low	Low	Moderate to high
Discharge persistence	Ephemeral	Ephemeral to Perennial	Invariant
Discharge site	Mountain	Piedmont	Valley bottom
Typical discharge morphology	Tinaja, seep, qanat	Small spring, seep, spring mound	Spring-marsh complex, wet playa

(2) local valley (basin fill) aquifers; and (3) regional (carbonate) aquifers. These aquifer types are described in the groundwater model (Appendix G) and their characteristics, related to springs, are summarized in Table 2.2. Springs fed by perched aquifers tend to be cool (<10°C) and commonly go dry during droughts. Springs fed from local aquifers may also change seasonally and go dry during extended droughts. Springs fed by regional aquifers, on the other hand, tend to be warmer (>20°C), and higher in solutes due to the depth and length of flow paths, and tend to have discharge rates that remain fairly constant over time intervals exceeding 50,000 years (Winograd et al. 1992). Size of spring ecosystems is a strong function of groundwater discharge. At the low end of discharge, seeps tend to support upland and facultative wetland species adapted to drier conditions. At the higher end of spring discharge rates, permanent ponds and riparian corridors support many endemic and endangered desert fish species.

Springs exhibit many morphologies and a single spring may change morphology with time. Common types range from lush open pools to seeps that exhibit damp earth with no open water; between these ends of a spectrum, there is a wide variety of wet meadows, marshes, permanently wet short stream segments in canyons, spring mounds, and saline springs and wet playas with no vascular plants. Aquatic organisms, riparian vegetation, and associated fauna all vary with spring type (Sada et al. 2005), but an anthropogenic overprint is ubiquitous, complex, and severe. Because current morphology is in part caused by human uses, it is unclear how the morphology can be related to functional characteristics. For instance, a marsh that is cleared and dredged in one location to provide open water for livestock may be functionally distinct from many less-disturbed open-pool springs.

2.5.3 Streams and Riparian Zones

Stream and stream-bank (riparian zone) systems consist of flowing water (lotic) and associated channel bed and floodplain environments. We restrict our discussion to perennially flowing streams and rivers, and those that support perennial flora and fauna. Many intermittent streams occur throughout the MOJN, and we consider the function of those systems to be more similar to Dry Systems in that rare flow events add pulses of resources to typically dry, or xeric systems. Plants along these intermittent streams for the most part are typical xeric species. Furthermore, we do not specifically address the Colorado River due to uniqueness of its extreme size and managed flows.

Two aspects of stream and riparian zones (referred to collectively here as riparian unless specified) separate them from other systems in semi-arid regions. The presence of (1) perennially flowing water that typically spans multiple environmental zones creates (2) unique mosaics of heterogeneous flow and bank environments that support a high degree of biodiversity. However, because all streams and rivers are dynamic and adjust their characteristics to climate, geology, topography, base level, and vegetation (Fitzpatrick 2001), they often share common processes, features, and interactions across a wide range of environments (Patten 1998).

Perennial streams and riparian areas are not common in MOJN and mostly occur in areas of high effective moisture, such as northern latitudes and high elevations, or in places where there is access to a significant groundwater supply. Most streams in the Mojave Desert Network are mountainous streams at GRBA. These mountain streams do not extend to alluvial valleys and tend to have distinct channel morphology (and thus habitat) that varies relatively systematically with position in the watershed (Montgomery and Buffington 1997). These streams respond more quickly to precipitation and tend to be connected to smaller (and thus more climatically sensitive) groundwater aquifers. Riparian areas encompass a small (less than 1 to 3%) portion of semi-arid landscapes, yet are among the most biologically diverse and important ecosystem components (Naiman and Decamps 1997; Patten 1998). In addition to obligate aquatic species, up to 80% of all vertebrates depend on riparian areas for at least one-half of their life cycles, and more than half are completely dependent on riparian habitats (Chaney et al. 1993).

Riparian areas also serve as important connectors for energy and materials among nearly all ecosystem types. They integrate effects from upstream and downstream regions, and in essence affect and are affected by all portions of both wet and dry ecosystems.

Pine Creek, Great Basin National Park. Photo courtesy Erik Beever USGS.

2.5.4 Montane Lakes

Natural lakes are rare in deserts, generally restricted to high-altitude areas with relatively great effective moisture, and found only at GRBA within MOJN. The large reservoirs of the Colorado River, Lake Mead and Lake Mohave, are not managed by the NPS, and are not considered in this model. Small spring pools that occur in many desert parks are described in the springs model (section 2.5.2 and Appendix G).

Six montane lakes occur in the southern Snake Range within GRBA. All lakes lie above 2900 m elevation and are associated with glacial moraines or cirque basins. The lakes are shallow (average 2.5 m) and vary in level, seasonally, due to porous glacial materials in dams and fluctuating local groundwater levels. As a result, riparian vegetation is limited. Forest or open areas border the high shoreline, and bare, rocky areas mark the shorezone within seasonal fluctuation ranges. Streams lead from the lakes but flow is seasonally variable.

Like most high-altitude lakes, these lakes did not originally support native fish, but trout have been introduced into Baker Lake, and brook trout were removed from Johnson Lake to facilitate introduction of Bonneville cutthroat trout in Snake Creek. Aquatic fauna are little-studied in GRBA, but spadefoot toad (*Scapiophus hammond*) is known in the park and other toads and frogs and the tiger salamander (*Ambystoma tigrinum*) probably occur.

Lake level fluctuations affect shorezone stability, creating barren rocky shores difficult for plants to establish. Lower lake levels generally correspond with

Baker Lake, Great Basin National Park. NPS photo.

higher water temperatures and less mixing of waters by wind, and probably limit flora and fauna. Decomposing organic material may result in anoxic conditions, stressing any aerobic benthic organisms in the lakes. Natural stratification due to seasonal ice cover and wind turnover may also result in habitat stratification for aquatic species. Long-term records of ice breakup suggest warming of lakes in the northern hemisphere (Magnuson et al. 2000); along with declines in snow volume and earlier snowmelt, lakes may become warmer and shallower in the future.

2.6 Conclusion

The complexity of ecological systems presents a fundamental challenge to the development of a comprehensive and effective long-term ecological monitoring program. Conceptual modeling is an approach that has been widely used by monitoring programs to simplify reality by distilling complex natural systems into key elements (Manley et al. 2000; Noon 2003). It is important to note that conceptual modeling is not a goal in and of itself, but a tool to guide thinking, communication, and organization (Maddox et al. 1999). Ultimately, the hierarchical set of conceptual models developed by the MOJN (Figure 2.1) incorporate both broad- and fine-scale factors, processes, and drivers, which inform the selection of indicators and the design of monitoring protocols, as well as provide a basis for interpreting monitoring data.

Chapter 3 Vital Signs

3.1 Introduction

Monitoring seeks to determine the status of and detect trends in indicators of ecological systems (Busch and Trexler 2003). Elzinga et al. (1998) defined monitoring as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Detection of ecological change or trend may trigger management action, determine progress toward a management objective, or generate a new line of inquiry/direction. There are many potential indicators of "ecological condition," and monitoring programs must select the best subset of indicators that also meet constraints such as management relevance, budgetary and staffing limitations, and feasibility of implementation.

The term "Vital Signs" was coined by the NPS to represent these ecological indicators of ecosystem condition, which are analogous to critical measures of human health such as pulse and respiration. Thus, Vital Signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. Vital Signs may occur at any level of organization (e.g., landscape, population, community) and may be compositional (e.g., variety of elements in the system), structural (e.g., organization or pattern of the system), or functional (e.g., ecological processes). Given this complexity, selecting the best Vital Signs for monitoring requires a structured, step-wise approach.

3.2 Overview of Vital Signs Selection Process

The complex task of developing a network monitoring program requires a front-end investment in planning and design to ensure that monitoring meets critical information needs of each park and builds upon existing information collected about park ecosystems. It also ensures that monitoring produces scientifically credible data that are accessible to park managers in a timely manner and maximizes partnerships with other agencies and academia. An 8-step approach was taken by the network to identify, prioritize, and select Vital Signs at both the park and network-levels. This step-wise, iterative process of selecting Vital Signs allows various ecological indicators to be compared and collectively selected for inclusion in the network's Vital Signs monitoring program. An overview of the 8 steps used for the selection of the MOJN Vital Signs is listed below. Note that due to certain logistical constraints, and the actual occurrence of certain workshops and meetings, we did not necessarily follow these 8 steps in sequential order.

1. Identify ecosystem drivers, stressors, and important processes through development of an initial conceptual ecological model for the network (NPS 2003a).
2. Conduct a series of small, park-based workshops to identify important resources (abiotic, biotic, processes), resource threats, management concerns, monitoring questions and Vital Signs for each network park.
3. Identify similarities and differences across parks and summarize Vital Signs, threats, management concerns, and monitoring questions at the network-level.
4. Review of network-level information by park staff.
5. Prioritize Vital Signs for each park based on management significance and legal mandate.
6. Conduct a network-level Vital Signs scoping workshop to complete scientific review of network-level Vital Signs and associated information; complete prioritization of Vital Signs based on ecological significance; provide additional information helpful to monitoring for high-priority Vital Signs (e.g., partnership opportunities, monitoring objectives).
7. Conduct a small workshop for network and park staff to initially select a "short

Analogous to indicators of human health such as pulse and respiration, Vital Signs are indicators of ecosystem health and condition.

list" of high-priority Vital Signs for the MOJN parks.

8. Conduct a small workshop for network and park staff to select a final, prioritized list of Vital Signs for the network.

From 1999 to 2003, three types of park-level workshops were held for the MOJN. The outcomes of these workshops are summarized in the next sections.

3.2.1 Lake Mead National Recreation Area Vital Signs Scoping Workshop (1999)

In spring 1999, the first in a series of Vital Signs scoping workshops was held at Lake Mead National Recreation Area and a candidate list of 88 Vital Signs was developed (NPS 1999c). The objectives of the LAME Vital Signs Workshop were to: (1) provide a peer review of the park's current resource management program (e.g., framework and ecosystem model, management and monitoring activities); (2) ensure that functions or processes necessary to maintain ecosystem integrity are part of program planning; and (3) provide direction for a monitoring program that assesses the health status and trends of the park's ecosystem. Workshop participants included academic scientists involved in research in the Mojave desert or a similar ecosystem, federal or state agency representatives involved in management or research activities occurring within LAME boundaries, and NPS staff. Workshop products included a list of reviewed ecosystem/park stressors and associated monitoring questions, and a candidate list of Vital Signs. This candidate list was subsequently adapted to each individual network park and served as a baseline for subsequent park-level vital sign scoping workshops. The LAME Vital Signs Workshop Summary is available on-line at http://hrcweb.lv-hrc.nevada.edu/mojn/data/lamewksp_report.htm.

3.2.2 Geologic Resource Evaluation Workshops (2003)

Between May and September 2003, the second series of MOJN Vital Signs scoping workshops were held to evaluate MOJN geologic resources. These Geologic Scoping Workshops were held at GRBA, JOTR, MOJA, MANZ, and PARA. MANZ was discussed only briefly at the MOJA workshop. Workshop objectives were: (1) to identify the status of geologic mapping efforts in each park, identify data gaps, and develop a strategy to complete baseline geologic maps; (2) introduce participants to the Vital Signs monitoring program and geologic indicators; (3) identify important geologic resources and related management issues and concerns; (4) identify resource threats; and (5) identify management/monitoring and research questions related to park geologic resources. Workshop participants included park and network staff, NPS-Geologic Resources Division (GRD) staff, and other non-NPS participants (e.g., USGS, university staff). Candidate Vital Signs were discussed and identified within the context of the geoindicator checklist (developed by the International Union of Geological Sciences) and revised by NPS-GRD staff. The primary workshop product was a final report including a basic description of park physiography and geology, important geologic features and processes, identification of threats and management concerns to geologic resources, and identification of monitoring and research questions. The results of geologic resource evaluation workshops were used to develop materials and populate databases used at subsequent park-level Vital Signs scoping workshops. Final geo-scoping workshop reports are available from the MOJN upon request (NPS 2003b, 2003c, 2003d, 2003e, 2004b, 2004c, 2004d).

3.2.3 Park-Level Vital Signs Scoping Workshops (2003)

During November and December 2003, the network conducted their third series of park-level Vital Signs scoping workshops at DEVA, GRBA, JOTR, LAME, and MOJA. Workshop objectives were to: (1) identify important park resources; (2) identify important management issues; (3) identify and prioritize park drivers and stressors; (4) identify park monitoring and research questions; and (5) identify candidate Vital Signs. In preparation for these

park-level workshops, network staff summarized priority resources, stressors, and resource concerns using resources including General Management Plans, Resource Management Plans, Strategic Plans, and information from Geologic Scoping Workshops. The focus of the 2003 workshop at LAME was to review and update the Vital Signs and monitoring questions identified during the 1999 workshop. For MANZ, candidate Vital Signs and information were cooperatively developed by the MOJN Network Coordinator and the MANZ Superintendent. For PARA, resources staff were queried and candidate Vital Signs for PARA were developed as part of LAME, due to its ecological similarity. This was a logical step because PARA was created from portions of LAME, Grand Canyon National Park, and BLM lands.

Participation in most workshops ranged from 13-18 individuals representing park and network staff, park cooperators/ scientists and park volunteers. Candidate Vital Signs at the park-level were identified within 5 broad categories: Air/Climate, Geology/Soils, Hydrology, Animals, and Plants. For each category, participants identified specific resources and resource issues important to their park. Responses ranged from small-scale, discrete resources (e.g., Devils Hole pupfish) to broad-scale ecosystem processes (e.g., geomorphic processes), and resources of value for societal reasons (e.g., charismatic species).

For each 'specific resource', park staff identified associated ecosystem stressors, specific threats, management concerns, and monitoring questions. Participants also prioritized ecosystem stressors (identified in an early conceptual model) for each park based on each stressor's management significance and potential impacts on resources. Scores were summed across parks to identify stressors of the greatest concern at the network-level. Individual, park-level databases were merged into a single, network-level database. This database included 113 candidate Vital Signs and was used to develop a Vital Signs framework for the network as well as for individual parks.

3.2.4 Network-Level Vital Signs Scoping Workshop (2004)

On May 25-27, 2004, the Network-Level Vital Signs Scoping Workshop was held in Las Vegas, NV to: (1) review identified management and scientific issues, resource threats, and monitoring questions; (2) review, revise, and prioritize candidate Vital Signs for long-term ecological monitoring at the network and park-levels; (3) for the top 20% of Vital Signs, revise justification statements, develop potential monitoring objectives, identify existing protocols/ methods, potential partnerships, cost-sharing opportunities, and ecological/ operational scales for measurement; and (4) develop a network of stakeholders with the common goal of preserving important network resources. Over 60 individuals representing 15 organizations participated in the workshop, including federal and state agencies, academic and research institutions, and non-profit organizations.

Participants were organized into 10-person work groups for each of five categories: (1) Air, Geology and Soils; (2) Hydrology; (3) Animals; (4) Plants; and (5) Human Use and Ecosystem. Each work group reviewed a specific set of candidate Vital Signs and was assigned a facilitator, recorder, and at least one park staff member with appropriate expertise to facilitate work flow and capture workshop results. An MS Access database was used to capture comments and provide updated information during the workshop. After individual work groups presented their results, all individuals re-convened to conduct the overall prioritization of Vital Signs. Prioritization of Vital Signs was based on management significance, ecological significance, and legal mandate, which were weighted 40%, 40%, and 20%, respectively. Workshop products included: (1) a revised list of management concerns and resource threats for level 2 Vital Signs; (2) a reduced list of 69 candidate Vital Signs for the network and individual parks (3) a prioritized ranking of this list for the network and individual parks; and (4) supporting information for the top 20% of network-level Vital Signs (e.g.,

justification statement, monitoring questions, etc.). The 2004 MOJN Vital Signs Scoping Workshop Report (Appendix H) and database output are available online at: http://hrcweb.lv-hrc.nevada.edu/mojn/workshop.htm.

3.2.5 Selection of High-priority Vital Signs (2004)

In July 2004, the MOJN Technical Committee reviewed the results of previous workshops to select a "short list" of 26 high-priority Vital Signs for the network. High-priority Vital Signs were identified based on a review of the prioritized network list. The Technical Committee also discussed Vital Signs ranked highly at a park, but not network, level and made decisions based on management and ecological significance, potential partnership and cost-sharing opportunities, existing baseline data, and socio-political considerations.

3.2.6 Selection of Final Network Vital Signs (2005)

The MOJN convened its last workshop on November 29-30, 2005 at LAME, Boulder City, NV. This workshop was attended by a quorum of MOJN Technical Committee members, resource specialists, and USGS professionals. The goal of this workshop was to select and prioritize a final set of Vital Signs from the "short list" identified at the previous workshop. Although the Technical Committee was committed to funding all selected Vital Signs for the next five years, the network is unable to fund all 26 of the identified Vital Signs due to programmatic and fiscal constraints. Thus, the workshop was a facilitated and directed discussion of the merits of each of the 26 Vital Signs. To start the process, the 26 Vital Signs were presented in the prioritized order determined at the previous workshop. After discussing the short list, each workshop participant identified 7 Vital Signs they believed should merit "final vital sign" status. Results of this voting process were considered a recommendation to the Technical Committee and thus were not binding. After a second round of discussion, the Technical Committee agreed to a final list of 20 Vital Signs. In Table 3.1, the final Vital Signs are listed within context of the NPS Ecological Monitoring Framework, a systems-based, hierarchical outline that facilitates comparisons of Vital Signs among parks, networks, and other programs.

3.3 Justification for Vital Signs

This section describes the significance and relevance of each final vital sign in evaluating the condition of MOJN park ecosystems. Vital Signs are presented in the same order as they appear in Table 3.1, by Level I categories of the NPS Ecological Monitoring Framework.

3.3.1 Air and Climate

Air Quality – Visibility and Particulate Matter, Ozone, Wet and Dry Deposition

Atmospheric characteristics and processes have fundamental effects on wet and dry systems (Figure 2.2) and can significantly affect visitor experience. Although most of the MOJN park units are some distance from densely populated urban centers in California, Arizona, and Nevada, many experience poor air quality from pollutants such as ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxics (NPS 2006a). Influenced by weather patterns, these atmospheric pollutants are carried by the wind, broken down by high temperatures and radiation, and then deposited as wet and dry particles in the air, water, soil, vegetation, and on wildlife and humans. Atmospheric deposition of nitrogen and sulfur compounds can acidify and contaminate water and soils, affect stability of biological systems, and cause a fertilization effect that alters soil nutrient cycling and vegetation species composition. Acidification of subalpine lakes at GRBA are of particular concern due to their extremely low buffering capacity. Also of concern are the changes in vegetation community composition, increased productivity of non-native plants, and subsequent increased plant biomass and fire frequency that may result from increased atmospheric deposition of nitrogen (Brooks 1999). In 2004, the American Lung Association State of the Air Report declared San

Bernardino County, CA (adjacent to JOTR, which is a non-attainment Class I air quality area, and MOJA, which is Class II) to have the poorest quality air (e.g., visibility, ozone) in the nation. Particulate matter has been linked to respiratory ailments in humans (e.g., eye irritation, bronchitis) and photochemical smog degrades visitor experience by obscuring scenic vistas and night skies. Recent data indicates that JOTR, MANZ, and MOJA are at high risk for foliar injury to plants from elevated ozone levels (NPS 2004a). Under the Clean Air Act and GPRA mandate, Class I park managers have a responsibility to monitor air quality for the adverse effects of air pollution and provide recommendations to protect park natural and cultural resources. To evaluate these hazards to ecosystem health, monitoring air quality conditions and its interactions with physical and biological components is vitally important.

Basic Meteorology

Climate is a primary factor controlling the structure and function of MOJN ecosystems. Measurements of temperature, precipitation, wind, humidity, soil moisture/temperature can indicate changing climatic conditions and patterns. Key to understanding ecosystem dynamics is an understanding of the roles of climate variability, hydrologic interactions with soils, and adaptive strategies of biota to capitalize on spatially and temporally variable moisture dynamics (Noy-Meir 1973; Rodriguez-Iturbe 2000; Reynolds et al. 2004). This information is highly relevant to the interpretation of other Vital Signs and provides a basis for understanding the response of desert ecosystems to future climate variation (Hereford et al. 2004).

3.3.2 Geology and Soils

Soil Hydrologic Function

In deserts, geology and soils provide the template upon which biota build integrated ecological systems. The availability of water is crucial, and small variations can drastically alter plant and animal communities. Both physical and chemical geologic attributes, such as soil texture, which influences moisture

Storm clouds over the Snake Range at Great Basin National Park. NPS Photo.

infiltration rates, and bulk density, control water availability. Soil type, in conjunction with plant communities and their dynamics, topography, and climate regimes, are primarily responsible for broad scale differences in soil moisture across the landscape. Plant-available soil moisture is a key factor in understanding ecosystem maintenance in desert ecosystems.

Soil Chemistry and Nutrient Cycling

Soil moisture and chemical nutrients provide the foundation for plant growth. Nutrient cycles are essential ecosystem processes and the linkages to decomposition are complex. Ecosystems on stable trajectories have biological interactions that tend to conserve key nutrients. Significant increases or decreases in nutrient compounds through stressors such as acidification or nitrification are good indicators of change (Whitford 2002). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition increase the dominance (density and biomass) of invasive plant species, particularly invasive grasses, with a concomitant decrease in the density, biomass, and species richness of native plant communities (Brooks 1999). In addition, decreased soil buffering and pH affect availability of N, P, and K and thus invasive grass distribution. These

Table 3.1. The final 20 Mojave Desert Network Vital Signs are presented within the context of the NPS Ecological Monitoring Framework. The table lists the ranking and importance at each park (from November 2005 Vital Signs Workshop, see Appendix H).

LEVEL 1	LEVEL 2	LEVEL 3	MOJN VITAL SIGN	RANK	PARKS WHERE VITAL SIGN IS IMPORTANT					
					DEVA	GRBA	JOTR	LAME	MANZ	MOJA
Air and Climate	Air Quality	Ozone	Ozone	7	X	X	X	X	X	X
		Wet and Dry Deposition	Wet and Dry Deposition	8	X	X	X	X	X	X
		Visibility and Particulate Matter	Visibility and Particulate Matter	6	X	X	X	X	X	X
	Weather/ Climate	Weather/ Climate	Basic Meteorology	1	X	X	X	X	X	X
Geology and Soils	Soil Quality	Soil Function and Dynamics	Soil Hydrologic Function	10	X	X	X	X	X	X
			Soil Chemistry and Nutrient Cycling	9	X	X	X	X	X	X
			Biological Soil Crusts	13	X	X	X	X	X	X
			Soil Erosion and Deposition	11	X	X	X	X	X	X
			Soil Surface Disturbance	12	X	X	X	X	X	X
Water	Hydrology	Groundwater Dynamics	Groundwater Dynamics and Chemistry	5	X	X	X	X		X
		Surface Water Dynamics	Surface Water Dynamics	4	X	X	X	X		X
	Water Quality	Water Chemistry	Surface Water Chemistry	14	X	X	X	X		X
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Plants	3	X	X	X	X	X	X
	Focal Species or Communities	Desert Communities	Vegetation Change	2	X	X	X	X	X	X
		Amphibians and Reptiles	Reptile Communities	19	X	X	X	X	X	X
		Birds	Riparian Bird Communities	18	X	X	X	X	X	X
		Mammals	Small Mammal Communities	20	X	X	X	X	X	X
	At-Risk Biota	T&E Species and Communities	At-Risk Populations	17	X	X	X	X		X
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire and Fuel Dynamics	15	X	X	X	X	X	X
	Landscape Dynamics	Land Cover and Land Use	Landscape Dynamics	16	X	X	X	X	X	X

Biological soil crusts contribute organic matter to soils and are sensitive to disturbance, Mojave National Preserve. NPS Photo.

extremes in soil chemistry result in unique landscapes/plant assemblages and management problems (salinity/toxicity) in network parks.

Biological Soil Crust Dynamics

Biological crusts are concentrated in the top 1 to 4 mm of the soil and comprise over 70% of the living ground cover. The main components of soil crusts are cyanobacteria, bryophytes, and lichens, which cover most soil spaces not occupied by green plants and are critical in reducing erosion, increasing water retention, and increasing soil fertility (Belnap 2001). Because plant cover is sparse in deserts, crusts are an important source of organic matter for desert soils. Large scale disturbance of biological soils crusts (by livestock grazing, human foot traffic, recreational and military vehicles, etc.) poses a significant threat to ecosystem integrity by increasing soil loss (erosion/dust), increasing the rate of water loss, and reducing soil fertility all of which may alter plant and animal communities. Initial studies in the Mojave desert indicate that crusts require more than a century for recovery and these recovery rates are dependent on climatic history, particularly variability in precipitation, severity of disturbance, and soil texture.

Soil Erosion and Deposition; Soil Disturbance

Disturbance of the soil surface is a natural process (e.g., animal burrowing, flooding) that can be aggravated by anthropogenic activities (e.g., grazing, off-highway vehicle use, mining). Soil surface disturbance causes dust generation, surface runoff, erosion, increased bare ground, decreased soil organic matter, increased invasive plant species cover, vegetation community change, all of which may negatively affect animal habitat and behavior. Loss of topsoil changes the capacity of soil to function and restricts its ability to sustain future uses. Erosion removes or redistributes topsoil, the layer of soil with the greatest amount of organic matter, biological activity, and nutrients (Belnap 2003). Erosion breaks down soil structure exposing organic matter within aggregates, which accelerates decomposition and loss. Degraded soil structure reduces the rate of water infiltration and increases runoff, which can lead to further erosion. The materials deposited by erosion can bury plants, cover roads and trails, accumulate in streams, rivers and reservoirs, degrade water and air quality, and damage or degrade cultural landscapes.

3.3.3 Water

Groundwater Dynamics and Chemistry

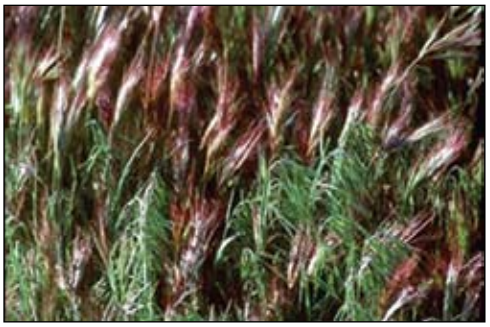
Groundwater is the source of most surface water expressions in the park, which create habitat for diverse aquatic, riparian, and terrestrial biota. Consequently, understanding and monitoring groundwater dynamics and chemistry has been identified as a top priority for network parks. Determining the status and trends and developing a better understanding of water table levels, groundwater flow paths, and the connection between groundwater and surface water resources are required for predicting the effects of natural and human-induced hydrological changes (e.g., municipal groundwater withdrawal) and the fate of contaminants (e.g., landfill leachate). Precipitation events slowly recharge desert basin aquifers, and this recharge feeds scattered springs and wetland habitats. Removing only a small fraction of groundwater from these basins can lower the water table and potentially dry up critical surface water resources. Land subsidence can disrupt surface drainage, reduce aquifer storage, cause

earth fissures, and damage wells and other infrastructure (Bawden et al. 2003). Groundwater withdrawal and contamination is considered a significant ecosystem stressor within the MOJN.

Surface Water Dynamics; Surface Water Chemistry

Surface water resources in MOJN parks (e.g., springs, seeps, lakes, streams, rivers, reservoirs) are sparsely distributed on the landscape, but are critical for the persistence of native biota and many endemic species. Therefore, monitoring surface water resources– both water quantity and quality parameters – was ranked 4th and 14th among all Vital Signs within the MOJN. Surface water dynamics and water chemistry have strong effects on aquatic biota, and therefore biological assemblages (e.g., aquatic macroinvertebrates) are often excellent indictors of flow regime, water chemistry, and disturbance history. Alteration of surface water resources within desert ecosystems has profound ecological and management implications, including loss of species diversity, extinction or extirpation of special-status and endemic species, alteration in the composition and distribution of plant and animal communities, alteration of culturally significant sites, and inability of parks to meet legal and policy mandates. Therefore, natural resource managers within the MOJN are very concerned about degradation of surface water resources.

Because surface waters in MOJN frequently derive their flow from regional groundwater systems, a primary cause of degradation is groundwater withdrawal and diversion. Due to recent drought conditions, and weather and water use predictions (Allen 2003), future pressures on groundwater resources are expected to increase, posing significant threats to surface water availability in network parks. Another source of water quality degradation in MOJN parks is contamination from mining, septic systems, and urban runoff. For example, Las Vegas Wash within LAME receives treated effluent and urban runoff from Las Vegas, NV, and is listed as highly contaminated or "impaired" under section 303(d) of the Clean Water Act. As a result, total maximum daily loads for total ammonia and total phosphorus have been established for the Las Vegas Wash (see Appendix D, Table 5). Finally, atmospheric deposition of pollution and nutrients carried from agricultural and urban development areas may contaminate park surface waters. These chemical and hydrologic changes can cause fundamental shifts in the chemical properties of park waters that lead to subsequent shifts in biotic communities, which depend on these waters for their survival.



Red brome is an exotic annual grass found in Mojave Desert Network parks. Photo courtesy T. Esque, USGS.

3.3.4 Biological Integrity

Invasive/Exotic Plants

The structure and composition of vegetation communities strongly define ecological communities and have significant effects on ecosystem processes. In the MOJN, invasive plants pose one of the greatest threats to natural and cultural resources of our parks. Non-native, invasive plant species are invading new areas and establishing at unprecedented rates because global trade and transportation have allowed these species to cross biogeographical barriers. Potential ecological damage from exotic invasive species includes alteration of natural disturbance regimes and ecosystem processes, and subsequent effects on native flora and fauna. Specific concerns include threatened and endangered species sustainability, alteration of density, biomass, and diversity of native plant communities, species extirpation/extinction due to changes in fire regime, and alteration of basic soil processes. Numerous non-native plant species have

been identified in MOJN park units. Invasive annual grasses are the most widespread and the greatest concern to park managers because of their effects on fire frequency and intensity.

Vegetation Change

The desert ecosystems found within the seven park units of the MOJN host a rich and diverse collection of plant communities and landforms (Berry et al. 2006). Vegetation and soil constitute the very foundation to which all ecosystem functions are intricately connected and dependent upon. Changes in vegetation composition and structure can have profound effects on nutrient cycling and soil properties. Climate models predict a warmer, drier future for the southwestern United States (Seager et al. 2007). Parks are also faced with the unknown effects of air pollution, habitat loss, and altered disturbance regimes (e.g., fire, land development). These factors will likely have significant impacts on upland plant communities of the MOJN (Brooks and Matchett 2006; Hereford et al. 2006). From the Vital Signs workshops, it was clear that riparian plant communities at seeps, springs, and streams are also of high management interest to parks, being closely tied to ground and surface water dynamics. The Vegetation Change vital sign combines the specific justifications for the individual vegetation communities that were not separated out as Vital Signs.

Reptile Communities

The Mojave and Great Basin deserts provide habitat to a diverse community of reptiles. Because of their diversity, abundance, and biomass in the MOJN, their representation in multiple trophic levels, ecological niches, and habitats, and their response to environmental change, reptiles may be good indicators of ecosystem health. Weather patterns (precipitation, temperature, solar radiation, etc.) influence reptile abundance and distribution by affecting their activity levels and patterns, their water balance, and their environment, including vegetation structure and food availability. Drivers and stressors affecting reptile communities include climate change, habitat disturbance and fragmentation, vegetation change (e.g., changes in plant community composition and structure), animal harvesting, introduced diseases, highway mortality, and other anthropogenic disturbances. Predictions of climate change include higher temperatures, longer and more severe droughts, and drier soils, which may limit water availability and require deeper burrowing to find cooler soils. Harvesting of adults by humans in the spring as well as year-round habitat fragmentation and disruption continually compromises the reproductive success of desert reptile populations. A significant number of species are of special concern, including the desert tortoise; federally threatened), chuckwalla (*Sauromalus obesus*), fringe-toed lizard (*Uma inornata*), and gila monster (Brussard et al. 1998).

Network and park staff discuss approaches to monitoring vegetation change with cooperators, Death Valley National Park. Photo courtesy Alice Chung-MacCoubrey.

Riparian Bird Communities

Birds are used widely as targets for management strategies, ecological assessments, and monitoring programs because they are scientifically and socially well known, and are responsive to natural and anthropogenic environmental change (Fleishman and

Yellow warbler in riparian vegetation at Cow Creek in Death Valley National Park. Photo courtesy Gerry/Vicki Wolfe.

MacNally 2006). They are consumers at nearly all trophic levels and vectors for dispersal of seeds and organisms from isolated habitats. There is also a strong interdependence between bird assemblages and vegetation spatial structure and composition (Fleishman et al. 2003; Fleishman and MacNally 2006). Almost all birds in the MOJN depend on wetland and riparian habitats during some phase of their annual cycle. In riparian habitats, obligate riparian bird species may be particularly good indicators of ecological change (e.g., least Bell's vireo). Degradation and destruction of riparian areas, particularly human-induced, are widely viewed as the most important causes of the decline of land bird populations in the MOJN (Brussard et al. 1998).

Small Mammal Communities

Small mammals are of particular interest due to their roles in soil processes, seed distribution and germination, plant herbivory, and food webs. Mammalian populations and communities may be good indicators of environmental change because environmental variables largely influence species composition and density. Research suggests that five environmental variables (including seasonal extremes in temperature, annual energy, moisture, and elevation) may predict up to 88% of the variation in mammalian species density for all of North America (Badgley and Fox 2000). Contemporary populations of 16 montane mammal species across the Great Basin-Mojave desert region are presently isolated on mountains and probably have been since the Pleistocene Epoch (Brussard et al. 1998). These mammals that occupy "sky islands" may be some of the first animals to be influenced by climate change due to proposed shrinking of these island habitats (McDonald and Brown 1992). Research in National Park units on the Colorado Plateau, Sierra-Cascades, and Rocky Mountains indicate that the number of mammal population extinctions has exceeded the number of colonizations since park establishment and that the rate of extinction is inversely related to park area (Newmark 1995).

At-Risk Populations

At-risk biota include species designated as rare, endemic, and NPS sensitive. All network parks except MANZ have "at-risk" species that are important components of the park's biodiversity and that are the focus of park management. Nearly 1,000 native plant species have been identified at DEVA, and approximately 12% of these native plants are considered special-status species, including two federally-listed plant species and 12 endemic plant species. Nearly all fishes, amphibians and many aquatic invertebrates have restricted distributions, are endemic, comprised of small populations, or are currently listed as threatened or endangered (e.g., Mohave tui chub [*Siphatales bicolor mohavensis*]). The primary management concern related to special status species is extirpation or in the case of endemic species, extinction. At-risk species are particularly sensitive to ecosystem change resulting from catastrophic (large or small scale) events (e.g., fire, flood), management actions, alteration of ecosystem dynamics, or cumulative impacts of non-catastrophic events (e.g., incremental changes over

time). This is because at-risk species tend to be associated with small and isolated populations where loss of a few individuals can translate into larger-scale biodiversity loss (e.g., subspecies, genetic level). The need for baseline and long-term monitoring data on at-risk species, including their presence, abundance, and distribution is considered important to the MOJN Vital Signs monitoring program.

Devastating effects of fire in pinyon-juniper woodlands of Joshua Tree National Park. USGS Photo.

3.3.5 Landscapes

Fire and Fuel Dynamics

Change in fire regime (size, frequency, intensity) may be the consequence of numerous stressors and drivers and is a significant threat to MOJN park ecosystems. The annual area burned in wildfires has generally increased in the western U.S. in past decades, partly due to build-up of woody fuels, drought, and invasion of non-native plant species (e.g., *Bromus* spp.). An understanding of Fire and Fuel Dynamics is critical to science-based management of shrubland, woodland, and forested ecosystems. Fire in the Mojave desert is considered historically infrequent, and desert shrublands were once considered 'fire-proof'. The invasion of alien annual grasses such as red brome (*Bromus rubens*) and cheat grass (*Bromus tectorum*) (Mack 1986; Salo 2004) has increased fire frequencies and intensities, and has become a resource management problem throughout low elevations in the Sonoran, Mojave, and Great Basin deserts (Brooks and Pyke 2001). Recurrent fire has devastating impacts on native plants that are poorly adapted to fire, leading to loss of native species, transitional shifts in communities, and potentially permanent replacement of native plant communities by alien annual grasslands (Brooks et al. 2003). Fuels modeling can help predict fire behavior, monitor fuel condition changes, provide fuel assessments, and help parks develop fuels management plans.

Landscape Dynamics — Land Use, Land Cover, and Landscape Pattern

Landscape-level processes such as habitat patch mosaic structure may strongly influence local flora and fauna populations. The character of a landscape's pattern (patch size and structure, distribution, connectivity) directly influences the distribution, abundance, and movement of animals (e.g., bighorn sheep), and the distribution, abundance, germination, and dispersal of plants. In deserts, where many of the organisms are living at or near the threshold for surviving the climatic extremes, the availability of resources in patches and ability to move among patches are critical factors (Whitford 2002). Changes in climate, fragmentation, change in fire regime, and grazing have had the greatest past and current impacts on landscape pattern in MOJN parks.

Seventy-five percent of the land cover in the Mojave region is shrub/scrubland (Davis et al. 1998), whereas land cover in GRBA and parts of PARA is dominated by woodland and forest cover. Land cover is affected by natural events, including climate variation, flooding, vegetation succession, and fire, all of which are susceptible to change in frequency or magnitude due to human activities. Today, human-induced change in land cover is a primary factor in habitat loss, the most significant contributor in the listing of threatened plant and animal species. Monitoring changes in land cover provides critical insights into current or future changes in ecosystem processes (e.g., geomorphic, hydrologic, soil, biological) and services (e.g., habitat, stabilizing soils).

Over three quarters of the Mojave desert is in federal jurisdiction (BLM, NPS, DOD). Private lands (21% of Mojave) and state lands occur in a checkerboard pattern embedded in a matrix of federal properties (Davis et al. 1998). Human

population in the Mojave-Great Basin desert region is predicted to increase with concomitant development of private lands, particularly near JOTR (29 Palms, CA), MOJA (Barstow, CA), and LAME (Las Vegas, NV). Land-use practices at the local and regional scale can dramatically affect soil quality, water quality and quantity, air pollution, habitat fragmentation, habitat loss, and contribute to the spread and introduction of invasive species. Monitoring changes in land use lends interpretive power to other Vital Signs and may contribute to early detection and management of future resource issues.

3.4 Vital Signs Protocol Development Strategy

Extensive discussions at Vital Signs workshops led to the selection of twenty final Vital Signs that represent a complimentary set of components, processes, and stressors and are of significant ecological and management interest to MOJN park managers. A conscious decision was made to select Vital Signs of common concern rather than those that were park-specific in nature. Thus, the final list is relevant to most or all of the parks (Table 3.1). Additional discussions need to occur between parks and network staff throughout the development process to achieve a successful and sustainable Vital Signs monitoring program for the MOJN.

The network faces several challenging issues in developing a successful monitoring program to address the final list of Vital Signs. Characteristics that make MOJN parks fascinating and spectacular places to visit also make them challenging to monitor. MOJN parks encompass significant physical and biological diversity and a large total combined acreage. To develop a program that effectively addresses twenty Vital Signs across over 3 million hectares of diverse, remote, and often inaccessible terrain would necessitate resources beyond those available to the program, particularly given that additional funds were not allocated for monitoring at Grand Canyon-Parashant National Monument.

To address these challenges, the network proposes to stagger the development of higher priority Vital Signs over several years, focus and limit Vital Signs objectives to a realistic and achievable set, integrate Vital Signs to increase sampling efficiency and reduce cost, postpone the development of lower priority Vital Signs, and seek external funds or partnerships to supplement program funds and augment monitoring activities. To reduce the number of Vital Signs under development during the first three to five years, lower priority Vital Signs will be postponed until higher priority Vital Signs protocols are developed, funds become available, or collaborative or partnership opportunities arise that reduce development or implementation costs. Starting in FY 2008, extensive discussions occurred between the MOJN Technical Committee, network staff, and cooperators to iteratively refine objectives for each vital sign to a technically-sound, financially-feasible, and scientifically-relevant set. Rather than selecting an overly ambitious set of objectives and compromising our ability to achieve them, the network will adopt the principle of selecting a smaller number of objectives and accomplishing them well.

The integration of Vital Signs has both scientific and programmatic advantages. In some cases, answers to some of the complex or 'big picture' monitoring questions may require analysis of data acquired from two or more related Vital Signs. For example, to address the question "are changes in the composition and structure of vegetation communities related to changes in soil characteristics and processes?" We need to use information from the Vegetation Change, Soil Chemistry, hydrology, disturbance, and Erosion/Deposition Vital Signs. Although monitoring data cannot be used to explore causal relationships, they provide insight into potential processes and relationships and provide hypotheses for future research. From a programmatic standpoint, integrating related Vital Signs can lower implementation costs through co-location and co-visitation of sampling sites (assuming sampling designs and schedules are compatible).

Table 3.2. Protocols planned for development, Vital Signs addressed, and relevant parks.
Protocol names in bold are those funded primarily by the network. Symbols identify parks at which a protocol will be implemented, characterize the funding source, and identify Vital Signs for which protocol development will be postponed. Absence of a symbol indicates that the vital sign does not apply to the park or will not be implemented at the park.

PROTOCOL NAME	PRIMARY VITAL SIGNS ADDRESSED	PARKS WHERE IMPLEMENTED						
		DEVA	GRBA	JOTR	LAME	MANZ	MOJA	PARA
Air Quality	Ozone	✧	✧	✧	✧	✧	✧	✧
	Wet and Dry Deposition							
	Visibility and Particulate Matter							
Climate	Basic Meteorology	✧	✧	✧	✧	✧	✧	✧
Integrated Upland	Soil Erosion & Deposition	+	+	+	+		+	+
	Soil Disturbance							
	Soil Chemistry & Nutrient Cycling							
	Soil Hydrologic Function							
	Vegetation Change							
	Biological Soil Crusts							
Riparian Vegetation	Vegetation Change	+	+	+	+		+	+
Riparian Birds	Riparian Bird Communities	+	+	+	+		+	+
Invasive/Exotic Plants	Invasive/Exotic Plants	+/✧	+/✧	+/✧	+/✧	+/✧	+/✧	+/✧
Fire and Fuel Dynamics	Fire and Fuel Dynamics	✧	✧	✧	✧	✧	✧	✧
Groundwater & Springs	Groundwater Dynamics & Chemistry	+	+	+	+		+	+
	Surface Water Dynamics							
	Surface Water Chemistry							
Streams and Lakes	Surface Water Dynamics		+					
	Surface Water Chemistry		+		✧			
Landscape Dynamics	Landscape Dynamics	+	+	+	+	+	+	+
Small Mammals	Small Mammal Communities	•	•	•	•	•	•	•
Reptile Communities	Reptile Communities	•	•	•	•	•	•	•
At-Risk Populations	At-Risk Populations	•	•	•	•	•	•	•

Legend:
+ Vital signs that the network will develop protocols for and implement monitoring using funding from the Vital Signs or water quality monitoring programs.
✧ Vital Signs that are monitored by a network park, another NPS program, or by another federal or state agency using other funding. The network will collaborate with these other monitoring efforts.
• Vital Signs that monitoring will likely be conducted in the future, but which cannot currently be developed due to limited staff and funding.

The MOJN proposes the development of 10 protocols over the next 3-5 years that would address seventeen Vital Signs (Table 3.2). Protocols for two Vital Signs (air quality and climate) will largely document standard methods used by park staff, NPS- Air Resources Division, and other partners to collect data from existing monitoring stations and identify how data will be stored and processed at MOJN. Monitoring methods for other Vital Signs protocols will be developed through collaborative efforts of MOJN staff, park staff, and university or agency partners. The remaining three Vital Signs will be developed after higher priority protocols have been developed and if funds are available, or if collaborative or partnership opportunities arise that reduce development or implementation costs. The three postponed Vital Signs include At-Risk Populations, Reptile Communities, and Small Mammal Communities. The riparian bird vital sign is slated for development because monitoring of this conspicuous and highly charismatic taxonomic group may be integrated with protocols addressing Vegetation Change, Surface Water, and Groundwater Vital Signs. Sampling designs for the proposed protocols are described in Chapter 4, and monitoring objectives for each protocol are presented in Chapter 5.

Chapter 4: Sampling Design

4.1 Introduction

Monitoring goals and objectives are linked to data collection through sampling designs. A quality sampling design is necessary to achieve intended monitoring goals and produce rigorous, robust, and defensible conclusions. To achieve the greatest precision, accuracy, and resolution, the design must carefully consider the physical, chemical, and biological characteristics of each particular vital sign and patterns of variability in space and time associated with that vital sign (Oakley et al. 2003). Development of sampling designs is often an iterative process that results in adjusting monitoring/sampling objectives to accommodate the practical constraints of cost, time, logistics, safety, available information, and technology (Elzinga et al. 1998).

This chapter presents an overview of general approaches taken by the MOJN for its suite of Vital Signs to be developed into monitoring protocols over the next 3-5 years. We provide an overview of how sampling designs are developed and define the relevant concepts and terminology associated with sampling design development. We then discuss two essential elements of a sampling design for long-term monitoring: sample size and magnitude of change. The final two sections describe the integration of Vital Signs, fieldwork and data, and outline preliminary design decisions for each vital sign, grouped by protocol. Specific design and decision justifications are included in individual vital sign protocol development summaries presented in Appendix I and in Chapter 5, and will be more formally discussed in monitoring protocol narratives.

4.2 Sampling Design Development

In this section, we discuss the general strategy and framework that the MOJN has adopted for constructing sampling designs. This strategy was employed during the writing of the protocol development summaries provided in Appendix I. Individual protocol narratives will describe the specific process for selecting the final sampling design.

White bursage (pale, short) and creosote bush on a piedmont near Kelso, Mojave National Preserve. Blue flags (background) mark plants being studied in a permanent monitoring plot. Photo courtesy D.M. Miller, USGS.

The first task is to define clear, concise, and realistic monitoring objectives for each vital sign. The objectives must be flexible enough to accommodate future changes in the environment, management issues, and funding. In addition, monitoring objectives should balance the needs of individual parks with the network-wide perspective. Usually long-term monitoring objectives are stated in terms of estimating status and trend of a particular vital sign at a park-wide scale.

Sampling designs should be as simple as possible while providing data that meet monitoring objectives. By maintaining simplicity and avoiding significant changes in design and methods, we can ensure consistency of implementation through time such that changes in status and trends are 'real' and not simply an artifact of changing methods and/or sampling designs (Oakley et al. 2003).

Sampling designs should be as simple as possible while providing data that meet monitoring objectives.

Another important aspect of the development of the sampling design is acknowledgment that it is an iterative process. As we continue to refine our objectives, we gain new insights into particular Vital Signs and the needs of park managers. Because our intent is to develop a robust monitoring program that can meet the needs of NPS managers well into the future, our designs must be able to accommodate changes in management and funding priorities, as well as environmental changes. Thus, our monitoring objectives must balance the needs of current park managers and future generations of managers who can expect environmental and management challenges we cannot foresee.

Status is a measure of the condition of a resource or attribute at a given point in time.

Trend is a measure of directional change over time.

The final sampling design is a result of a series of decisions about where, when, and how to sample a vital sign. Typically, multiple target variables of a vital sign are of interest. For example, for the Vegetation Change vital sign, relative abundance, mortality, and regeneration are variables that might be measured. The target variable is not necessarily the same as the measured variable (de Gruijter et al. 2006). For example, for vegetation change, relative abundance is one of the target variables of interest, but the actual measured variable may be percent cover or stem counts. We consider the vital sign as a whole entity when developing the sampling design; the measurements taken can be modified to account for the multiple target variables of interest. The following questions provide a brief overview of sampling design issues we considered after establishing the monitoring objectives:

1. What is the population of interest?
2. What is the sampling frame or collection of sampling units?
3. What will actually be measured on each sample unit (measured variables)?
4. What are the potential sources of non-sampling error? For example, does the sampling frame represent the target population? Is there a potential for missing values? Does the actual field method of measurement have potential observer errors, detection errors, or instrumentation problems?
5. How does the vital sign vary in space and time?
6. What is the appropriate temporal window, and time interval between sampling occasions, for sampling?
7. What is the appropriate choice of sampling design type (e.g., ocular estimates of vegetation cover) and what are the attributes of this chosen design type?
8. What are the budget, time, and/or safety constraints?

These questions are not exhaustive, but provide a starting point for discussions about sampling-design decisions for each vital sign. We address many of these questions, including target populations and sampling frames, allocation and arrangement of samples (*membership design*), and frequency of sampling occasions (*revisit design*), for each vital sign grouped by protocol. These are summarized in a preliminary framework in Table 4.1. The specific protocol narratives will address the actual measurements to be taken at sampling locations (*response design*) and the number of samples required to meet the stated objectives (*sample size*). In the next section we define the italicized terms and provide more details concerning sampling design terminology and concepts adopted by the MOJN.

4.3 Sampling Design Concepts and Terminology

Sampling designs should be concise and understandable. Overly complex designs can be confusing and may reduce accessibility of results to the monitoring program audience, many of whom are not well versed in statistics and sampling design theory. The MOJN program will be designed as simply as possible, with complexity added only as needed to achieve objectives. Of course, to monitor ecosystem structure, function, and processes, some level of complexity cannot be avoided, particularly when dealing with large, remote, and difficult-to-access landscapes (McDonald and Geissler 2004).

As discussed in Chapters 1 and 3, our monitoring objectives call for the estimation of ***status, trend***, or both. We are intentional in our use of those two terms and follow definitions reviewed by Urquhart et al. (1998) and McDonald (2003). **Status** is a measure of a current attribute, condition, or state, and is typically measured with population means or totals. **Trend** is a measure of directional change over time and can occur in some population parameter such as a mean (*net trend*), or in an individual member or unit of a population (*gross trend*). Status applies to specific points in time, whereas trend pertains to measurements recorded at multiple time periods. Status typically is served best by a spatially extensive sample, while trend is less reliant on large samples and usually

requires more temporally-intensive sampling. The balance between spatial and temporal extent sets up the first cost-benefit decision, and is one that must be addressed through a careful consideration of program objectives.

After defining clear and concise monitoring objectives, the next important step in developing a sampling design is to define the collection of animals, plants, natural resources, or environmental attributes of interest within a specified study. A population consists of **elements**, the objects on which a measurement is taken (Scheaffer et al. 1990). The actual elements sampled are referred to as the **sampling unit**; they are non-overlapping collections of elements (in most cases, the sampling unit is the same as the element). A **target population** is defined as the complete collection of sampling units upon which inference is made. Note that this is a statistical population and it may or may not refer to a biological population. Without a clear idea of the target population, the remaining decisions concerning sampling design development are impossible to make.

We try to quantify our target population by using a **sampling frame**, defined as the collection of sampling units. Common examples of sampling units in the MOJN monitoring program include plots, quadrats, and polygons on a digital map, or discrete phenomena such as lakes, springs, or stream segments. The sampling frame could be a list of elements (e.g., list of springs) or a map of discrete areal elements (e.g., vector-based GIS coverage of a park). A **sample** is a subset of sampling units of a population (**sampled population**) that are measured.

Another consideration for sampling-design development is potential sources of non-sampling error. Non-sampling error may affect the precision and accuracy of estimates from sampling efforts (Lessler and Kalsbeek 1992). **Frame error** is the error resulting from the disparity between the target population and sampled population. Frame error, similar to sampling error, is reduced by increasing the number of units in the sampled population (i.e., increasing the sample size). Over-coverage occurs when the sampled population contains elements not included in the target population. Under-coverage occurs when elements of the target population are omitted from the sampled population. **Non-response error** results from the failure to obtain responses (i.e., measurements) for the entire chosen sample. When missing outcomes are very different from the outcomes obtained, the estimates calculated from the responding portion of the sample are biased. **Measurement error** is defined as the difference in measurements obtained and the true value of the measure and may include detection errors from observers and instrument errors. The three components of non-sampling error: frame, non-response, and measurement, may not always be avoidable, but survey planning and design that accounts for these error sources may be helpful in reducing the effects of non-sampling error on target population estimates.

The next important step in developing a sampling design is determining where to distribute sampling locations. If the sample is generated using some type of random draw, the sample is said to be a **probability sample**. Whenever possible we have used a probability sample to monitor MOJN Vital Signs. We prefer probabilistic sampling designs because they permit valid inference to the sampled population. Because MOJN parks are typically quite large, probabilistic sampling is being employed for most Vital Signs (see "membership design" below).

A familiar probabilistic sampling design is **simple random sampling**, which involves drawing units from a population at random with equal probability of selecting any individual unit. Unfortunately, this often fails to produce an ideal spatial sample in ecological settings because of uneven spatial patterns inherent to a simple random draw and concordant environmental spatial patterns. In particular, simple random samples generated from a population can often be patchy or clustered, with groups of sample sites

closer to one another than to other groups of samples, and large areas of the frame can remain unsampled. In addition, certain rare or uncommon elements may be missed entirely.

An alternative approach, and one that the MOJN is proposing to use for some of the Vital Signs requiring a probabilistic sample, is to draw a spatially-balanced random sample following the methods described by Stevens and Olsen (2004). This approach, often referred to as **GRTS** (generalized random-tessellation stratified), allows for a spatially-balanced random draw of sample units with variable inclusion probabilities and an ordered list of sample units that can support additions and deletions of sample units while retaining spatial balance. These features provide considerable flexibility and efficiency to the MOJN program. In addition, because of the size and topographic complexity of our parks, it may be necessary and efficient to **stratify** sampling based on elevation, landform, soils, or other physical characteristics. Also, we will investigate using unequal probability samples such that adequate sample sizes are allotted to unique and high-priority sub-populations.

A **judgmental sample** is one where the subset of units is hand-picked non-randomly by a researcher. The scope of inference is only to individual sampling units because the sample does not typically represent other sites that were not chosen. In the MOJN, a set of judgmentally selected springs that are connected to the carbonate-rock aquifer will be monitored because of the high management concern of potential withdrawals from the aquifer and the biological importance of the habitat surrounding these springs for rare, endemic, and endangered species. We refer to judgmentally-selected sampling sites as **index sites** in the remaining chapters.

Another alternative to probabilistic sampling used in the MOJN program is the **census**, which involves obtaining a response from every element in the target population. However, an adequate sampling frame and survey design that ensures a true census requires that the census is free of frame error. Though rarely possible in most ecological applications, it can occur, for example, with the use of satellite imagery to determine land cover change. Satellite imagery may also contain sources of frame error depending on the pixel resolution and the temporal frequency of images used to detect change.

Once the target population, sampling frame, and a strategy for drawing samples are determined, the temporal aspect of sampling must be considered. Obviously the specifics concerning the sampling occasion, time of year (season or month) and time of day, is dependent on the particular aspect of the vital sign being measured. However, for larger parks it may not be feasible to actually visit the entire sample within a given sampling occasion due to travel time and other factors. Thus, most sample designs proposed for the MOJN will rotate field sampling efforts through various sets of sample units over time. In this situation, it is useful to define a **panel** of sample units to a group that is always sampled during the same sampling occasion or time period (Urquhart and Kincaid 1999; McDonald 2003). The way in which sample units in the sample population become members of a panel will be called the **membership design** (McDonald 2003). The allocation procedure could be a probabilistic sample, a judgmental sample, or a census.

The temporal scheduling of sampling, particularly when multiple panels are being used, requires a **revisit design** (Urquhart and Kincaid 1999; McDonald 2003). See Figure 4.1 for a schematic representation of, and notation for, different revisit designs. MOJN has adopted notation for revisit designs for brevity and consistency following McDonald (2003). Under this notation, the revisit plan is represented by a pair of digits. The first is the number of consecutive occasions that a panel will be sampled, and the second is the number of consecutive occasions that a panel is not sampled before repeating the sequence. The total number of panels in the rotation design is normally the sum of digits in the notation. For

example, using this notation the digit pair [1-2] means that members of three panels will be visited for one occasion, not visited for two occasions, then visited again for one occasion, not visited for two occasions, and so on. If a single panel is to be visited every sample occasion, its revisit design would be [1-0]. The notation [1-1] indicates that a panel is to be sampled on an alternating schedule. The notation [1-n] means a panel is to be visited once and never again. The notation [1-0,1-5] means that units in one panel will be visited every occasion, while units in six other panels will be visited once every six years. This particular design is called a **split-panel**.

Response design (measurements taken at sampling locations) and **sample size** (the number of samples required to meet stated monitoring objectives) are two essential components of any sampling design that are detailed in the protocols themselves (see overview, Chapter 5), but we introduce them briefly in this chapter. Response design and sample size components are developed after basic decisions regarding target and sampling population, spatial allocation and membership, and revisit strategies have been made. In addition, a response design is usually necessary before sample size can be estimated appropriately. This is particularly true when response decisions, such as plot shape and size, strongly influence the variability of population estimates. However, we must decide about sample size in order to finalize decisions about membership and revisit design, and in practice, sampling designs arise out of an iterative process in which the order of operations is not rigid. As with the design decisions described above, sample size is primarily an exercise in cost-benefit trade-offs, and must be determined through careful consideration of program objectives.

Beginning with the simplest, in which a single panel or set of sampling units, such as a group of streams or vegetation plots, are visited on every sampling occasion, and ending with a complex split-panel design in which the first panel is sampled on every occasion and five panels are revisited on two consecutive occasions and then "rested" for three occasions.

	SAMPLE OCCASION									
PANEL	1	2	3	4	5	6	7	8	9	10
Design (1-0)										
1	X	X	X	X	X	X	X	X	X	X
Design (1-n)										
1	X									
2		X								
3			X							
4				X						
5					X					
6						X				
7							X			
8								X		
9									X	
10										X
Design (2-n)										
1	X									
2	X	X								
3		X	X							
4			X	X						
5				X	X					
6					X	X				
7						X	X			
8							X	X		
9								X	X	
10									X	X
Design (2-3)										
1	X	X				X	X			
2		X	X				X	X		
3			X	X				X	X	
4				X	X				X	X
5	X				X	X				X
Design (1-0, 2-3)										
1	X	X	X	X	X	X	X	X	X	X
2	X	X				X	X			
3		X	X				X	X		
4			X	X				X	X	
5				X	X				X	X
6	X				X	X				X

Figure 4.1. Examples of five different revisit designs (reproduced from MacCluskie et al. 2005).

4.4 Sample Size Considerations and Magnitude of Change

Populations in the real world are dynamic, and change over time is expected. What is important is whether or not there has been *meaningful* change (meaningful to the ecosystem, public, or park manager), what has caused the observed change, and whether or not further change in the resource is expected.

To understand what constitutes a meaningful and significant change, we must differentiate between statistical significance and biological significance. Statistical significance relies on probability and is influenced by sample size. Even minor changes (from a biological perspective) will be statistically significant if the sample size is large enough. So, regardless of statistical significance, we would consider something biologically significant if it facilitates a major shift in ecosystem structure or function (e.g., loss of one or more species, addition of non-native species, changes in ecosystem processes, etc.).

Thus, from a monitoring standpoint, we are concerned with both statistical and biological significance. We want to know whether we are likely to detect a change statistically that we also consider biologically meaningful. To answer this we need to decide what level of statistical significance we want to attain (i.e., our Type I error rate orβ, discussed below), what level of change we consider biologically meaningful and that we hope to detect (i.e., the "effect size"), the amount of variation among sampling units, and the number of sampling units.

In addition to our monitoring objectives, we need to define our **sampling objectives**. **Sampling objectives** establish a desired level of statistical power (1-β to detect a specified minimum detectable change or effect size and acceptable levels of false-change (α or the probability of a Type I error) (Elzinga et al. 2001). Sample size is a function of each of these components, and decreasing sample size, which can be desirable for cost effectiveness, will often force acceptance of higher error and lower power. These tradeoffs are mitigated by reducing variance estimates, either through modifications in response design, another component of the sampling design (e.g., revisit design), or by accepting a higher minimum effect size (Steidl et al. 1997).

In general, sample size should be large enough to give a high probability of detecting any changes that are of management, conservation, or biological importance, but not unnecessarily large (Manly 2001). Scientists traditionally seek to reduce Type I errors, and accordingly prefer small α levels. In a monitoring program such as ours with a strong resource-conservation mandate, however, it is preferable to employ an early warning philosophy by tolerating a higherα, but consequently increasing the power to detect differences or trends (Sokal and Rohlf 1995; Roback and Askins 2005).

For our initial set of protocols, we will use power analyses to determine the approximate sample size needed to detect significant levels of change. Given our specification of α, desired power, and effect size, combined with information on the variance of the response variable in question (obtained from available data or comparable analogous data, where available), it is possible to calculate the sample size required to achieve these results.

We may use simple equations (Elzinga et al. 2001; Thompson 2002) for approximating sample sizes for design-based estimators of status. Trend analysis requires model-assisted methods; therefore, sample size calculations for such models require the use of statistical packages such as SAS (SAS Institute, Inc). For complex designs estimating trend (e.g., panel designs), power analyses based on simulations are required. We will work with statisticians to implement simulation-based approaches using familiar statistical software packages (e.g., SAS software and R programming language [http://www.r-project.org/]). Further, we will recalculate sample sizes periodically for individual Vital Signs as data become available in order to refine and revise sampling designs, and ensure that objectives are being met and sampling resources are being optimally allocated among Vital Signs.

4.5 Logistical Constraints of Sampling Designs

Several characteristics of MOJN parks and their natural resources impose significant logistical constraints on spatial and temporal aspects of sampling designs. First, MOJN parks encompass some of the largest park acreages in the lower 48 states. Consequently, safe access to potential sampling sites, either by road, trail, or backcountry hiking, may not always be logistically feasible or cost-effective, given the remote and rugged nature of some portions of the parks (e.g., mountainous areas within DEVA). To address this issue, we intend to use a weighted approach that allocates a greater proportion of the sample to areas within a predetermined distance from roads and a smaller proportion of the sample to the more remote areas of the parks. In addition, as mentioned elsewhere (e.g., Chapter 5), we intend to coordinate data collection for multiple Vital Signs, either by co-location or co-visitation of established sampling sites. Second, MOJN parks experience extreme weather conditions that vary from park to park (e.g., cool temperatures at the top of Wheeler Peak in GRBA, at the same time that temperatures at DEVA exceed 48°C). Consequently, access to some of the parks may vary seasonally, field work may be performed safely only within certain seasons, and particular Vital Signs may only be sampled within specific temporal windows (e.g., plants that are seasonally present). These issues will be carefully evaluated and addressed using a variety of appropriate revisit designs for each individual monitoring protocol. Finally, an additional approach that the network is currently investigating is the use of high-resolution aerial photography to extend ground-based sampling measurements (e.g., vegetation cover attributes) to remote, inaccessible areas within parks.

4.6 Overview of Sampling Designs for Mojave Desert Network Vital Signs

Table 4.1 lists the 10 protocols planned for development, the vital signs they address, and the proposed sampling design for each protocol. For each protocol, the table identifies the target population(s) based on monitoring objectives (identified in Chapter 5, Table 5.1), allocation and arrangement of samples (*membership design*), and frequency of sampling occasions (*revisit design*). Opportunities for integrating Vital Signs through co-visitation and co-location are also listed.

The Integrated Upland Protocol will monitor long-term trends in focal vegetation communities, including creosote-bursage communities (upper photo) and Joshua tree woodlands (lower photo), Joshua Tree National Park. Upper photo courtesy Stacy Manson. Lower photo courtesy Penny Latham.

4.6.1 Example: Integrated Upland Protocol

MOJN parks encompass a wide range of plant communities, from saltbush and creosotebush at low elevations to bristlecone pine communities at the highest elevations. Park managers are interested in understanding long-term trends in composition and structure of these communities (vegetation change) as well as soil properties and processes across MOJN parks. Since changes in vegetation can have profound effects

Table 4.1 Summary of sampling design components for each of 10 protocols planned for development (and associated Vital Signs).

PROTOCOL NAME	VITAL SIGN	TARGET POPULATION	MEMBERSHIP DESIGN	REVISIT DESIGN	INTEGRATION OPPORTUNITIES
Air Quality	Ozone	Existing air quality monitoring stations	N/A	[1-0]	
	Wet and Dry Deposition				
	Visibility and Particulate Matter				
Climate	Basic Meteorology	Existing weather stations	N/A	[1-0]	
Integrated Upland	Vegetation Change	Upland shrub communities	Probabilistic (GRTS)	Rotating Panel	Invasive/Exotic Plants Fire and Fuel Dynamics Landscape Dynamics
	Biological Soil Crusts	BSCs in upland shrub communities			
	Soil Erosion and Deposition	These processes and characteristics within upland shrub communities			
	Soil Disturbance				
	Soil Chemistry/Nutrient Cycling				
	Soil Hydrologic Function				
Riparian Vegetation	Vegetation Change	Cottonwood, willow, and palm oasis communities at large persistent springs	Probabilistic (GRTS)	Rotating Panel	Invasive/Exotic Plants Groundwater and Springs Streams and Lakes Riparian Birds Landscape Dynamics
		Perennial stream vegetation (GRBA)			
Riparian Birds	Riparian Bird Communities	Riparian-obligate breeding birds at large persistent springs	Probabilistic (GRTS)	Rotating Panel	Riparian Vegetation Groundwater and Springs Streams and Lakes
		Riparian-obligate breeding birds along perennial streams (GRBA)			
Invasive/ Exotic Plants	Invasive/Exotic Plants	In upland shrub and riparian communities	Judgmental and Probabilistic	TBD	Integrated Upland Riparian Vegetation Fire and Fuel Dynamics
		Prioritized watch list	Judgmental	TBD	
Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fires within MOJN parks	TBD	TBD	Invasive/Exotic Plants Integrated Upland
Groundwater and Springs	Groundwater Dynamics and Chemistry	Wells	Judgmental	TBD	
	Surface Water Dynamics and Surface Water Chemistry	Carbonate-aquifer springs	Judgmental	Rotating Panel	Riparian Vegetation Riparian Birds
Streams and Lakes	Surface Water Dynamics and Surface Water Chemistry	Status of 303(d) waterbodies (LAME)	Census	[1-0]	Riparian Vegetation Riparian Birds
		Permanent streams (GRBA)	TBD	Rotating Panel	
		Lakes (GRBA)	TBD	TBD	
Landscape Dynamics	Landscape Dynamics	MOJN parks, including buffer around park boundaries	Census	TBD	Integrated Upland Riparian Vegetation

on soil properties and vice versa, the study of one necessitates the study of the other. For this reason and those discussed above for co-location and co-visitation of Vital Signs, we plan to design protocols that simultaneously address Vegetation Change, Biological Soil Crusts, and soils-related Vital Signs (Soil Chemistry and Nutrient Cycling, Soil Hydrologic Function, Soil Erosion/Deposition, and Soil Disturbance).

Financial and logistical constraints require that we limit our objectives for the Vegetation Change vital sign to a subset of these communities. For this vital sign, we identified two target populations of interest for long-term monitoring: shrub and riparian communities. We selected shrub communities because this physiognomic class collectively represents a large proportion of each park and captures several focal communities of interest (Joshua tree, blackbrush, and sagebrush), thus providing a common theme among parks and increasing our ability to discern landscape-scale change in upland vegetation and soils. From the Vital Signs workshops, it was also clear that riparian communities were of high management interest to parks, due to the significant degree of biodiversity, productivity, and human impacts that occur in these systems. We propose to address these two disparate communities as separate protocols because their different ecological characteristics and spatial distributions across the landscape necessitate different sampling designs and methods.

Here we discuss a potential sampling design for the Integrated Upland protocol, which integrates sampling for shrub communities, biological soil crusts, and associated soil processes and characteristics. We plan to design protocols that simultaneously co-locate and co-sample parameters estimating vegetation change and soil condition to maximize data integration among Vital Signs and minimize travel costs. A random, probability-based sampling approach is desirable because we want to make inferences across MOJN park landscapes, which are very large.

The GRTS approach is advantageous because selected points that turn out to be inaccessible may be replaced by a subsequent sample point from the same draw without losing spatial dispersion and randomness.

The unequal representation of shrub communities across the landscape poses a challenge that may be remedied by an unequal probability GRTS approach. Whereas an equal probability GRTS draw may result in insufficient sample sizes of specific shrub communities, an unequal probability draw may ensure adequate sample sizes within unique high-priority communities, such as Joshua tree. Figure 4.2 illustrates the sample site locations resulting from an unequal probability GRTS draw for Joshua Tree National Park (JOTR). Of 100 sample sites, twenty-three were allotted within Joshua tree communities and seventy-seven were allotted within creosotebush communities.

We delineated the sampling frame by vegetative community for this example only. Optimally, the sampling frame will be delineated by physical characteristics or features such as elevation, landform, or soils to avoid sampling frame error that may result when vegetative communities shift across the landscape. In future discussions with the Integrated Upland protocol working group, we will refine the membership, revisit, and response designs, sampling methods, sample size requirements, and logistical strategies for implementing the protocol at all network parks. We anticipate an extended period of time dedicated to sample site selection as we 1) explore base data (spatial and tabular) useful for selecting sites and estimating sample size, and 2) resolve issues associated with applying an inference-based approach to these large parks.

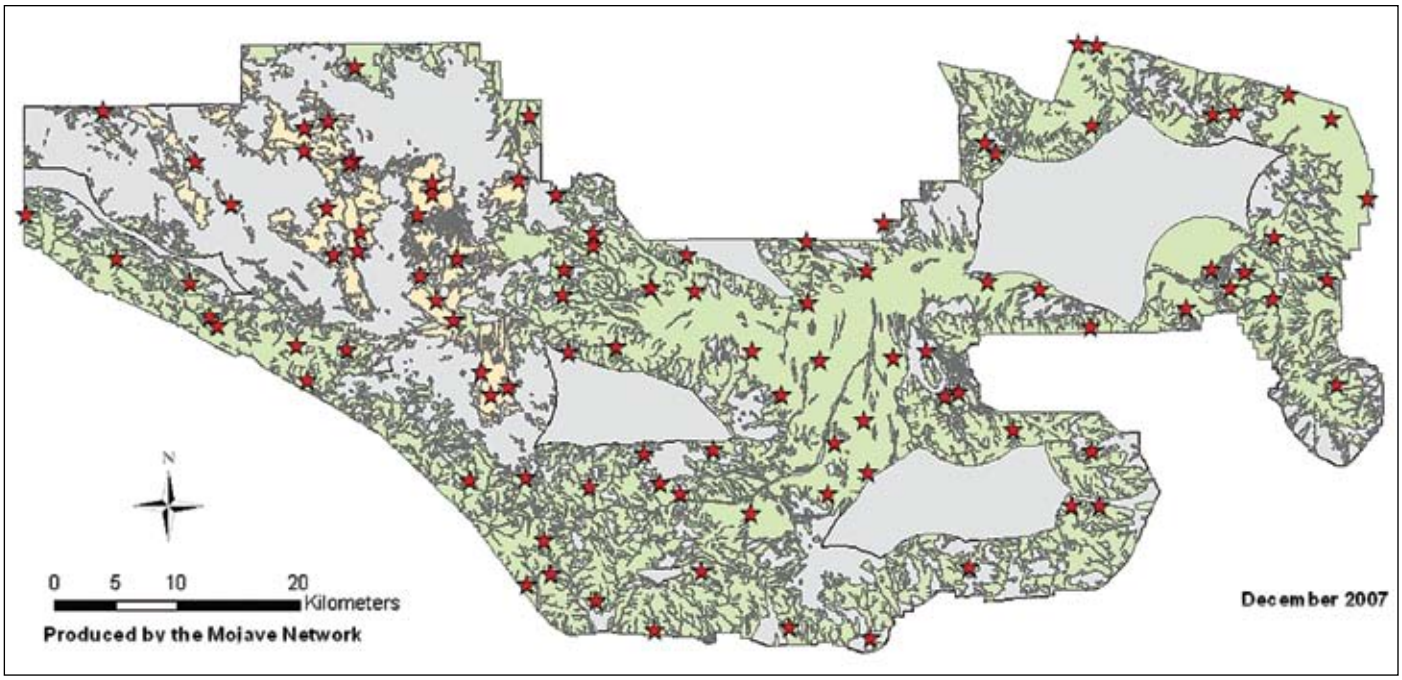


Figure 4.2. Site locations from an unequal probability generalized random-tessellation stratified sample for the Integrated Upland protocol at Joshua Tree National Park. Of 100 sample sites (stars), twenty-three were allotted within Joshua tree communities (orange area) and seventy-seven were allotted within creosotebush communities (green area). Only areas within 5 km of a road were included in the sampling area.

Chapter 5: Sampling Protocols

5.1 Introduction

Monitoring protocols are the key, on-the-ground, functional elements of our program. Formal, peer-reviewed protocols ensure consistent and reliable monitoring, and provide for project and program continuity as personnel change. Our protocols and their associated development process emphasize careful selection and testing of methods and sampling designs, comprehensive and detailed review by National Park Service and external, non-NPS experts prior to implementation, and careful, detailed documentation to ensure consistent implementation over time. Where possible, the network will take advantage of existing protocols, particularly those that have already undergone I&M and peer review. Even in those cases, the protocols need to be adapted for the particular circumstances of MOJN parks. The following sections describe protocol development planning documents (Protocol Development Summaries), guidance specifying the content of each protocol document, the protocol development process, and protocols planned for development by the MOJN over the next three to five years.

5.2 Protocol Development Summaries

Protocol Development Summaries (PDSs) are required for all monitoring protocols planned for development and implementation by the network monitoring program. The PDS is a short document that identifies the vital sign of interest, describes why the protocol and monitoring is needed, specific issues and questions being addressed, specific monitoring objectives, proposed methodological approach, and other details. The typical PDS includes the following material:

- **Protocol Title**
- **Parks Where Protocol will be Implemented**: Names or 4-character codes for the parks where the protocol is likely to be implemented over the next 5 years.
- **Justification/Issues being Addressed:** A paragraph or two justifying why this protocol needs to be developed.
- **Monitoring Questions and Objectives to be Addressed by the Protocol**
- **Basic Approach:** Description of any existing protocols or methods that will be incorporated into the protocol, the basic methodological approach, and sampling design.
- **Principal Investigators and NPS Lead:** The name and contact information for the Principal Investigators (P.I.s) and for the NPS project manager responsible for working with the P.I.s to ensure that the protocol meets network and park needs.
- **Development Schedule, Budget, and Expected Interim Products**: Description of expected costs, time lines, and interim products (annual reports, sampling designs, etc.).

Protocol development summaries for nine MOJN protocols proposed for development in the next 3 to 5 years can be found in Appendix I. The development of PDSs is an iterative process, requiring extensive input and feedback from park staff and cooperators to develop a succinct summary and realistic set of protocol development plans. PDSs will be updated as necessary to reflect the latest decisions on objectives, target populations, methods, cooperators, and other pertinent information. Additional PDSs for the remaining three Vital Signs will be developed in the future as time, funding, and collaborative opportunities are identified.

5.3 Protocol Format and Content

Monitoring protocols will follow the document standards described in Oakley et al. (2003). This guideline specifies format and content for the protocol document, and emphasizes a modular structure that facilitates information access while supporting a well-documented history of change and revision. The following paragraphs summarize the several components of a typical MOJN monitoring protocol.

Monitoring protocols are detailed study plans that explain how data are to be collected, managed, analyzed, and reported, and are a key component of quality assurance for natural resource monitoring programs. (Oakley et al. 2003).

Monitoring protocols consist of several discrete sections detailing protocol background, sampling objectives, sampling design (including location and time of sample collection), field methods, data analysis and reporting, staffing requirements, training procedures, and operational requirements (Oakley et al. 2003). The first section is the narrative, which provides the background and rationale for vital sign selection, including a summary of pertinent research background, local research history, and a clear statement of park management information needs concerning the vital sign being monitored. The narrative also discusses specific measurable objectives and monitoring questions and identifies how the data to be collected in the monitoring effort will address these questions. Narratives also summarize the design phase of the protocol development and document key decisions made. Documenting the history of a protocol during its development phase helps ensure that future refinement of the protocol continues to improve the protocol and is not mere repetition of previous trials or comparisons (Oakley et al. 2003). Narratives also provide a listing and brief summary of all Standard Operating Procedures (SOPs), which are developed in detail as independent sections in the protocol.

Protocol SOPs are discrete sections that carefully and thoroughly explain in a step-by-step manner how each procedure identified in the protocol narrative will be accomplished. At a minimum, separate SOPs address pre-sampling training requirements, data to be collected, equipment operations, data collection techniques and methods, data management, data analysis, reporting, and any activities required at the end of a field season (e.g., post-sampling equipment maintenance and storage). One SOP identifies when and how revisions to the protocol are undertaken. As stand-alone documents, SOPs are easily updated compared to revising an entire monitoring protocol. A revision log for each SOP identifies any changes that are implemented, by whom, when, and why – emphasizing in a practical way the nature of protocols as "living documents." The final elements or sections in a typical protocol will include literature cited and, where appropriate, attachments such as appendixes, data tables, handbooks, or any other supporting information.

Complete monitoring protocols identify supporting materials critical to the development and implementation of the protocol (Oakley et al. 2003). Supporting materials are any materials developed or acquired during the development phase of a monitoring protocol. Examples of this material may include databases, reports, maps, geospatial information, species lists, analytical tools tested, and any decisions resulting from these exploratory analyses. Material not easily formatted for inclusion in the monitoring protocol also may be included in this section.

5.4 Protocol Development Process

Once a vital sign has been selected, the next step is to develop a monitoring plan and formal monitoring protocol for that vital sign. Successful development of a monitoring protocol often involves a multiyear effort to determine the appropriate spatial and temporal scale for sampling and to test sampling procedures before they are implemented for long-term monitoring. In many cases, such development requires specialized technical expertise and access to equipment or resources that may not be directly available to a monitoring program. For the MOJN I&M Program, protocol development will be performed through collaborative projects that take advantage of diverse agency, academic, and other professional expertise that leverage and augment network resources. Current collaborators providing key technical assistance include USGS, U. S. Forest Service, and Cooperative Ecosystem Studies Unit (CESU)-affiliated academic experts. In general, MOJN staff will be the primary developers of protocol-associated data management and documentation procedures, and will oversee both field testing and future implementation in network parks.

The general protocol development process is as follows. Network staff, park staff, and collaborators identify

the key monitoring objectives and questions, and types of data needed to best answer those questions. Next, the protocol development workgroup selects or develops appropriate sampling methods and spatial and temporal revisit designs, with the support of a statistician. Method and design development takes into account specific properties of the sampled resource. Following field-testing (and possible revision), protocol SOPs are drafted to detail all methods, designs, and related information. Finalized protocol documents are then sent through an informal internal and formal external (peer and expert) review process. Following reviews and revision, the approved protocol will be accepted for full implementation by the program, and implementation will commence according to the design and schedule set for that protocol. Given the lengthy and involved process of protocol development, the network plans to use and modify existing protocols whenever feasible to meet our needs.

5.5 Protocol Overview and Development Schedule

The MOJN I&M Program has identified twenty high-priority Vital Signs for monitoring at network parks. Of these, seventeen will be the focus for development and implementation within the next three to five years (see Table 5.1 and Chapter 9, Table 9.1). The remaining three Vital Signs are not slated for development within this timeframe, but will be addressed in the future as time and resources permit.

Integration of data collection for multiple Vital Signs, either by co-location or co-visitation, can be advantageous for financial, logistical, and ecological (e.g., minimize human-caused disturbance) reasons. Given the large size of MOJN parks, the wide spatial distribution of target populations to which the network plans to make inferences, and associated logistic challenges of sampling these populations, the efficiencies associated with co-location and co-visitation allow the network to achieve more with its limited financial resources. Information from co-located or co-visited Vital Signs may also provide a more holistic, ecological assessment of condition and in some cases, insight into underlying causes of ecosystem change. Integration is most appropriate when Vital Signs are ecologically related and exhibit strong spatial or temporal linkages, when monitoring objectives are complimentary, and when sampling designs are similar.

MOJN staff working with University of Nevada Las Vegas (UNLV) partners to check invertebrate pitfall traps, Lake Mead National Recreation Area. Photo Courtesy Alex Suazo, UNLV.

The MOJN is making a concerted effort in the early stages of protocol development to facilitate communication among different protocol development teams to permit identification of areas of overlap and potential integration. As a result of these initial discussions, the MOJN plans to develop 10 protocols to address 17 network Vital Signs. Similar to the Northern Colorado Plateau Network and Southern Colorado Plateau Network, the MOJN plans to integrate soils and vegetation Vital Signs into a single protocol (Integrated Upland) due to the close linkages between these ecosystem components. The spatial and temporal alignment that results from co-location and co-visitation will make it easier to jointly model resulting soils and vegetation data (i.e., avoids problems associated with misaligned data). We also plan some degree of integration for data collection, analysis, and interpretation among several of the 10 protocols.

In Table 5.1, we identify the 10 protocols to be developed over the next three to five years, the Vital Signs they address, their justification and objectives, and parks where they will be implemented. As of the close of FY 2008, we've initiated development of five protocols, including the Integrated Upland, Groundwater and Springs, Streams and Lakes, Air Quality, and Invasive/Exotic Plants, each of which is currently in a different stage of development (see Table 9.1). In FY 2009, the network will facilitate interchange among all protocol working groups to achieve a combined set of monitoring objectives that are as integrated and synergistic as possible. The network will also initiate development of an additional three protocols in FY 2009, including Weather and Climate, Riparian Vegetation, and Fire and Fuel Dynamics. The remaining protocols: Landscape Dynamics and Riparian Birds, will be initiated in FY 2010. The MOJN will coordinate protocol development with the national program and other networks to avoid a redundancy in efforts and to build upon existing work, particularly those for Landscape Dynamics and Invasive/ Exotic Plants.

Table 5.1. Monitoring protocols to be developed and implemented between 2008- 2012. Summaries of these protocols are listed below and include the start-up year for development, the primary network Vital Signs addressed, the justification, monitoring objectives, and relevant parks where the protocol will be implemented.

START-UP YEAR	NETWORK VITAL SIGN	JUSTIFICATION	MONITORING OBJECTIVES	PARKS
	INTEGRATED UPLAND MONITORING PROTOCOL			
FY 2008	Vegetation Change Soil Erosion and Deposition Soil Disturbance Soil Chemistry and Nutrient Cycling Soil Hydrologic Function Biological Soil Crusts (BSC)	Soils, vegetation, and biological soil crusts are the central components of ecosystems between which critical ecological processes and interactions occur. Soils structure plant communities by influencing nutrient and moisture availability. Plants and BSCs influence soils through primary production, soil stabilization, and their effects on moisture infiltration, nutrient and hydrologic cycles, and disturbance regimes. Because plants, soils, and BSCs are tightly linked and affected by similar drivers and stressors (e.g. climate, atmospheric deposition, fires, floods, invasive species, recreational activity, grazing), they will be monitored together.	1. Determine trends in composition, structure, mortality, relative abundance, and regeneration within upland shrub communities. 2. Determine status and trends in abundance and composition of BSCs within upland shrub communities. 3. Determine status and trends in soil chemistry and nutrients (particularly nitrogen), the magnitude and extent of soil erosion and surface disturbance, and soil hydrologic function within upland shrub communities. 4. Determine trends in distribution and abundance of non-native plant species within upland shrub communities.	DEVA GRBA JOTR LAME MOJA PARA
	GROUNDWATER AND SPRINGS MONITORING PROTOCOL			
	Groundwater Dynamics and Chemistry Surface Water Dynamics Surface Water Chemistry	Springs are intimately linked to groundwater, and the ecological characteristics of individual springs are strongly affected by groundwater source and dynamics, necessitating an integrated approach. Surface water resources are sparsely distributed on the landscape but are critical for the persistence of native biota – including many endemic, rare, threatened, or endangered species.	1. Determine status and trend in ground water resources, as estimated from existing wells. 2. For index springs, determine the status, trend, and natural range of variability of flow. 3. For index springs, determine the status, trend, and natural range of variability in core water chemistry parameters. 4. Determine status and trend of biotic communities in index springs, including aquatic macroinvertebrates and aquatic vertebrates.	DEVA GRBA JOTR LAME MOJA PARA
	STREAMS AND LAKES MONITORING PROTOCOL			
	Surface Water Dynamics Surface Water Chemistry	Relative to their abundance in the landscape, streams and lakes are disproportionately important in terms of biodiversity, productivity, and other ecosystem functions. Several streams and rivers at LAME are listed as impaired on state 303d lists, and 4 streams at GRBA are recognized by Nevada as Class A waters. GRBA has by far the largest number of streams (10) and lakes (6) of any park in the network, and both habitats are thought to be susceptible to human stressors, including groundwater withdrawal, climate change, and atmospheric pollutants.	**Water Quality Objectives** 1. Identify the regulatory status and determine trends in water quality at 303(d) streams of Las Vegas Wash at LAME. 2. Identify the regulatory status and determine trends in water quality of the Class A streams within GRBA. **Non-regulatory Objectives** 1. Identify trends in discharge in GRBA streams, particularly in lower reaches in contact with the regional carbonate aquifer. 2. Determine status and trend in core water quality parameters in GRBA streams. 3. Determine status and trend in stream macroinvertebrate assemblages in GRBA streams. Use regional bioassessment criteria to determine whether macroinvertebrate assemblages indicate "reference/unimpaired" or "stressed/impaired" status. 4. For perennial lakes within GRBA, determine whether water level, lake ice phenology, or water chemistry parameters (specifically pH and metals) change over time.	GRBA LAME

Table 5.1 Monitoring protocols to be developed and implemented between 2008- 2012 (continued).

START-UP YEAR	NETWORK VITAL SIGN	JUSTIFICATION	MONITORING OBJECTIVES	PARKS
FY 2008	**AIR QUALITY MONITORING PROTOCOL**			
	Ozone Wet and Dry Deposition Visibility & Particulate Matter	The deposition of atmospheric pollutants may have significant effects on soil chemistry, vegetation, and ecosystem processes. Monitoring air quality will provide important reference data for interpretation of other Vital Signs (e.g., soil chemistry and vegetation change)	1. Identify seasonal and annual trends in climate (temperature, precipitation) using data from existing monitoring stations. 2. Determine status and trends in air quality (Ozone, Dry and Wet Deposition, visibility-reducing pollutants) using data from existing monitoring stations	All
	INVASIVE/EXOTIC PLANTS MONITORING PROTOCOL			
	Invasive/Exotic Plants	Invasive exotic plant species pose one of the greatest threats to natural and cultural resources of MOJN parks. Impacts include displacement of native plants, degradation of wildlife habitat, fundamental changes to ecosystem processes (e.g., nutrient cycling), and alteration of disturbance regimes (e.g., establishment of grass/fire cycle). Early detection is key to effective management.	1. Detect incipient populations and new occurrences of target invasive plants in prioritized areas (vector corridors and areas of high management significance). 2. Estimate the status and trend of established target invasive plants (frequency and abundance) in upland shrub communities, riparian communities, and priority management sites. 3. Provide recommendations to determine trends in abundance of target and secondary invasive plant species and native plants following past management practices.	All
FY 2009	**WEATHER AND CLIMATE MONITORING PROTOCOL**			
	Basic Meteorology	Changes in weather patterns and climate trends are major drivers in all ecosystems. This vital sign will provide important reference data for interpretation of other Vital Signs.	1. Determine how local and regional trends in climate and air quality conditions are related to other Vital Signs.	All
	RIPARIAN VEGETATION MONITORING PROTOCOL			
	Vegetation Change	Riparian areas in the MOJN parks have greater biological productivity, biodiversity, and rates of biogeochemical cycling and storage than surrounding uplands and are one of the most threatened habitats in MOJN parks. Native riparian vegetation is threatened by groundwater withdrawal, human visitation, invasive plants, and altered disturbance regimes (e.g., fire).	1. Detect significant shifts in community composition, structure, distribution, and areal extent of vegetation in cottonwood/willow-dominated, palm oasis, and streamside communities. 2. Determine the status and trend in abundance, mortality, and regeneration of principal riparian plant species (dominant or target). 3. Detect trends in the frequency and abundance of target invasive plant species in these riparian communities.	DEVA GRBA JOTR LAME MOJA PARA
	FIRE AND FUEL DYNAMICS MONITORING PROTOCOL			
	Fire and Fuel Dynamics	Altered disturbance regimes are a priority management concern to managers at MOJN parks, who are, in particular, concerned with changes in fire frequency and intensity indicated by numerous recent, large, and high intensity fires within parks. Understanding the nature, direction, and potential effects of these changes in fire regime are critical to understanding potential threats to native species and ecosystem processes.	1. Document changes over time in the causes and patterns of burning, and evaluate how changes vary among major vegetation types and areas of differing fire regime classifications. 2. Determine post-fire vegetation successional patterns among major vegetation types and fire regime categories. 3. Determine if abundance and distribution of invasive annual grasses are changing over time, and if those patterns vary among major vegetation types and fire regime categories.	All

Table 5.1 Monitoring protocols to be developed and implemented between 2008- 2012 (continued).

START-UP YEAR	NETWORK VITAL SIGN	JUSTIFICATION	MONITORING OBJECTIVES	PARKS
FY 2009	**LANDSCAPE DYNAMICS MONITORING PROTOCOL**			
	Landscape Dynamics	Increasing land use and development around parks will have increased impacts on fragile desert resources. Monitoring changes in land cover composition, configuration, and connectivity will help managers understand and manage future threats to park ecological integrity.	1. Determine trends in land cover distribution within and adjacent to MOJN park boundaries. 2. Identify patterns of change for relevant land cover types within and adjacent to MOJN park boundaries. 3. Document land use changes that correspond with changes in land cover distribution and patterns.	All
	RIPARIAN BIRD MONITORING PROTOCOL			
	Riparian Birds	Birds have public appeal and are sensitive indicators of change. Data from bird monitoring has high value because it provides information unique from that of other Vital Signs (e.g., responses by consumers), and parks have a legal mandate to address landbirds under the Endangered Species Act and Migratory Bird Treaty Act. Eighty percent of bird species in the Mojave-Great Basin region are associated with riparian vegetation, and federally endangered bird species are present in the MOJN.	1. Use occupancy data to determine status and trends of principal riparian-obligate breeding bird species of concern in cottonwood or willow-dominated, palm oasis, and streamside riparian communities. 2. Determine status and trends in the abundance of riparian-obligate birds during the breeding season in the specified riparian communities. 3. Estimate status and trends in riparian breeding bird community richness in specified riparian communities.	DEVA GRBA JOTR LAME MOJA PARA

6.1 Introduction

The central mission of the NPS I&M Program is to provide timely and relevant scientific information about the status and trends of park resources to park managers. To accomplish this, the network will require a data management system that effectively addresses the generation, preservation, documentation, and transmission of data and the information contained within. Good data management is the means by which scientific data, and the derived information about our natural resources, become part of our NPS heritage. A robust system for data management is particularly important for a long-term monitoring program where the lifespan of a dataset will span the careers of many individuals. Recognizing this, founders of the NPS Servicewide I&M Program established data management as a cornerstone to all monitoring programs. Thus, networks are expected to invest at least thirty percent of available resources on data management and to fully integrate data management into network processes and procedures. The Data and Information Management Plan (DMP; Appendix J) is one element in the network's effort to achieve this goal of high-quality data and information management. With proper data management, analysis of high quality monitoring data will provide information that improves our understanding of ecological relationships, expands our knowledge and understanding of ecological patterns and principles, and ultimately facilitates park management (Figure 6.1).

6.2 Goals and Objectives of Mojave Desert Network Data Management

The success of our program in providing timely and relevant information on the condition of park resources hinges upon our ability to produce, manage, and deliver this information, and the subsequent knowledge derived, to its intended audience. Our overall strategy for achieving this goal focuses on ensuring the quality, interpretability, security, longevity, and availability of our natural resource data. In implementing a data and information management system, the network will strive for the following:

- Confidence in the security and availability of natural resource data and related information
- Easy access to most information, and appropriate safeguards for sensitive information
- Awareness of the intended use and limitations of each dataset
- Infrastructure and documentation that encourages data exploration
- Compatibility of datasets for exploration and analysis at larger scales and across disciplines
- Implementation of standards and procedures that facilitate information management, and that reinforce good habits among staff at all levels of project implementation – project leaders, technicians, and volunteer data collectors
- A proper balance between the standards needed to ensure quality and usability, and the flexibility to meet specific needs and encourage innovation

. . .founders of the NPS Servicewide I&M Program established data management as a cornerstone to all monitoring programs.

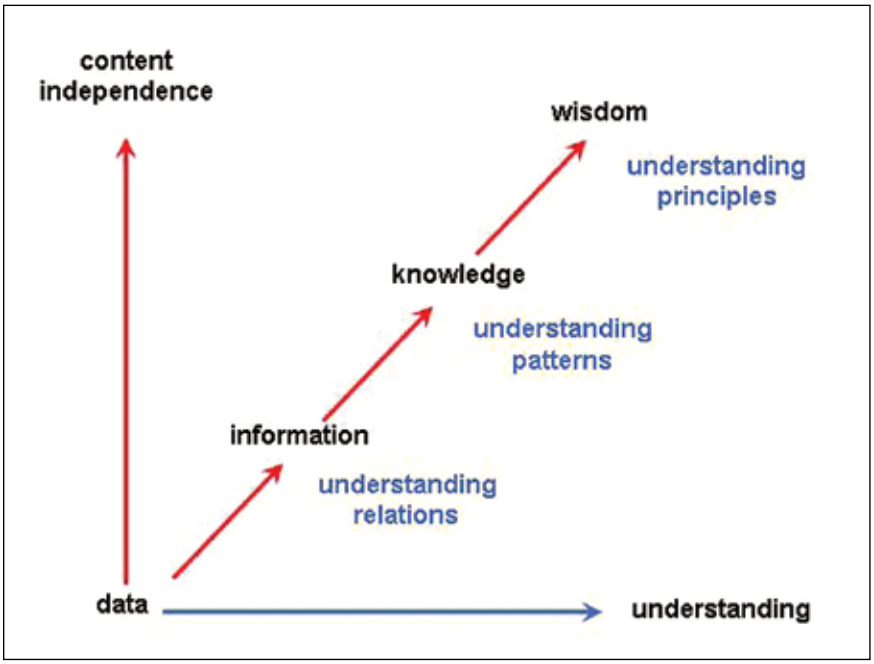


Figure 6.1 Understanding data (Bellinger 2004).

- A natural resource culture, which views data not as a commodity but as the lifeblood of our work

The MOJN DMP outlines how the network intends to implement and maintain a system that will serve the data and information management needs of our I&M Program. This plan reflects our commitment to establishing and maintaining a robust system for data management to ensure the availability and usability of high-quality natural resource information.

The MOJN DMP describes how the network will:

- Support I&M Program objectives
- Acquire and process data
- Assure data validation and quality control
- Document, analyze, summarize, and disseminate data and information
- Maintain nationally developed data management systems
- Maintain, store, and archive data

The goal of the MOJN's data management program is to maintain, in perpetuity, the ecological data, information, and knowledge that results from the network's resource inventory and monitoring work (e.g., datasets, databases, metadata). The purpose of the DMP is to describe the resources and processes required to ensure the following standards for data acquired or managed by MOJN:

- *Accuracy*: Analyses performed to detect ecological trends or patterns require high quality data with minimal error and bias. Inconsistent or poor-quality data can limit the detectability of subtle changes in ecosystem patterns and processes, lead to incorrect interpretations and conclusions, and could greatly compromise the credibility and success of the I&M Program. To ensure that MOJN produces and maintains data of the highest possible quality, procedures are established to identify and minimize errors at each stage of the data lifecycle.
- *Security*: Digital and hard-copy data must be maintained in environments that protect against loss, either due to electronic failure or to poor storage conditions. MOJN digital data are stored in multiple formats on a secure server, and are part of an integrated backup routine that includes rotation to off-site storage locations. In addition, MOJN is working with NPS museum curators and archivists to ensure that related project materials such as field notes, data forms, specimens, photographs, and reports are properly cataloged, stored, and managed in archival conditions.
- *Longevity*: Countless datasets have become unusable over time either because the format is outdated (e.g., punchcards), or because metadata is insufficient to determine the data's collection methods, scope and intent, quality assurance procedures, or format. While proper storage conditions, backups, and migration of datasets to current platforms and software standards are basic components of data longevity, comprehensive data documentation is equally important. MOJN uses a suite of metadata tools to ensure that datasets are consistently documented, and in formats that conform to current federal standards.
- *Usability*: One of the most important responsibilities of the I&M Program is to ensure that data collected, developed, or assembled by MOJN staff and cooperators are made available for decision-making, research, and education. Providing well-documented data, in a timely manner, to park managers is especially important to the success of the program. MOJN must ensure that:
    - data can be easily found and obtained
    - data are subjected to full quality control before release
    - data are accompanied by complete metadata
    - sensitive data are identified and protected from unauthorized access and distribution

Table 6.1 Natural resource data provided on Mojave Desert Network and National Inventory and Monitoring Program websites.

WEB APPLICATION NAME	DATA AVAILABLE AT SITE
NPSpecies	Database of plant and animal species known or suspected to occur on NPS park units and as a species keyword search for reference materials.
NatureBib	Bibliography of park-related natural resource information.
IRMA	Portal to a variety of NPS information sources; will include NPSpecies, NatureBib and NPS Data Store links.
Data Store	Park and network -related metadata and selected datasets (spatial and nonspatial).
NPStoret	Database for water quality assessment.
MOJN Websites	Through the use of the network's inter- and intra-net web sites and the use of MS SharePoint, reports, summaries, outreach materials, and monitoring data and information for MOJN projects and tools for data, data downloads, and database templates will be made available, MOJN Intranet.

6.3 Data Management Infrastructure and Systems Architecture

The national data management plan guidance document (NPS 2008) defines infrastructure (hardware) and architecture (software), and outlines how infrastructure and systems architecture need to be addressed by the network. Since the network office and staff are hosted at LAME, our IT resource needs are integrated with LAME.

The MOJN's main mechanism for distribution of the network's inventory and monitoring data will be the World Wide Web, which will allow data and information to reach a broad community of users. As part of the National I&M Program, web-based applications and repositories have been developed to store a variety of park natural resource information (Table 6.1).

The real value of MOJN's information is when it reaches those who can apply it (Figure 6.1 above). If the web portals listed above (Table 6.1) do not meet a specific user's requirements, MOJN data management staff will work with users on an individual basis to ensure receipt of the desired information in the requested format.

6.4 Data Management Plan Model

In the past, I&M network data management plans were written as an iterative group process.

Under this model, network data managers were assigned to one of four groups. The first group worked together to develop and submit a plan the first year. The second group built upon salient elements of the first plan, filled in gaps, and revised materials to develop an improved version the second year. By the third iteration, the data management plan was comprehensive, but also lengthy, which was discouraging to readers and difficult to implement. Plans also contained redundancy, repeating in each iteration the same set of information (legal mandates, policies, and general data stewardship guidelines). Consequently, the fourth and last group of data managers have designed and written their plans based on a new model. To avoid repeating the same general information (adding to its length) and having to periodically update each network plan with new national guidance and legal mandates, the new model proposes:

- To produce a national-level data management plan guidance document that maintains the overarching documentation (what and why concerning data/information stewardship) and legal mandates regarding management plan development, and that is easily referenced and can be used in the development of a new network data management plan.
- To produce a new network-level data management plan that is more applicable (how and when concerning data/information stewardship), easily understood, and does not require the lengthy background documentation and legal mandates.

The MOJN DMP is written as both a standalone document and as a support document for the network's Final

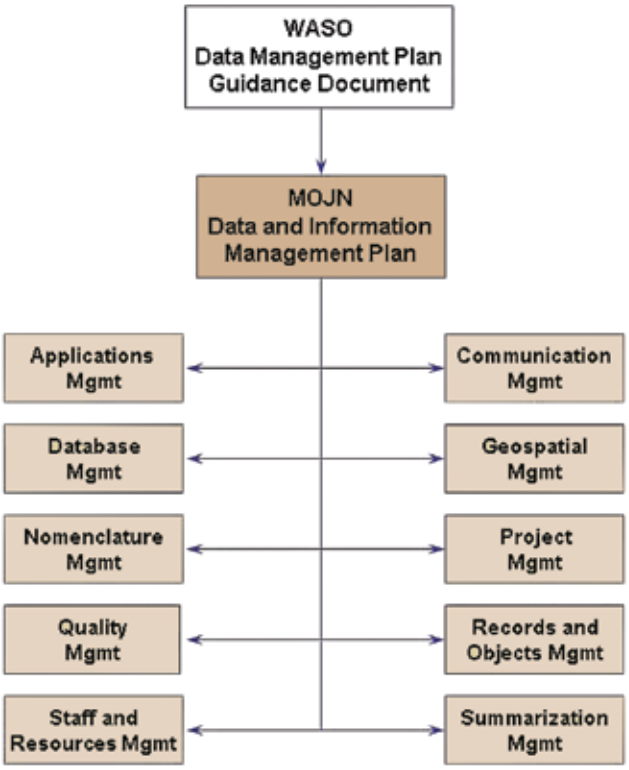


Figure 6.2 Management sections of the Mojave Desert Network Data and Information Plan.

Vial Signs Monitoring Plan to guide the management of data as well as subsequently-produced information and knowledge. Hence, the plan is a condensed or abbreviated link between the national data management plan guidance document (NPS 2008) and the more technically oriented and applicable supporting documentation (management sections and standard operating procedures) that are appended to the plan (Figure 6.2). The supporting documentation are the dynamic guidance that will provide users (park and network staff, cooperators, and others) with the practical tools to access any particular data and/or information management procedure. The supporting documentation is composed of SOPs that have been arranged into categories of related procedures (i.e., management sections) as illustrated in Figure 6.2. The national guidance document contains the legal mandates and over-arching justifications, the network plan is the connection between the national guidance and the network-level management sections and SOPs.

6.5 Data Management Roles and Responsibilities

Data management is collaborative work that involves many persons with a broad range of expertise and abilities. All network staff have a role in data stewardship, and project datasets and products reflect all those who have contributed. Table 6.2 summarizes the roles and responsibilities related to network data management, from field-based data collection, to final distribution and archiving. The fundamental role of the network data manager is to coordinate these tasks.

6.6 Data Sources and Priorities

There are multiple sources of significant data related to natural resources in the MOJN parks. The types of work that may generate these data include:

- Inventories
- Monitoring
- Protocol development pilot studies
- Special-focus studies performed by internal staff, contractors, or cooperators
- Research projects performed by external scientists
- Studies performed by other agencies on park or adjacent lands
- Resource impact evaluations related to park planning and compliance
- Resource management and restoration work

Because the I&M Program focuses on natural resource inventories and long-term monitoring, MOJN's first priority is the management of data and information that results from these efforts. However, the standards, procedures, and approaches to data management developed by MOJN carry over and are being applied to other natural resource data sources. For example, all natural resource parks need a basic suite of resource inventory data in order to manage their resources and support a successful monitoring program. The National I&M Program has determined that 12 inventory datasets, including both biotic and abiotic components, will be acquired by all parks. MOJN

Table 6.2 Roles and responsibilities related to network data management.

ROLE	PRIMARY RESPONSIBILITIES RELATED TO DATA MANAGEMENT
Project leader	Direct operations, including data management requirements, for network projects
Project crew leader	Supervise crew; communicate regularly with data manager and project leader
Project crew member	Collect, record, perform data entry, verify data; organize field forms, photos, other related materials
Resource specialist	Evaluate validity and utility of project data; document, analyze, publish data and associated information products
GIS specialist	Oversee GPS data collection; manage spatial data; prepare maps; perform spatial analyses
IT specialist	Apply database and programming skills to network projects; maintain information systems to support data management
Quantitative ecologist	Determine project objectives and sample design; perform and document data analysis and synthesis; prepare reports
Network data manager	Ensure program data and information are organized, useful, compliant, safe, and available
Network coordinator	Coordinate and oversee all network activities
Park or regional curator	Ensure project results (documents, specimens, photographs, etc.) are cataloged and accessioned into NPS or other repositories
I&M data manager (national level)	Provide service-wide database support and services; provide data management coordination among networks
End users (managers, scientists, interpreters, public)	Inform and direct the scope of science information needs; interpret information and use to direct or support decisions

is working with individual parks and national NPS programs to acquire and standardize these basic resource datasets, and make them widely available. The datasets are:

- Natural resource bibliography
- Documented species list of vertebrates and vascular plants
- Species distribution and status of vertebrates and vascular plants
- Vegetation map
- Base cartographic data
- Soils map
- Geology map
- Water body location and classification
- Water quality data
- Location of air quality monitoring stations
- Air quality data
- Weather data

6.7 Data Management and the Project Lifecycle

I&M projects are typically divided into five broad stages: initiation, planning, execution, monitoring and control, and closure (Figure 6.3). During all stages, data management staff collaborate closely with project leaders and participants.

Specific data management procedures corresponding to these five stages are described in the chapters of the MOJN DMP (Appendix J). Chapters 1-5 develop the data management framework. Chapter 6 is devoted to data acquisition, processing, and reporting, while Chapter 7 provides a framework for verifying and validating data that are collected and entered into databases. Dataset documentation is the subject of Chapter 8, data ownership and sharing is presented in Chapter 9, and data dissemination, including issues such as compliance with

Prioritizing data management efforts in a sea of unmanaged data

- Highest priority is to produce and curate high-quality, well-documented data originating with the Inventory and Monitoring Program
- As time and resources permit, assist with data mangement for current projects, legacy data, and data originating outside the Inventory and Monitoring Program that complement program objectives
- In addition, help ensure good data management practices for park-based natural resource projects that are just beginning to be developed and implemented

the Freedom of Information Act, are addressed in Chapter 10. Chapters 11 and 12 provide a framework for the long-term maintenance, storage, and security of MOJN data.

6.8 Water Quality Data

The water quality component of the Natural Resource Challenge requires that networks archive all water quality data collected as part of the monitoring program in a STORET (STORage and RETrieval, EPA 2006) database maintained by the NPS Water Resources Division (WRD). MOJN will be developing an MS-Access database that consolidates available water quality data collected in and near the 7 MOJN park units. Associated with this database are assessment tools to evaluate water quality standards that allow comparisons of historical and current data with applicable state standards. MOJN will maintain this

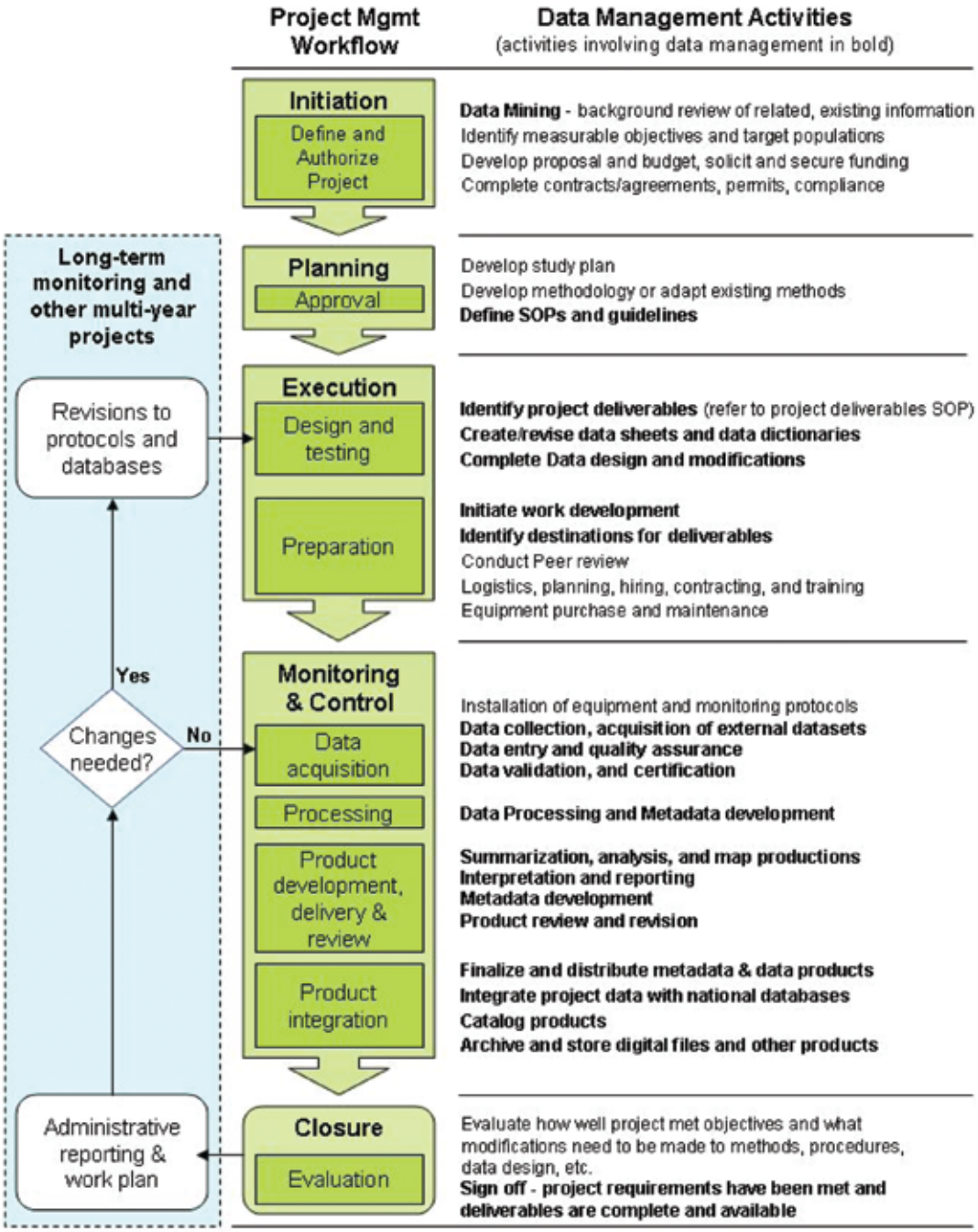


Figure 6.3 Project workflow and data management activities.

database and integrate new data collected so it can serve as an ongoing tool for the network's long-term water quality monitoring and analysis needs.

On an annual basis, MOJN will compile and format new water quality data from the MOJN H2O MS-Access database into an electronic data deliverable (EDD) that is compatible with WRD-STORET. WRD will ensure that content is transferred to the Environmental Protection Agency's STORET database (Figure 6.4).

6.9 Data Management Plan Maintenance

The MOJN approach is to maintain a DMP that is useful to a broad audience, and that can provide guidance on data management practices at a number of different levels. MOJN will keep the plan simple, flexible, and evolving, and include data users in the decision-making process whenever possible.

The document has undergone an initial prescribed review process that included both an internal network review (e.g., technical committee members and network staff), and an extensive review that involved the regional data/GIS coordinator, data management staff from the Washington Support Office I&M Program, and other network data managers. MOJN will update the plan to ensure that it accurately reflects the network's current standards and practices. Recommendations for changes can be forwarded to the network data manager by any interested party or user of network inventory and monitoring data (e.g., park resource managers, project leaders, technicians, superintendents, external users). These recommendations will be discussed by data management and network staff and appropriate actions will be decided. Simple changes can be made immediately in the document, while substantive changes will be made during version updates. The most current version of the plan is available on the MOJN website (http://science.nature.nps.gov/im/units/mojn/index.cfm).

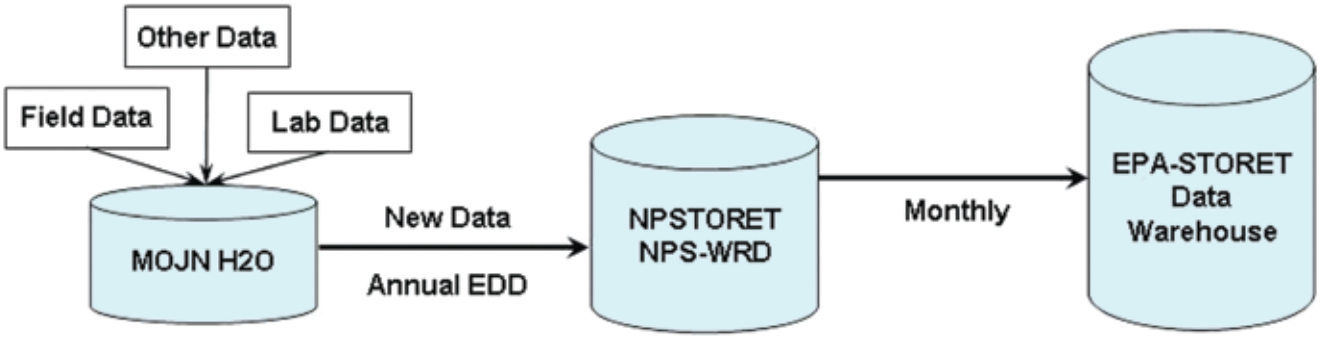


Figure 6.4 Simplified flow diagram for water quality data.

Chapter 7: Data Analysis and Reporting

Data analysis, interpretation, and reporting are crucial components in the development and implementation of the MOJN I&M Program. Data compiled from monitoring projects will be used by diverse audiences – NPS park managers and superintendents, scientific collaborators, educators – who might have different requirements and needs. Recognizing this fact, and following National I&M Program guidance, a minimum of one-third of the network's resources are committed toward the management, analysis, and timely reporting of I&M information. Success of this program depends on the ability to deliver meaningful information to parks regarding the status and trend of park Vital Signs, and this is the key link in completing the adaptive management cycle (Figure 7.1).

This chapter summarizes the major themes and concepts of the network's plan for analysis and reporting. Figure 7.2 summarizes the major approaches to analyses and reporting tools that will be pursued and how they interact with outside research to support the network's programmatic goals. The data analysis section describes four categories of data analysis and identifies lead individuals for each analysis. The reporting section describes different reporting tools, their content, intended audience, frequency and format, and responsible parties. Specific details on analysis of each vital sign is beyond the scope of this chapter and will be included within the monitoring protocols that correspond to specific Vital Signs. Several of these are currently under development as described in Chapter 5.

7.1 Data Analysis

Successful data analysis depends upon well-articulated questions and objectives and appropriate, statistically-valid sampling designs. Appropriate sampling designs are critical because they allow statistically rigorous conclusions and inferences to be reached about the status and trend of each vital sign. As described in Chapter 4, simple and flexible sampling designs are emphasized in the network, partly to facilitate data analysis. These typically are "unstructured" designs with a minimum of stratification, known and typically equal sample selection probabilities, and simple membership designs. Straightforward and flexible designs in turn facilitate direct and interpretable analytical approaches. By emphasizing a design-based approach to monitoring, inferences can be drawn directly from designs and can minimize reliance on assumptions (Edwards 1998; Manly 2001). This will be particularly true for estimation of status, where classical sampling theory for finite populations is well-developed and provides design-unbiased estimators of population parameters such as the population mean and variance (Thompson 2002). Selected sampling designs also support, and often require, the use of model-assisted or model-based approaches. This is particularly true for trend estimation, and to address sampling and non-sampling errors (year, site, and residual random effects), missing data, and important auxiliary variables (Urquhart and Kincaid 1999; Thompson 2002). Mixed linear models are useful for analyzing trend in data collected through rotating panel designs, an approach, which has been proposed for some of the Vital Signs (Urquhart et al. 1993; VanLeeuwen et al. 1996, Urquhart

The timely analysis and reporting of information on status and trends of vital signs is critical to the process of adaptive management.

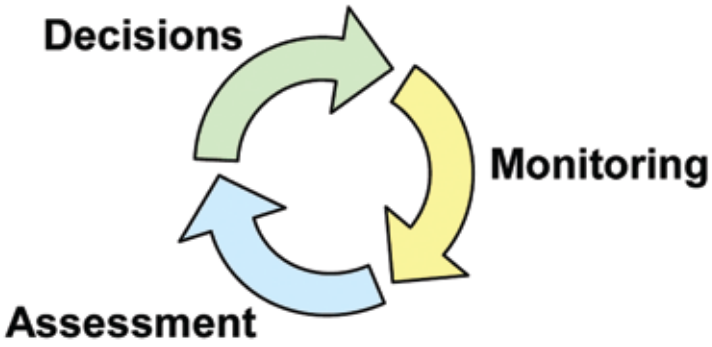


Figure 7.1 Conceptual diagram of adaptive management illustrating the iterative cycle of monitoring, assessment, and decisions.

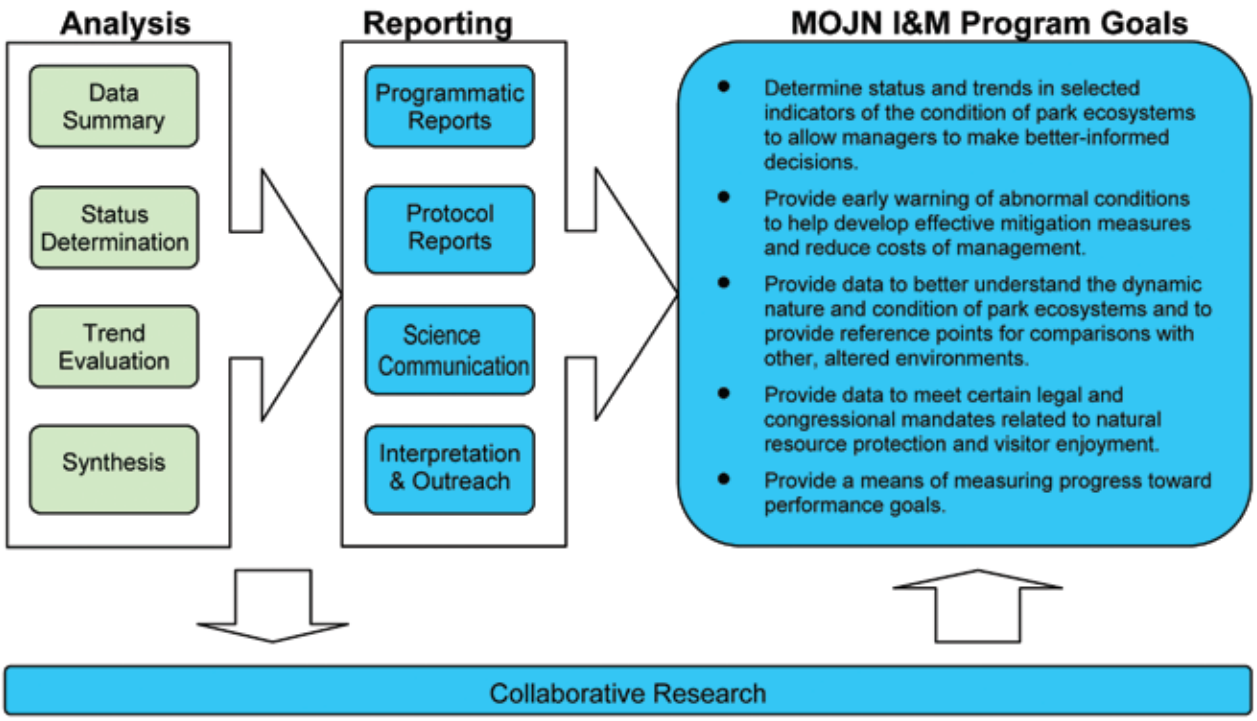


Figure 7.2 Relationships between analyses, reporting, research, and the Mojave Desert Network program goals.

Successful data analysis depends on well-articulated questions and objectives and appropriate, statistically-valid sampling designs.

et al. 1998; Urquhart and Kincaid 1999; Piepho and Ogutu 2002; Sims et al. 2006). For data that fail to meet normality assumptions, a Generalized Mixed Model can be used (Purcell et al. 2005). Several other networks (Sierra Nevada, Upper Columbia Basin, and Klamath) are currently collaborating with statisticians at Oregon State University and University of Idaho on implementation of these models within SAS and the R package for water quality and other Vital Signs. Such models can provide more precise parameter estimates, can be used to generate and test hypotheses about the ecological processes underlying observed patterns, and under the best circumstances, can be used to predict future scenarios. To deliver meaningful information to park managers, it is important not only to report on a trend, but to provide some interpretation of the trend and potential underlying causes.

Selection of specific analytical tools for interpreting monitoring data is a function of monitoring objectives, assumptions regarding the target population, and the level of confidence desired, or practical, given natural and sampling variability. Each monitoring protocol developed by the MOJN will contain detailed information on analytical tools and approaches for data analysis and interpretation, including rationales for a particular approach, advantages and limitations of each procedure, and SOPs for each prescribed analysis.

Four general categories of analysis for MOJN Vital Signs and the lead analyst responsible for each are summarized (Table 7.1). The Project Leader for a protocol will be the lead analyst and thus will ensure that data are analyzed and interpreted within protocol and program guidelines. The lead analyst may rely on non-NPS cooperators to assist with analysis and interpretation. The MOJN is currently employing the services of statisticians at Oregon State University, Montana State University, and University of Idaho through a cooperative agreement. This arrangement, or something similar, will provide high-level analytical support in the future.

Table 7.1. Four approaches to analyzing monitoring data and the individuals responsible for analyses.

TYPE OF ANALYSIS	DESCRIPTION	LEAD ANALYST & SUPPORT
Data Summarization/ Characterization	Calculation of basic statistics of interest and initial screening, including: • Measures of central tendency (mean, median) and variation (range, variance, S.E.) • Identification of missing values and outliers (box-and-whisker plots, queries, QA/QC) • Graphical summaries & visual inspection of data Summarization procedures are specified in the monitoring protocols and include measured and derived variables and matrices for community analyses.	Lead: Project Leader for protocol Support: Field crew leads, network staff, park staff
Status Determination	Analysis and interpretation of vital sign status to address the following questions: • Do observed values exceed a regulatory standard or a known ecological threshold? • How do observed values compare with the range of historical variability for a vital sign? • What is the precision (i.e., variability) and confidence in the status estimate? • What is the spatial distribution (park, network, ecoregion) of observed values at time of evaluation? • Do these patterns suggest relationships with other factors not accounted for in the sampling design? • What environmental factors function as covariates and influence the measurement values? Design-unbiased population estimators (e.g., Horvitz-Thompson) will be used to determine status.	Lead: Project Leader for protocol Support: Network staff, Park staff, Cooperators or Partners, regulatory and Subject-Matter Experts
Trend Evaluation	Evaluations of interannual trends will seek to address: • Is there continued directional change in indicator values over the period of measurement? • What is the estimated rate of change (and associated measure of uncertainty)? • How does this rate compare with rates observed from historical data, other indicators from the same area, or other comparable monitoring in the region? • Are there unforeseen correlations that suggest other factors should be incorporated as covariates? (correlations, regression analyses) • If no trend was detected, what was the power to detect trend, given observed levels of variability? Analysis of trends will initially employ graphic portrayals (Cumulative Sum [CUSUM] and control charts), then repeated-measures and time-series using mixed linear models.	Lead: Project Leader for protocol Support: Network staff, Statisticians, Park staff, Cooperators or Partners, regulatory and Subject-Matter Experts
Synthesis	Examination of patterns across Vital Signs and ecological factors to gain broad insights into ecosystem processes and integrity, which may include: • Tests of hypothesized relationships, congruence among indicators, and covariate influence • Development of analytical and predictive models • Integrative approaches (ordination of community data, multiple regression, diversity and conservation-value indices, Bayesian hierarchical and graphical models) • Evaluation of competing a priori-specified models that explain dynamics in Vital Signs; model averaging, variable weights, and prediction Synthetic analyses will require close interaction with academic and agency researchers and has great potential to explain ecological relationships in the non-experimental context of vital signs monitoring. Integration with results from other monitoring and research is critical.	Leads: Network Coordinator & Ecologist Support: Project Leaders, Statisticians, Data management staff, Park staff, Cooperators or Partners, regulatory and Subject-Matter Experts

7.2 Communications and Reporting

As part of the NPS effort to "improve park management through greater reliance on scientific knowledge," data analysis and reporting are cornerstones of the I&M Program. Effective communication tools are critical for conveying status and trends information to a wide range of audiences. The primary audience for many I&M products is at the park-level, providing park managers with information needed to make better-informed decisions. However, certain products are intended for other key audiences including park planners, interpreters, Congress, the President's Office of Management and Budget, external scientists and the general public.

Effective communication tools are critical for conveying status and trends information to a wide range of audiences.

To effectively communicate monitoring information and results with a variety of audiences, analysis and interpretation must occur on a regular basis, and results must be communicated in formats specific to intended audiences. With the assistance of a CESU cooperator at Colorado State University and the NPS-Natural Resource Program Center, MOJN will develop a science communication plan which identifies natural resource education and communications techniques to be used for internal and external audiences.

MOJN reporting mechanisms are based on national guidance, have been modified to fit network needs, and fall into four categories: programmatic, protocol-related, science communication, and interpretation/outreach. The following sections describe each report category and how they differ in content, purpose, and audience. These details are also summarized in Table 7.2. Each monitoring protocol will also contain additional and specific information on data summary, analysis and reporting requirements and procedures.

7.2.1 Programmatic Reports and Review

The Annual Administrative Report and Work Plan (AARWP) report specifies annual objectives, accomplishments, and expenditures to a variety of audiences, ranging from park superintendents and staff to national program managers and Congress. The 5-year Program Review is an avenue for evaluating the efficacy, accountability, and scientific rigor of the monitoring program. Following this review, network staff and protocol leads have primary responsibility for implementing the resulting recommendations. Table 7.2 contains a summary and Chapter 8 contains additional detail on programmatic reports and review.

7.2.2 Protocol-related Reports and Review

Protocol reports document the collection, analysis, and interpretation of monitoring data and results of periodic protocol reviews. Annual protocol reports document monitoring activities for the year, including any changes to the protocols, and describe the current status of monitored resources. Completed every 3-5 years, trend analysis and synthesis reports describe trend analyses, identify patterns, and synthesize data within multiple spatial contexts. These thorough and detailed reports are intended primarily for resource managers and scientists.

Protocol reviews will be conducted after completion of one full monitoring cycle (i.e., full rotation through all panels) and likely, in conjunction with the corresponding trend analysis and synthesis report. Protocol reviews will include a peer-review process to evaluate effectiveness (protocol design, minimum change detection levels achieved, SOPs, etc.), implementation success (schedule, budget, logistics), and information management (QA/QC, archiving processes, communication products, etc.), and to determine whether and what types of changes are warranted. Network staff and protocol leads are the primary recipients of this information and are responsible for implementing recommendations. See Chapter 8 for further detail.

7.2.3 Science Communication

Scientific journal and other professional articles will be published to

communicate advances in knowledge to the scientific community and to achieve an important and widely acknowledged means of quality assurance and quality control. The scrutiny of the scientific peer-review process is one of the best methods for ensuring scientific rigor in the program's methods, analyses, results, and conclusions. As the opportunity arises, network staff and cooperators will submit manuscripts and present findings at professional symposia, conferences, and workshops. Scientific journal articles and other publications based on MOJN data and projects will be tracked by the network through the publications section of the AARWP.

7.2.4 Interpretation and Outreach

The MOJN will develop a variety of avenues for communicating monitoring goals, activities, and results to park staff and the public and maintaining visibility for the program. One avenue will be an electronic newsletter, distributed two times a year, that distills scientific findings into non-technical articles of interest to park managers and the general public. In addition, network staff and cooperators will meet periodically to interact with park staff (superintendents, resource managers, park specialists, interpretive staff, etc.) and present monitoring goals, network activities, and vital signs objectives. Network and park staff will explore whether this would be best accomplished through a single annual network meeting (i.e., Science Day) at a central location or a series of meetings at various locations throughout the network. In an effort to expand the scope of our outreach and generate interest among local school teachers and students, the network will explore the development of a Citizen Science program, where student volunteers collect data (e.g., long-term phenology records) for the monitoring program.

Websites are important for improving visibility and promoting communication, coordination, and collaboration among various entities. The MOJN internet website serves as a centralized repository for all finalized, reviewed reports and summaries, which do not contain sensitive information. The network intranet site facilitates the internal distribution of NPS documents.

In June 2007, over 100 members of the natural resource community attended the Mojave Desert Network's inaugural science day event. NPS Photo.

Table 7.2. Summary of reporting mechanisms to be used by the Mojave Desert Network.

TYPE OF REPORT	PURPOSE OF REPORT	PRIMARY AUDIENCE	FREQUENCY	REVIEW PROCESS
PROGRAMMATIC REPORTS				
Annual Administrative Report & Work Plan	• Account for funds and FTEs expended. • Describe objectives, tasks, accomplishments, products of the monitoring effort. • Improve communication within park, network, and region.	Superintendents, Technical Committee, MOJN staff, regional coordinators, and national program managers; Used for annual report to Congress.	Annual	Reviewed and approved by PWR Regional Coordinator and national program manager
Monitoring Program Review	• Formally review operations and results at 5-yr intervals • Implement the quality assurance and peer review process.	Superintendents, park resource managers, MOJN staff, national program managers, external scientists, partners	5-year intervals	Peer review at national level, MOJN Board of Directors & Technical Committee
PROTOCOL-RELATED REPORTS				
Annual Reports for each Protocol	• Summarize annual data and document monitoring activities for the year • Describe status of the resource • Document changes in monitoring protocols • Communicate monitoring efforts to parks	Superintendents, park resource managers, MOJN staff, national program managers, external scientists and partners.	Annual	Peer reviewed at network-level
Trend Analysis and Synthesis Reports	• Determine patterns/trends in resource condition • Discover new characteristics of resources and correlations among resources • Interpret data within park, multi-park, network, and regional contexts • Recommend changes to management (feedback for adaptive management)	Superintendents, park resource managers, MOJN staff, external scientists	3-5 year intervals for resources sampled annually	Peer reviewed at the network-level
Summary of Trend Reports	• Summarize Comprehensive Trend Analysis and Synthesis Reports to highlight key findings and recommendations.	Superintendents, park resource managers, interpreters, general public	Commensurate with frequency of Comprehensive Reports	Peer reviewed at the network-level
Protocol Review	• Review protocol design and products to determine necessary changes • Ensure peer-review and quality assurance	Superintendents, park resource managers, MOJN staff, national program managers	5-year intervals	Peer reviewed at regional and/or national level, MOJN Board of Directors, Technical Committee

Table 7.2. Summary of MOJN reporting mechanisms (continued).

TYPE OF REPORT	PURPOSE OF REPORT	PRIMARY AUDIENCE	FREQUENCY	REVIEW PROCESS
SCIENCE COMMUNICATIONS				
Technical Bulletins, Journal articles, and Book Chapters	• Make scientific contributions to ecological and monitoring science. • Subject I&M activities and approaches to unbiased peer review. • Elevate scientific standing and authority of program.	MOJN staff, scientific community, park resource managers	Variable	Peer reviewed by journal or book editor
Symposia, workshops, and conferences	• Communicate to scientists and managers. • Expose I&M activities to regional or national scientific community. • Elevate scientific standing and authority of program.	Resource managers of federal and state agencies, MOJN park staff, scientific community	Variable	May be peer reviewed by editor, if written papers are published
INTERPRETATION AND OUTREACH				
Resource Brief	• For each protocol, report activities and explain the significance and relevance of the scientific findings in non-technical manner	Park staff, interpreters, general public	Annual	Peer reviewed at the network-level
Newsletter	• Improve awareness of network goals, activities, and findings by park staff and the public • Distill scientific findings into non-technical articles of general interest • Provide information to interpretive programs	Park staff, agency partners and cooperators, interpreters, general public	Twice per year by email & on MOJN website	Peer reviewed at network-level
Park presentations and/or Science Days	• Report progress and activities of network • Summarize information on MOJN vital signs • Identify emerging issues and generate new ideas • Facilitate interactions among park resource managers and external scientists	Park resource managers, MOJN staff, cooperators, and partners	Variable	Peer reviewed at network-level
Internet and Intranet Websites	• Improve public awareness through web presence • Centralized repository of all final reports to ensure products are easily accessible in commonly-used electronic formats • Facilitate internal distribution of NPS documents	Superintendents, park resource managers, MOJN staff, national program managers, scientific community, general public	As reports are finalized	Only reviewed, finalized products without sensitive information will be posted

Chapter 8: Administration and Implementation of the Monitoring Program

This chapter describes administration of the MOJN monitoring program, including program oversight and guidance, the proposed staffing plan, integration with park operations, partnerships, and the periodic review process.

8.1 National and Regional Context

MOJN is one of eight I&M networks in the Pacific West Region (PWR; Figure 8.1). In addition to its unique Mojave ecosystems, MOJN contains landscapes with ecological similarities to a number of surrounding networks, including Northern Colorado Plateau Network, Southern Colorado Plateau Network, Upper Columbia Basin Network, and Sierra Nevada Network at higher elevations, and Chihuahuan Desert Network and Sonoran Desert Network at lower elevations. As such, MOJN is in a position to benefit from, build upon, or coordinate with existing efforts at these other networks in order to develop its program.

8.2 Program Location

Core staff of the MOJN are duty-stationed at Lake Mead National Recreation Area (LAME) in Boulder City, NV. This location was selected due to the park's central location in the network and proximity to cooperators at other federal agencies, universities, and research institutes. Starting in FY 2009, network staff will be housed in a small, network-funded office building at LAME, which will be supported and maintained by the park. The park also provides administrative and IT support in exchange for a small percentage of network funds. As needed and as appropriate, other network staff may be located at other parks within the network (e.g., data miners based at parks where data mining occurs).

8.3 Guidance from National and Regional Programs

National and Regional programs play important roles in guiding program development and implementation. The National I&M Program establishes standards and guidelines based on Natural Resource Challenge legislation and agency policy, reviews and retains approval authority for completed Vital Signs (or Phase III) Monitoring Plans, and provides technical and administrative guidance on network program development. National I&M guidance and funding is provided by Washington Support Office (WASO) through the National I&M Program Manager, the Pacific West Region (PWR) office, and the PWR Regional I&M Coordinator.

The PWR Regional I&M Coordinator oversees program development for 8 PWR networks, ensures compliance with National I&M Program guidelines, serves as an ex-officio member of the MOJN Board of Directors, and supervises the MOJN Network Coordinator (as well as other PWR network coordinators). Divisions of the NPS Natural Resources Program Center have responsibilities for completing baseline resource inventories and to serve as subject matter experts for Vital Signs within their purview.

The National I&M Program interfaces with local network oversight groups (MOJN Board of Directors [BOD] and Technical Committee [TC]) through the PWR Regional I&M Coordinator and the MOJN Network Coordinator. National program guidance, directives, and requests usually flow from the National I&M Program Manager through the PWR Regional I&M Coordinator to the MOJN Network Coordinator, who then distributes information to the BOD and TC. Accountable to the NPS Associate Director, the network provides reports and updates (typically prepared by the Network Coordinator and staff) to the National I&M Program Manager through the PWR Regional I&M Coordinator.

As one of 32 networks receiving funding from the National I&M Program and Water Resources Division, MOJN is required to submit an administrative report and work plan to the National I&M Program that summarizes (1) accomplishments and an accounting

The National I&M Program establishes standards and guidelines based on Natural Resource Challenge legislation and agency policy...

Figure 8.1. Pacific West Region Inventory & Monitoring Program networks. Map courtesy of Pacific West Region GIS group.

of funds spent during the previous year, and (2) scheduled activities and budget allocations for the coming year. The report provides the National I&M Program Manager with accomplishments and budget information needed for the annual Report to Congress, which allows the network and national program to show accountability for funds received through the Natural Resource Challenge. The AARWP is discussed further in section 8.8.

8.4 Local Program Oversight and Direction

Local program oversight and direction within the MOJN is provided by the BOD, TC, and Network Staff. This section describes the responsibilities, structure, and composition of the MOJN BOD and TC. Specific details may be found in the MOJN Charter (approved April 2003) and MOJN Charter Amendment 2 (approved December 2005; See Appendix K).

The MOJN BOD is responsible for developing a strategic vision for long-term monitoring, ensuring the overall effectiveness and success of the network's monitoring efforts, and for providing program accountability. The BOD makes decisions on budget, long-term staffing, and program direction based on technical assistance and advice provided by the TC and Network Coordinator. Voting members of the BOD include the 7 park Superintendents of the network (Table 8.1). The Chair of the BOD is the park Superintendent that serves as liaison to the Regional Leadership Council, typically a 2-year term. Non-voting, ex-officio members that play an advisory role include the Regional Coordinator, Network Coordinator, Natural Resource Advisory Committee (NRAC) representative, and Great Basin CESU coordinator (Table 8.1). While the Network Coordinator is a common member to both the BOD and TC, additional representation of the BOD at TC meetings (by the Superintendent Liaison) and the TC at BOD meetings (by the current NRAC representative) ensures stronger communication among these groups. The BOD meets at least twice per year in person and by conference call as needed. Decisions are typically made by consensus.

The MOJN TC is responsible for providing technical assistance, advice, and recommendations to the MOJN BOD. Voting members include the 5 Park Resource Chiefs, representatives from MANZ and PARA (designated by park Superintendents), the Network Coordinator, and the MOJN Science Advisor (Table 8.2). The MOJN Network Coordinator serves as the Chair of the TC and coordinates its efforts. Non-

The MOJN Board of Directors is responsible for developing a strategic vision for long-term monitoring, ensuring the overall effectiveness and success of the network's monitoring efforts, and for providing program accountability.

Table 8.1. Mojave Desert Network Board of Directors: current members and their roles. [a]

TITLE	NAME	VOTING MEMBER	ADVISORY ROLE
Superintendent, DEVA	JT Reynolds (Chair, BOD)[a]	X	
Superintendent, GRBA	Andrew Ferguson	X	
Superintendent, JOTR	Curt Sauer	X	
Superintendent, LAME	William Dickinson	X	
Superintendent, MANZ	Les Inafuku	X	
Superintendent, MOJA	Dennis Schramm	X	
Superintendent, PARA	Jeff Bradybaugh	X	
PWR Regional Coordinator	Penny Latham		X
MOJN Network Coordinator	Alice Chung-MacCoubrey		X
Regional NRAC Representative	Kari Yanskey		X
Great Basin CESU Coordinator	Angie Evenden		X

[a] Membership as of Sept. 2008. Reynolds will be succeeded by Sauer as Chair in January 2009.

Table 8.2. Mojave Desert Network Technical Committee: current members and their roles.[a]

TITLE	NAME	VOTING MEMBER	ADVISORY ROLE
MOJN Network Coordinator (Chair)	Alice Chung-MacCoubrey	X	
Resource Chief, DEVA	Linda Greene/ David Ek	X	
Resource Chief, GRBA	Tod Williams	X	
Resource Chief, JOTR	Paul DePrey	X	
Resource Chief, LAME	Kent Turner	X	
Resource Chief, MOJA	Bob Bryson	X	
Representative, MANZ	Les Inafuku	X	
Representative, PARA	Kari Yanskey	X	
MOJN Science Advisor	Debra Hughson	X	
Superintendent Liaison	Jeff Bradybaugh		X
Great Basin CESU Coordinator	Angie Evenden		X
Designated Park Staff	Various		X

[a] Membership as of Sept. 2008.

The MOJN Technical Committee is responsible for providing technical assistance, advice, and recommendations to the MOJN Board of Directors.

voting members play an advisory role and include designated park staff, the Superintendent Liaison, and Great Basin CESU coordinator (Table 8.2). The TC meets at least twice per year in person and by conference call as needed. TC members express the needs of individual parks but make decisions based on greatest benefit to the network. Decisions are typically made by consensus.

8.5 Staffing Plan

MOJN staff and their activities are intended to support the following National I&M Program goals and to implement them at the network-level in a manner to address local park needs:

- Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.
- Inventory the natural resources and park ecosystems under National Park Service stewardship to determine their nature and status. MOJN staff will assist parks and national programs in developing baseline inventories of natural resources in the parks and developing data management systems to aid park managers in accessing and utilizing inventory information.
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments. MOJN staff will develop an integrated, scientifically credible, long-term ecological monitoring program to efficiently and effectively monitor status and trends of selected Vital Signs and develop data management and decision support systems to aid park managers in accessing and utilizing monitoring information for management purposes.
- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making. MOJN staff will work with various park divisions to make natural resource interpretation and protection an integral part of overall park management.
- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives. MOJN staff will cooperate with other agencies and organizations to share resources, achieve common goals, and avoid unnecessary duplication of effort and expense.

8.5.1 Mojave Desert Network Staff

The proposed MOJN staffing strategy is designed to support the programmatic

functions above, employing a core of professional, permanent staff to oversee and implement the program and a variety of temporary staff to conduct shorter-term projects (e.g., vegetation mapping), develop data management infrastructure and procedures, and perform field data collection and management. Table 8.3 summarizes title, grade, primary duties, and other information for each position we propose and the phase they will contribute to. Core network staff are responsible for implementing and managing the I&M Program over the long-term. The Implementation Phase is the period during which monitoring protocols are sequentially developed, tested, and implemented, baseline inventories are conducted to support protocol development, and data management infrastructure is developed. Temporary positions proposed for the Implementation Phase will conduct shorter-term projects and other activities that will support protocol development or facilitate the transition to full implementation (e.g., data mining, spatial data acquisition and manipulation). The Monitoring Phase is the period that occurs after all protocols have been developed, refined, and implemented and data management procedures are in place. At this point, the network's primary focus will be performing and reporting on monitoring activities and managing resulting data. Temporary positions proposed for the Monitoring Phase will collect field data or provide data management support for resulting data. Staffing needs during the Monitoring Phase are difficult to define in greater detail because protocols are not fully developed. Thus staffing needs for this phase will be addressed in an iterative manner by the Network Coordinator, BOD, and TC as protocols are completed. All network positions are subject to BOD approval.

Core Network Staff

Core staff is defined as permanent staff required to implement and manage all aspects and activities of the network inventory and monitoring program. Currently, three of five core positions are filled, including the Network Coordinator, Ecologist, and Data Manager. The Aquatic Ecologist role will be addressed by a cooperator in FY 2009 and will be filled in FY 2010. The Program Assistant position will be filled in FY 2009. Duties of each core position are described below.

Network Coordinator: The Network Coordinator is responsible for the overall management and supervision of the program. The coordinator consults with the MOJN BOD and TC, the Regional I&M Coordinator, and the National I&M Program Manager to establish general program direction and to develop strategies for accomplishing goals. Duties include coordination and oversight of inventory-related activities, the design, development, and implementation of the monitoring program, including development and testing of protocols, ensuring scientific rigor, etc., overseeing the development and implementation of the data management program, and ensuring communication and dissemination of program activities and results. Program management duties include formulation and management of budgets, planning, hiring and supervision of network staff, development of contracts and agreements, and preparation of annual program reports and work plans. As a biologist, the Network Coordinator also serves as project lead on Vital Signs protocol development, overseeing protocol design and testing, implementation, and data collection, analysis, and reporting for several Vital Signs protocols.

Data Manager: The Data Manager is responsible for data and information stewardship at the network. The Data Manager develops and implements the Data Management Plan and associated SOPs, which ensure long-term data quality, integrity, security, and availability to network and staff, cooperators, and other parties. The Data Manager supports program activities by designing and managing databases for inventory and monitoring projects, assisting in development of data collection forms, QA/QC procedures, and automated reports, ensuring that datasets are fully documented and validated, data are disseminated to various parties, and

Table 8.3. Proposed staffing plan for different phases of the Mojave Desert Network monitoring program. Core staff are augmented by additional positions, which meet specific needs of the Implementation and Monitoring phases.

	POSITION	GS LEVEL	STATUS	DUTY STATION	PRIMARY DUTIES	PHASE III (FY 2007-08)	IMPLEMENTATION PHASE (FY 2009-11)	MONITORING PHASE (FY 2012 ON)
Core Network Staff	Network Coordinator	12	Perm	LAME	Program development & management; monitoring implementation; staff supervision; communication.	1.0	1.0	1.0
	Data Manager	11	Perm	LAME	Oversee & coordinate data management activities.	1.0	1.0	1.0
	Ecologist	11	Perm	LAME	Monitoring design, data analysis and reporting- upland protocols		1.0	1.0
	Aquatic Ecologist	9/11	Perm/ term	MOJA/ DEVA/ LAME	Monitoring design, data analysis and reporting- WQ and water/riparian-related protocols		1.0	1.0
	Program Assistant	7	Perm/ term	LAME	Budget & agreements tracking, travel, timekeeping, records mgt., etc.		0.5	0.5
Implementation	Vegetation Ecologist[a]	9	Term	LAME	Coordinate and oversee vegetation mapping at network parks.		1.0	-
	GIS specialist	7/9	Term	LAME	Compile spatial data. Develop procedures for utilizing and disseminating spatial data		1.0	-
	Data Mining Technicians	5/6/7	Term	Various	Support basic inventories and development of monitoring protocols	4.0	3.0[b]	
Monitoring	Data Technician	5/6/7	Term	TBD	Provide GIS, database, and data management support.		-	1.0
	Biological Science Technicians	5/6/7	Term	TBD	Field data collection and data entry.		- [b]	2.0
	Physical Science Technicians	5/6/7	Term	TBD	Field data collection and data entry.		- [b]	2.0

[a] position is cost-shared between parks and network

[b] Three full time equivalent (FTE) data mining positions will be funded through FY 2009. In FY 2010, the data mining positions will be eliminated, and the network may begin acquiring biological or physical science technician positions proposed for the Monitoring Phase.

associated contracts and agreements are managed effectively. The Data Manager also manages and coordinates IT equipment and activities, maintains spatial data associated with network I&M projects, and incorporates spatial data into the network GIS.

Ecologist: The Ecologist will provide statistical and analytic support to network monitoring projects and coordinate the development and implementation of upland monitoring protocols. Accordingly, the Ecologist develops sound sample designs, analytic approaches, and inference strategies (with assistance from statistical cooperators as necessary), works with cooperators to develop protocols and associated SOPs, conducts pilot testing and protocol implementation, oversees data collection, analysis, reporting, and dissemination of project analyses and reports, and develops and manages protocol-related contracts or agreements.

Aquatic Ecologist: The Aquatic Ecologist will work with the network cooperator and park staff to develop, refine, and test protocols to address water quality, groundwater, surface water, and riparian-related Vital Signs and protocols, ensuring that protocol objectives are financially and logistically realistic. The Aquatic Ecologist will be the primary lead on implementing these protocols, ensuring data quality, project documentation and metadata, and preparing and disseminating project analyses and reports. These tasks will involve coordination with park staff and oversight of associated data collection (from the field or existing sources), including the supervision of associated technicians. This individual will be the primary technical contact for partners working on water and riparian resource issues.

Program Assistant: The Program Assistant will serve as a central contact for network staff that performs or coordinates administrative tasks, facilitates communication between network staff at different locations, and standardizes personnel procedures and practices for the network. Duties will include tracking and reporting budget status, procurement, timekeeping, travel management, agreements tracking, property inventory, office logistics, meeting and workshop arrangements, and filing network records and reports. This position will either be shared with another network or park program or will address other duties or roles within the MOJN I&M Program.

Additional Network Staff for the Implementation Phase

During this phase, several positions are needed to support the completion of basic inventories, development of monitoring protocols, and establishment of spatial data management infrastructure, procedures, and policies that will be maintained in the long-term by the Data Manager. These positions are described below. The Data Mining Technician positions are currently filled, and the GIS Specialist will be hired in FY 2009. Further discussions are required to determine when the Vegetation Ecologist position will be filled and how the position will be funded. Optimally, these positions will end upon completion of their respective projects (e.g., data mining), which should correspond with the start of full implementation, but positions may be terminated earlier in response to budget limitations.

Vegetation Ecologist: Vegetation maps play an important role in park management activities and decisions and in the development of the Vital Signs monitoring program. Vegetation mapping of the mandated 270 park units is coordinated and funded through the national Vegetation Mapping Program, and only one of the network's large parks (JOTR) has been addressed to date. Due to the number of large parks in the network and the diversity of vegetation they encompass, vegetation mapping projects will be complex and will require extensive coordination and oversight. The MOJN Vegetation Ecologist will assist parks in coordinating and accomplishing vegetation maps in an efficient manner and with a network-wide perspective. The cost for this position will be shared between the network and network parks. The Vegetation Ecologist will work with

network, park, and national program staff to develop a realistic strategy and timeline for vegetation mapping at the network's numerous large parks. Based on this mutually agreed-upon work plan, this individual will coordinate and oversee vegetation mapping activities at various parks, including conducting planning meetings, coordinating activities with park staff and cooperators, developing and managing contracts and agreements on project tasks (e.g., classification, photo-interpretation, etc.), hiring technicians and overseeing field work as needed, developing project budgets and work plans, and preparing annual reports and presentations.

GIS Specialist: The GIS specialist will compile and refine relevant park spatial data, including that for the 12 basic inventories and other network-sponsored inventories. This individual will work with the data manager to develop infrastructure, procedures, and policies for utilizing and disseminating spatial data from inventory and monitoring activities, work with the network coordinator and other network staff to support spatial aspects of protocol development (e.g., sample frame delineation and site selection), and work with network staff and cooperators to develop a landscape monitoring protocol.

Data Mining Technicians: The Data Mining Technicians conduct data mining to support or complete inventories and to support protocols undergoing development. Due to the park-specific nature of their duties, these individuals are duty-stationed at parks rather than at the network office at LAME. Data Miners have documented park references in NatureBib, populated NPSpecies with links to references, and located and entered metadata on datasets pertinent to network Vital Signs, protocol development, vegetation mapping, and other baseline inventories. Data mining technicians will complete duties related to these tasks in FY 2009.

Additional Network Staff for the Monitoring Phase

For the Monitoring Phase (after all protocols have been fully implemented), the network will require several positions to conduct data collection and management. By designating these positions as temporary, the network retains the flexibility to adjust the number, type, and duration of positions, associated costs, and activities addressed. These positions are described below.

Data Technician: The Data Technician will provide GIS, database, and other data management support to the Data Manager, particularly in developing and implementing standard operating procedures associated with monitoring protocols. The Data Technician will also conduct data mining associated with inventories and to support protocols still undergoing development.

Biological and Physical Science Technicians: We present an approach that utilizes several technicians year-round for data collection during the field season and other important duties during the off-season (data entry and mining). These technicians' primary duties will be field data collection, data entry, and data verification according to methods described in monitoring protocols. Where possible, data collection periods for different protocols will be staggered such that technicians could collect data for two or more protocols each year. Outside the field season, two or more technicians would perform data entry and management, equipment maintenance, and data mining for inventory projects not completed during the Implementation Phase. In addition to addressing data management and mining for the network and associated parks, maintaining at least two or more technicians year-round would also promote consistency in field staff and protocol implementation among years and avoid problems associated with attracting and hiring seasonals on an annual basis. It is difficult to predict the number of positions required prior to completion of monitoring protocols, but due to the magnitude of network parks and associated field work, it is likely that more field assistance will be required than the network can afford. Ultimately, the number and type of positions (seasonal or term), duty stations, and funding source (network, park, and

other) will need to be determined by the Network Coordinator, BOD, and TC as protocols are developed. Additional methods for acquiring or supplementing field technicians are discussed below.

8.5.2 Role of Park Staff and Cooperators

Park staff involvement with the I&M Program is integral to its success. Park staff involvement in protocol development is critical to ensure that monitoring data are relevant to park needs, and we have incorporated salary costs for several pay periods of park staff time in FY 2009 (see Chapter 10). In addition, the costs of implementing monitoring protocols across the vast areas, rugged terrain, and remote landscapes of MOJN parks will likely be very high. If protocol implementation relies solely on I&M funds, the network may be required to scale back protocol objectives, the number of sites sampled, or drop lower priority protocols. With the contribution of park staff time (both professional and technical) to protocol implementation, the network will be able to achieve a greater proportion of its monitoring objectives or implement a larger number of protocols. Additional benefits of park staff involvement include greater program visibility at parks, park staff with vested interests in monitoring results, greater interaction between network and park staff, and greater integration with park activities. Recognizing these benefits, the network must also acknowledge the potential risk that park leadership, priorities, and budgets may change and park staff may be re-directed away from monitoring activities. Thus, the monitoring program must remain flexible enough to accommodate changes in park personnel and contributions while maintaining as much consistency and continuity as possible. The nature and magnitude of park contributions to protocol development and implementation will be discussed among the Network Coordinator, BOD, and TC in FY 2009.

Cooperators are also critical to the development and implementation of monitoring protocols, providing high levels of knowledge and expertise to specific projects and network activities. The network has engaged a variety of university and federal agency cooperators to provide support on conceptual models, protocol development, statistical design, and data management. Cooperative relationships with other networks, universities, nonprofit organizations, and federal agencies will be explored to develop additional protocols in FY 2009 and FY 2010 and to meet short- or long-term staffing requirements. In addition, cooperative agreements and partnerships will be explored to provide or supplement field assistance during the Monitoring Phase.

8.6 Integration with Park Operations

Developing and implementing the Vital Signs monitoring program at MOJN network parks will require continued collaboration and cooperation with multiple park divisions and programs. Resource management staff have been involved in development of the MOJN program from early in its inception. Park biologists, botanists, physical scientists, hydrologists, and key management staff participated in critical park and network workshops (e.g., geo-scoping, water resources, and Vital Signs selection workshops) and contributed to the development and evaluation of conceptual models and the drafting of Protocol Development Summaries. The network's Science Advisor and park professional staff (physical and biological) will continue to play important roles in protocol development and implementation.

The network will also work with park staff to resolve numerous logistical issues associated with protocol implementation (e.g., hiring, housing, and supervising field crews). We will work closely with park staff to make arrangements to sample sites located in remote areas, which may constitute a large number of sites. We will also work closely with parks and local Park Safety Officers to participate in safety programs and training–including backcountry communication procedures, first aid, and development of job hazard analyses for

each Vital Signs protocol. As part of the protocol development process, it will be important for protocol working groups to identify areas where integration with park operations is critical to ensure effective and efficient implementation. Park housing will be needed for field crews. This will require early communication with park administrative and maintenance staff who manage housing and other park divisions (that compete each year for available housing).

Another key area of integration will be with the parks' Divisions of Interpretation. In addition to using our website (inter- and intranet), newsletters, fact sheets, and brochures to share information, we will work with the Interpretive Divisions, Natural Resources Program Center (NRPC) Education and Outreach Division, and associated cooperators to develop a Science Communication Plan that outlines effective strategies for communicating monitoring results to diverse audiences.

All MOJN staff members play important roles in communication and integration with park staff. As best possible, MOJN staff will periodically participate in park meetings (e.g., staff meetings, park workshops, strategic planning, and lecture series) to maintain contact with park staff and involvement with park activities. To foster awareness of network activities, and program results, network staff will also periodically provide presentations on the I&M Program, results of Vital Signs monitoring, and data management, and provide training and assistance as needed to effectively use I&M products, tools, and databases.

Partnerships will aid the MOJN in meetings its monitoring goals. Cooperators from University of Nevada-Reno discuss collaborative opportunities with park and network staff at Grapevine Springs, Death Valley National Park. Photo courtesy Stacy Holt.

8.7 Partnerships

The MOJN has partnered with other federal agencies, universities, and other networks to initiate the development of the Vital Signs monitoring program and plans additional partnerships to develop and test remaining protocols in FY 2009 and FY 2010. Current or recent partnerships are as follows:

Cooperative Agreements (CESU)

- University of Nevada—Las Vegas (Dr. Soukup) - To develop soils component of the Integrated Upland monitoring protocol.
- University of Nevada—Las Vegas (Dr. Palmer)- To design databases for inventory and monitoring data and evaluate spatial data for the network's GIS program.
- University of Nevada—Las Vegas (Dr. Abella)- To develop the invasive/exotic plant monitoring protocol.
- Desert Research Institute (Dr. Sada)—To develop springs inventory protocols (Level I & II) and conduct Level I springs inventory protocol at four network parks.
- Great Basin Institute (Dr. Keir) — To provide field assistance in conducting Level I springs inventory protocol at four network parks.
- University of Idaho (Dr. Caudill)— To develop and implement the MOJN Water Quality Monitoring Plan and two water-related monitoring protocols (Groundwater and Springs; Streams and Lakes).
- University of Idaho (Dr. Steinhorst)—A joint CESU agreement with three other PWR networks to provide statistical review and support for

Table 8.4. Description and schedule for various review processes in the Mojave Desert Network monitoring program.

REVIEW TYPE	SCHEDULE	AUTHOR OR LEAD	PARTIES INVOLVED	OBJECTIVES
Annual Administrative Report and Work Plan	Annual	Network Coordinator & Network Staff	Board of Directors, Technical Committee WASO I&M Program	Provide yearly accountability for program. Report on accomplishments and explain goals and projects for the next fiscal year.
3-year Start-up Review	FY 2012	WASO Monitoring Program Lead	WASO Monitoring Program Lead and Review Panel	Evaluate operational and administrative aspects of program to determine whether program practices, procedures, and timelines are effective, realistic, and sustainable.
5-year Periodic Program Review	5-year intervals, beginning in 2017	Network Coordinator & Network Staff	WASO I&M Program, Board of Directors, Technical Committee	Evaluate administrative and technical aspects of program for efficacy, scientific rigor, integration, and success in achieving programmatic goals. Involves a synthesis of data collected to date and an evaluation of program structure and function.
Protocol Reviews	After completion of one monitoring cycle	MOJN protocol lead and cooperators	Internal and external subject matter experts, Network Coordinator, Technical Committee	Evaluate implementation of protocols, evaluate scientific and technical merits of protocols, evaluate information management and management relevance, and make recommendations for improvement.

protocol and monitoring plan development.

- University of Idaho (Dr. Wright)— To provide support on various aspects of the monitoring plan.
- University of Washington (Dr. Agee) — A joint CESU agreement with the Regional Coordinator and other PWR networks to coordinate and conduct peer-review of network protocols and to provide technical and administrative assistance to the network.
- Colorado State University (Dr. Bruyere) — A joint CESU agreement with NRPC Education and Outreach and other networks to develop a science communication plan for MOJN.

Interagency Agreements

- U.S.D.A.—Agricultural Research Service- Jornada Experimental Range- To evaluate the use of high-resolution aerial photography for estimating vegetation cover and composition and augmenting ground-based sampling of these parameters.
- U.S. Geological Survey-Western Regional Science Center and Western Ecological Research Center—To develop and write conceptual models and assist in development of Fire and Fuel Dynamics and other protocols.
- U.S. Forest Service-Rocky Mountain Research Station —To develop vegetation component of Integrated Upland and Riparian Vegetation protocols.
- Bureau of Reclamation— A joint agreement with the national vegetation mapping program to 1) prepare a vegetation mapping workplan for the MOJN and 2) develop a vegetation map at MANZ.
- Bureau of Reclamation—To provide short-term office space to network staff.

8.8 Program Review

To ensure long-term effectiveness of the monitoring program, the network will periodically review different aspects of the program (administrative, technical, and operational) and incorporate the resulting recommendations. In Table 8.4 is a summary of the formal review processes that MOJN plans to conduct, their objectives, involved parties, and corresponding schedule.

Each year, the network prepares the AARWP, which reports accomplishments and expenditures for the previous fiscal year and proposes objectives, activities, and a budget for the coming fiscal year. The AARWP is an annual method for tracking progress, promoting

accountability, and communicating activities and accomplishments to the network (BOD & TC) and the national program. Cumulatively, the network's AARWPs provide a long-term administrative record and history. The AARWP is prepared by the Network Coordinator and staff, is reviewed by the BOD, TC, and Regional Coordinator, and is signed by the Network Coordinator, Regional Coordinator, and BOD Chair for submission to WASO.

In FY 2012, the network will undergo a three-year start-up review to evaluate the operational and administrative aspects of the monitoring program and ensure long-term success and sustainability. This initial review is conducted by the WASO Monitoring Program Lead, is intended to be a relatively informal assessment of monitoring program objectives, procedures, timelines, and trajectories, and will provide recommendations for programmatic adjustments.

After the three-year start-up review, the MOJN monitoring program will undergo periodic program reviews on a five-year schedule. This review will evaluate administrative and technical aspects of the program, including program effectiveness, accountability, structure and function, scientific rigor of protocols and associated data, integration with park activities, and effectiveness of outreach and partnership activities.

As the building blocks of the network's monitoring program, individual protocols will also undergo review. Once each protocol has been implemented for one entire monitoring cycle (i.e., full rotation through all panels), the network will review the scientific, technical, and administrative aspects of the protocol and its implementation. The protocol lead and cooperators will provide materials for review by external subject matter experts, park professional and management staff, and the TC. This review will evaluate whether protocol objectives are being met, whether data collected or technical aspects of field implementation suggest modification of methods or exploration of new techniques, and whether information is appropriately managed and reported.

Chapter 9: Schedule

This chapter describes the MOJN timeline for developing and implementing Vital Signs protocols across network parks. It also summarizes the frequency and timing of monitoring for each vital sign and its associated protocol.

9.1 Protocol Development

For most protocols, development includes refining objectives, developing sampling designs, testing methods through pilot studies, and preparation of a protocol narrative and SOPs for review. Protocol developers must conform to WASO guidance on protocol format and content. Each protocol will undergo scientific peer-review and approval. The review process was developed by the PWR Regional I&M Coordinator and is coordinated by Dr. Jim Agee, a cooperator at University of Washington. The following provides a general overview of the network protocol development schedule. The network proposes to develop 10 protocols in the next 3-5 years to address 17 Vital Signs. The proposed schedule (Table 9.1) has been devised at a pace manageable by network staff, which includes the recent addition of a network ecologist in late FY 2008. In addition to this general summary, more detailed information regarding timelines and the current status of individual protocols can be found in Appendix I.

In FY 2007, three protocols were initiated under guidance of the Network Coordinator and a university cooperator, Dr. Christopher Caudill (University of Idaho). These include the Integrated Upland, Groundwater and Springs, and Streams and Lakes protocols. Development of two additional protocols, Air Quality and Invasive/Exotic Plants, was initiated in FY 2008 (Table 9.1). The network will begin development of three additional protocols in FY 2009, including Weather and Climate, Riparian Vegetation, and Fire and Fuel Dynamics. The remaining protocols, Landscape Dynamics and Riparian Birds, will be initiated in FY 2010 (Table 9.1). Pending the completion of the 10 protocols and/or the availability of staff, funding, and opportunities for collaboration, development of the remaining 3 Vital Signs (Small Mammals, Reptiles, At-Risk Populations) may be initiated in FY 2011 or beyond.

MOJN protocol development updates can be found online at the network webpage. Visit ***http://science.nature.nps.gov/im/units/MOJN/index.cfm*** *for more info!*

Valley-mountain pair in the northern Mojave desert. Photo courtesy D.M. Miller, USGS.

Table 9.1. Proposed schedule for protocol development and implementation for the Mojave Desert Network.

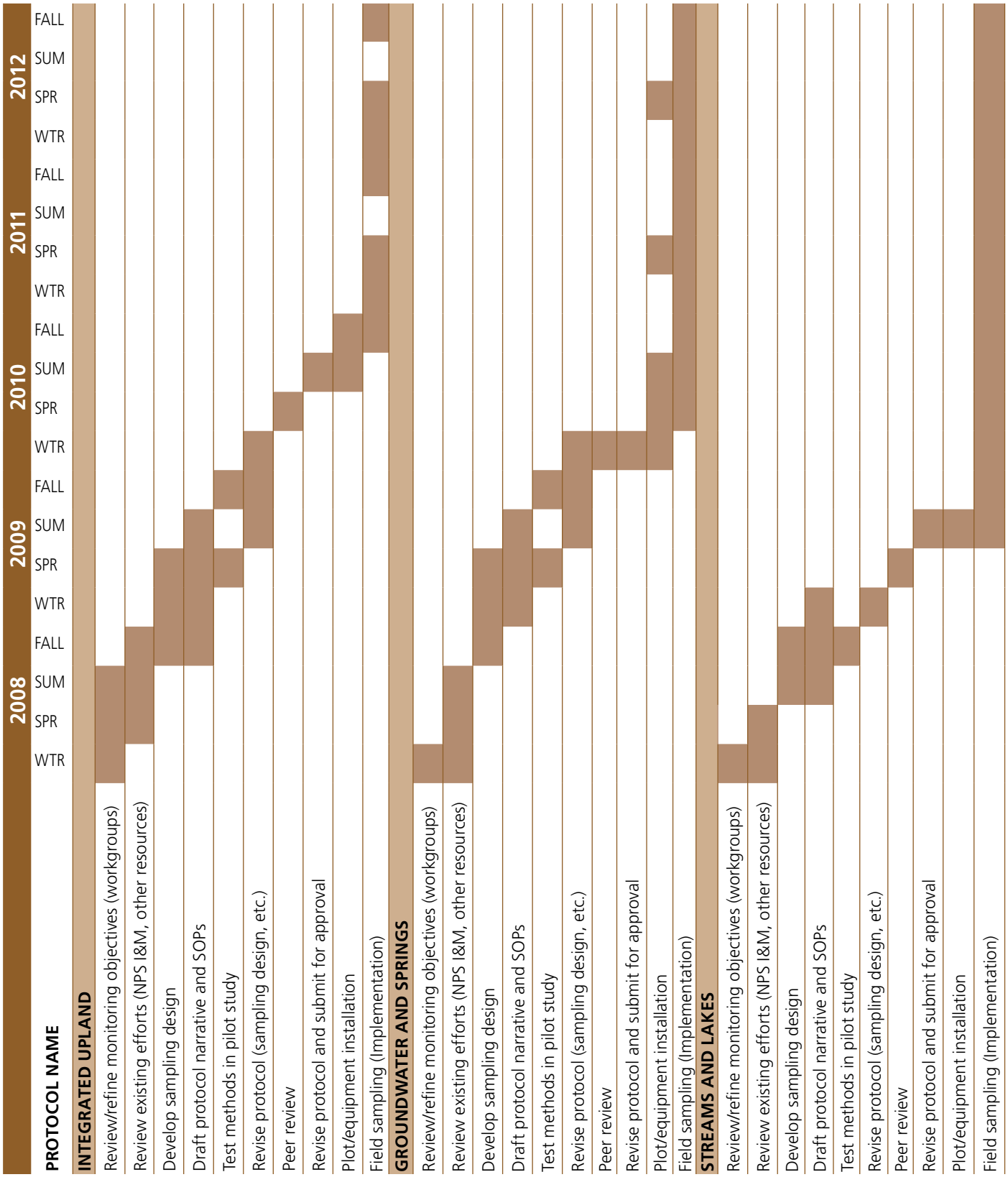


Table 9.1 Proposed schedule for protocol development and implementation for the Mojave Desert Network (continued).

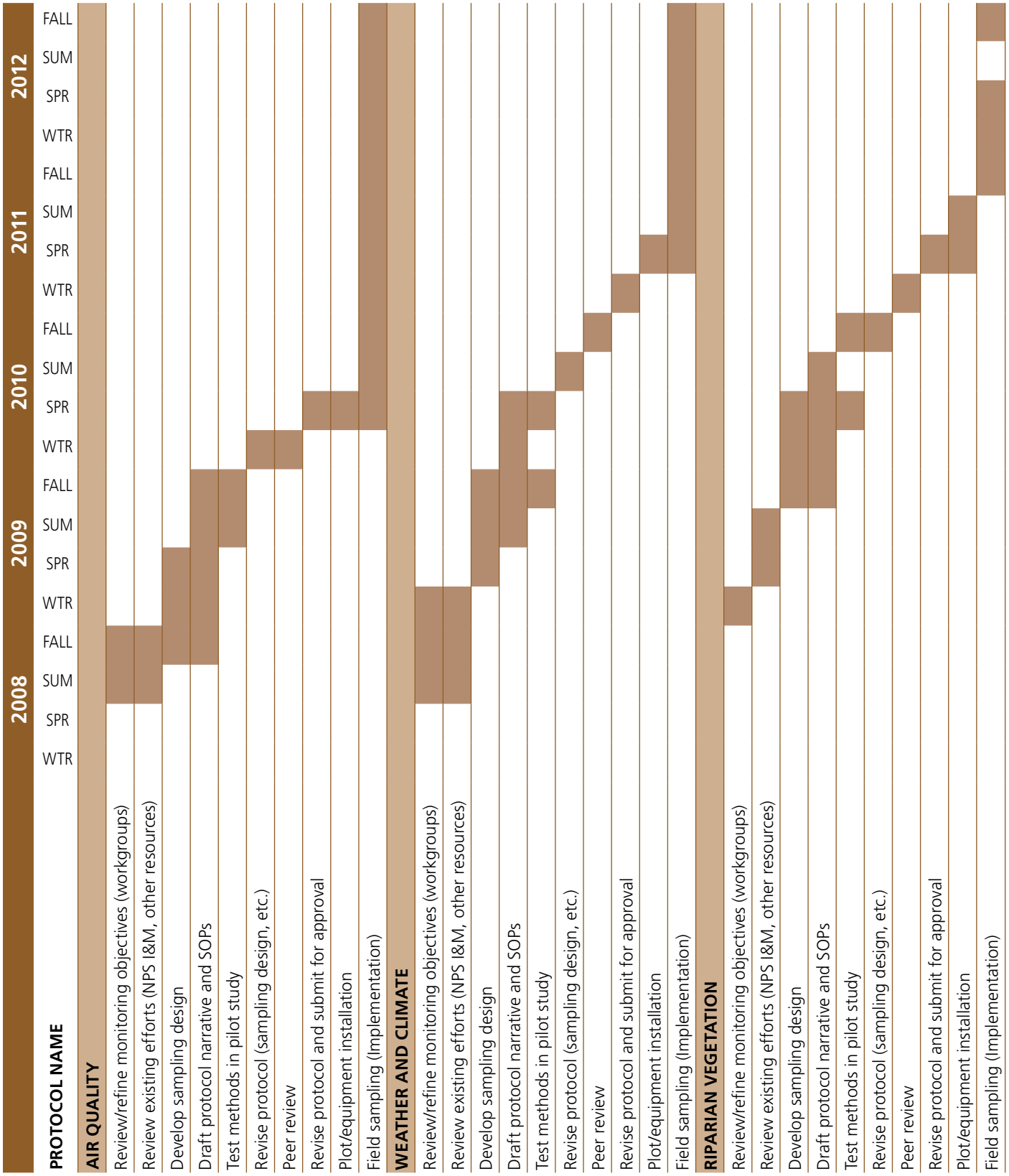


Table 9.1 Proposed schedule for protocol development and implementation for the Mojave Desert Network (continued).

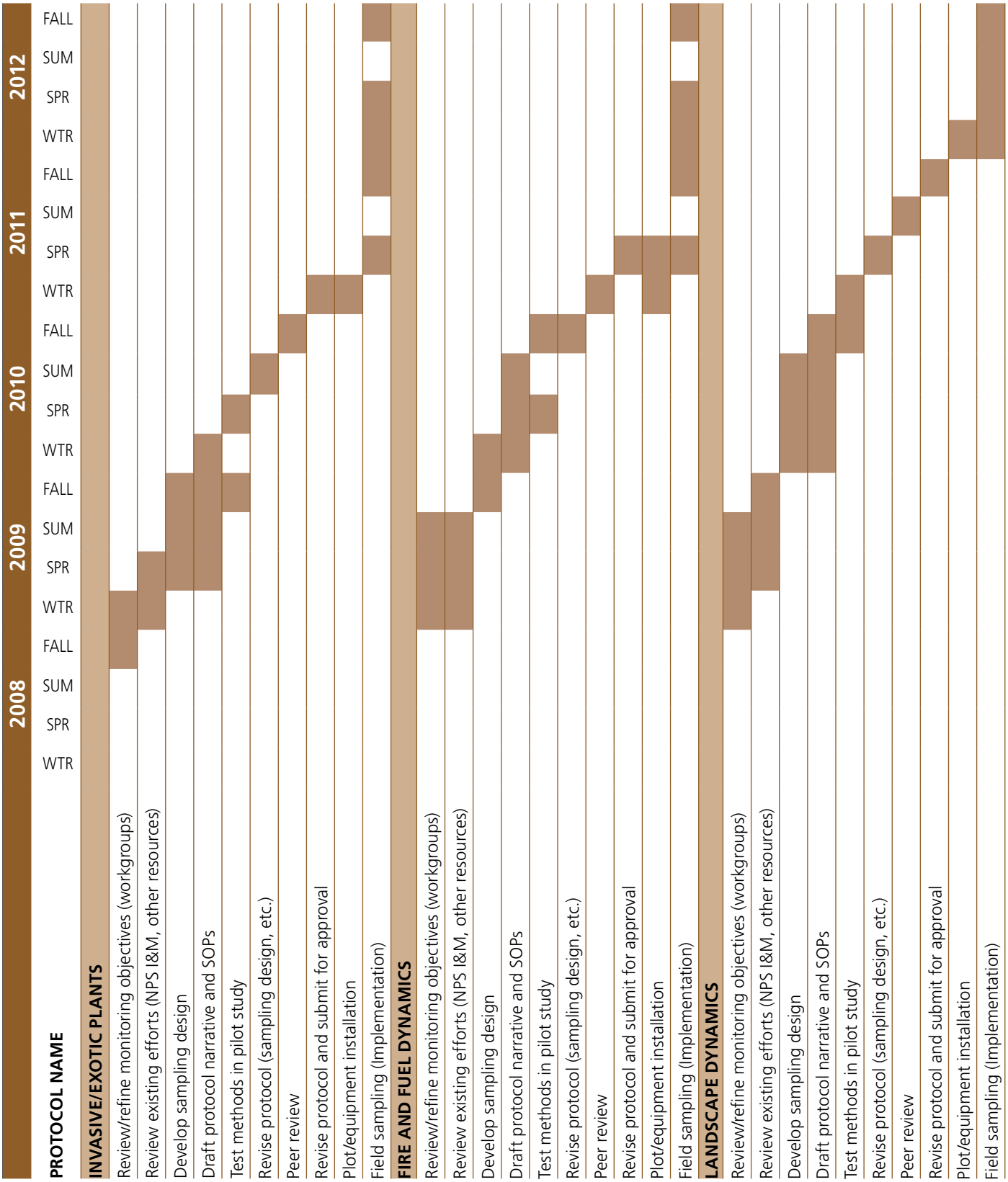


Table 9.1 Proposed schedule for protocol development and implementation for the Mojave Desert Network (continued).

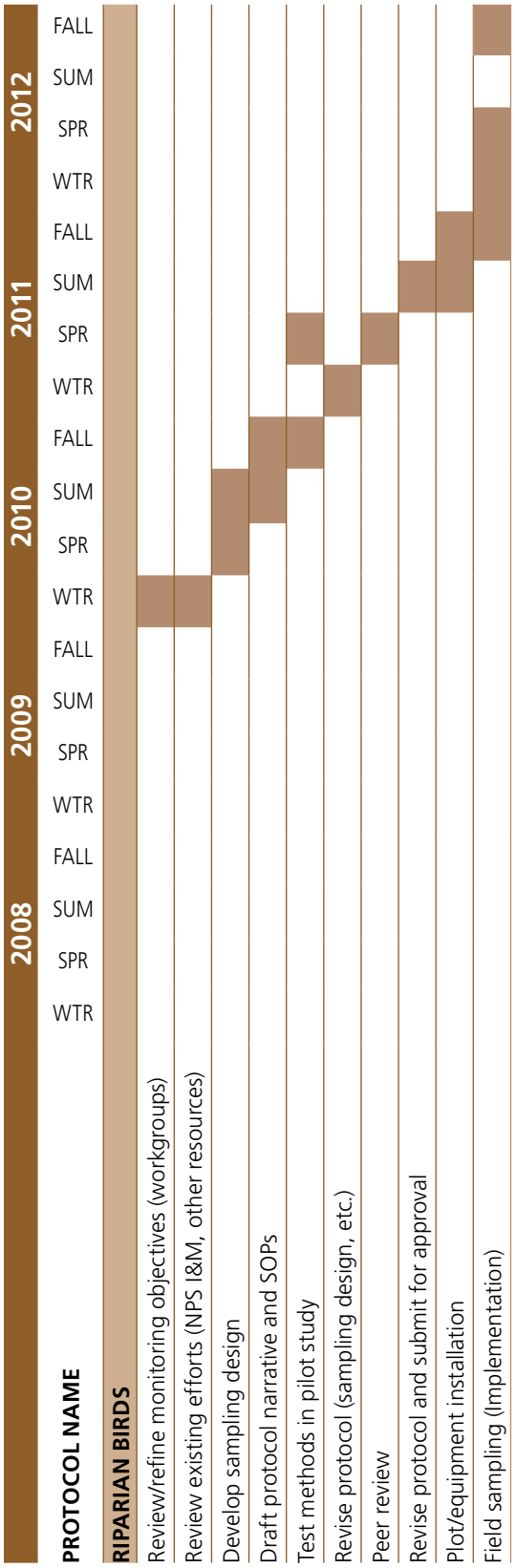


Table 9.2. Frequency, timing, and type of sampling for the 10 protocols addressing 17 Vital Signs for the Mojave Desert Network parks.

PROTOCOL	MODULE	DATA COLLECTION METHOD	MONTH											
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Integrated Upland	Vegetation	Field			S	S	S				S	S	S	
	Soils component	Field			S	S	S				S	S	S	
Riparian Vegetation		Field			S	S	S				S	S		
Riparian Birds		Field			S	S	S							
Invasive/Exotic Plants	Early detection	Field	I			I	I				I	I	I	I
	Status & trends	Field			I	I					I	I		
Groundwater & Springs	Groundwater level	Automated	I	I	I	I	I	I	I	I	I	I	I	I
	Spring discharge	Automated	I	I	I	I	I	I	I	I	I	I	I	I
	Water chemistry	Field	I			I			I			I		
	Aquatic biota	Field				I						I		
Streams and Lakes	Stream water chemistry	Field								I				
	Stream water chemistry	Automated					I	I	I	I	I			
	Stream discharge	Automated	I	I	I	I	I	I	I	I	I	I	I	I
	Lake water level	Automated	I	I	I	I	I	I	I	I	I	I	I	I
	Lake water chemistry	Automated						I		I				
	Stream macroinvertebrates	Field								I				
Air Quality		Automated	I	I	I	I	I	I	I	I	I	I	I	I
Weather & Climate		Automated	I	I	I	I	I	I	I	I	I	I	I	I
Fire & Fuel Dynamics		TBD						TBD						
Landscape Dynamics		Remote Sensing						TBD						

TBD = to be determined. Site membership design: I = index sites, S = probabilistic sample.

9.2 Sampling Frequency and Timing

Frequency and timing of sampling varies by protocol (Table 9.2). Some data collection will occur continuously (e.g., spring discharge, air quality parameters, etc.) and some will occur at specific periods during the year (e.g., vegetation sampling, riparian bird monitoring, etc.). Field work will typically occur during spring and fall. Summer field work will be limited because biological activity is at a minimum during these hot summer months and because of the logistical and safety issues associated with working in extreme summer temperatures.

Chapter 10: Budget

This chapter presents the budget for the MOJN Vital Signs Monitoring Program for FY 2009, the network's first year of operation after approval of the final Monitoring Plan. We first present the FY 2009 network budget in the format used for the Annual Administrative Report and Work Plan (Table 10.1), and then provide the same budget in greater detail and with an estimate of resources devoted to information and data management (Table 10.2).

In FY 2008, MOJN received $860,000 from the National I&M Vital Signs Monitoring Program and $76,900 from the NPS Water Resources Division. These values represent the net funding after 1) an increase in Vital Signs Monitoring Program funding by $20,600 for cost of living increases and 2) a reduction of 1.56% due to a congressionally-imposed Across the Board (ATB) rescission. Combined, these funding sources serve as base funds with which the network Vital Signs and water quality monitoring programs will be developed and implemented. We expect these amounts to remain relatively fixed, except for periodic cost of living adjustments for federal employees and potential ATB rescissions. Vital Signs Monitoring Program funds are held in Washington Office base accounts and are transferred annually through the Pacific West Regional Office to LAME, the network's host park. All funds are managed by the MOJN Network Coordinator under the auspices of the BOD, with assistance from the Budget staff at LAME. The BOD approves the Annual Work Plan with input from the Network Coordinator and TC. The work plan directs expenditure of funds to projects, parks, and offices.

In FY 2009, the network will enter the Implementation Phase, defined in Chapter 8 as the period when the network will be developing and implementing monitoring protocols (FY 2009-11), developing data management infrastructure, and completing inventories that support protocol development. These activities will be accomplished through a combination of core network staff, temporary network staff, and external cooperators (via CESU cooperative agreements and interagency agreements), the costs of which constitute a majority of the program budget (Table 10.1 and 10.2). Costs for core network staff are approximately 31% in FY 2009. After the one remaining core network position (aquatic ecologist) is hired, core network staff will cost approximately 37%. This percentage will increase gradually over time due to cost of living and step increases. An additional 29% of the program budget is dedicated to temporary personnel who will support activities associated with protocol development, testing, and field implementation. Upon entering the Monitoring Phase (full implementation of all protocols), temporary personnel requirements will change from protocol development and inventory activity to protocol implementation (field data collection, data entry, etc.). The staffing plan in Chapter 8 presents one approach to achieving field data collection (several MOJN-funded technicians), but additional field assistance will likely be required and the network will explore all staffing options for implementing protocols (MOJN temporary staff, park staff, partnerships, cooperative agreements, or some combination) with the MOJN BOD and TC as protocols near completion.

In FY 2009, approximately 20% of the program budget will be allocated to external cooperators or contractors to provide assistance on protocol development and data management (Table 10.1). Through these agreements and contracts, we will obtain technical and statistical support as we initiate or continue development of protocols (Table 10.2). Operations, equipment, and travel expenses during the Implementation Phase (Table 10.1 and 10.2) will be allocated to startup equipment purchases, general administrative costs, General Services Administration (GSA) vehicles, and travel related to meetings, visiting parks, training, and protocol testing. These categories of expenses will increase as protocols are implemented (equipment costs, logistics support, field travel,

Each year, the MOJN Board of Directors approves an Annual Work Plan, which is prepared by the Network Coordinator with input from network staff and the Technical Committee.

Table 10.1. Summary budget for the Mojave Desert Network Vital Signs Monitoring Program in the first year of implementation (FY 2009).

MOJN VITAL SIGNS MONITORING BUDGET	FY 2009	
INCOME		
Vital Signs Monitoring	$860,000	
Water Resources Division	$76,900	
Funds Available	$936,900	
	Amount	% by Budget Category
EXPENDITURES		
Personnel- Core	$285,937	31%
Personnel- Temporary	$268,268	29%
Cooperative Agreements	$188,217	20%
Contracts	$45,500	5%
Operations/Equipment	$100,528	10%
Travel	$48,450	5%
Total Expenditures	$936,900	

etc.). Relative to other networks, these expenses may constitute a larger proportion of the program budget due to the vast, remote, and rugged landscapes across which the protocols will be implemented.

Guidelines for developing a monitoring program suggest that approximately 30% of the overall budget should be allocated to information/data management to ensure data quality and longevity and to facilitate communication of monitoring results. In Table 10.2, we provide the percent of time that each network position or cooperator is expected to devote to information/data management in FY 2009. Approximately 43% of the network budget will be used towards data and information management during the Implementation Phase. In the Monitoring Phase, data management-related staff supporting protocol and program development will be reduced, and monitoring-related data management duties will be performed by core network staff, temporary field-going staff, and the data technician.

Table 10.2. Detailed budget for the Mojave Desert Network Vital Signs Monitoring Program in the first year of implementation after review and approval of the monitoring plan.

MOJN VITAL SIGNS MONITORING BUDGET			FY 2009	
INCOME				
Vital Signs Monitoring		$860,000		
Water Resources Division		$76,900		
	Total Income	**$936,900**		
EXPENDITURES				
CORE PERSONNEL	**GS LEVEL**	**AMOUNT**	**AMOUNT ALLOCATED TO DATA MANAGEMENT**	
Network Coordinator	12	$101,054	5%	$ 5,053
Data Manager	11	$90,177	100%	$ 90,177
Ecologist	11	$67,791	5%	$ 3,390
Program Assistant (1/2 FTE)	7	$26,915	10%	$ 2,692
TEMPORARY PERSONNEL OR ASSISTANCE				
Various park staff (e.g., Science Advisor; 2PP)	various	$9,000		
Vegetation mapping coordination (4mo)	7	$18,634	20%	$ 3,727
GIS Specialist	9	$58,623	100%	$ 58,623
Data Mining Technicians (3)	5/6/7	$177,011	100%	$177,011
Misc. personnel costs		$5,000		
	Subtotal	**$554,205**		**$340,671**
COOPERATIVE AGREEMENTS				
Integrated Upland Protocol		$40,000	20%	$ 8,000
Groundwater and Springs Protocol		$25,000	20%	$ 5,000
Invasive/Exotic Plants Protocol		$73,217	20%	$ 14,643
Science Communication Plan- development		$15,000	25%	$ 3,750
Remote Sensing Techniques Development		$35,000	20%	$ 7,000
	Subtotal	**$188,217**		**$ 38,393**
CONTRACTS				
SCA intern support- housing		$13,000		
Water chemistry & macroinvertebrate analyses		$20,000		
Office maintenance		$5,000		
Vital Signs Monitoring Plan—formatting & printing		$7,500		
	Subtotal	**$45,500**		
OPERATIONS/EQUIPMENT				
Streams and Lakes monitoring equipment		$ 12,150		
Groundwater and Springs monitoring equipment		$14,750		
Integrated Upland monitoring field equipment		$12,000		
GSA vehicles		$7,000		
LAME Administrative Support		$10,000		
General supplies and furniture		$13,628		
Network – service agreements & license upgrades		$10,000		$ 10,000
Computers, hardware, & software		$14,000		$ 14,000
IT Assessment		$7,000		
	Subtotal	**$100,528**		**$ 24,000**
TRAVEL				
Network staff- meetings, conferences, & training		$37,200		
Water quality monitoring-related meetings		$4,000		
Park staff—network-related meetings & conferences		$7,250		
	Subtotal	**$48,450**		
			Data Management	
	Total Expenditures	**$936,900**	**43%**	**$403,064**

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GLOSSARY OF TERMS AND CONCEPTS

Alluvial fan—an outspread, gently sloping mass of alluvium deposited by a stream, especially in an arid region where a stream issues from a narrow canyon onto a plain or valley floor.

Anthropogenic effects—are caused by or attributed to humans. As used here, they are human influenced factors that cause stress in natural systems.

Attributes—any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term indicator is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003; http://science.nature.nps.gov/im/monitor/Glossary.htm).

Bajada—a broad, gently inclined, detrital surface extending from the base of mountain ranges into an in-land basin.

Biological integrity—the ability to maintain and support a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Biome—a climax community that characterizes a particular natural region.

Biota—the animal and plant life of a region.

Carbonate rock—rock formed from the carbonates of calcium, magnesium, and/or iron (e.g., limestone or dolomite).

Conceptual models—purposeful representations of reality that provide a mental picture of how something works to communicate that explanation to others.

Degradation—an anthropogenic reduction in the capacity of a particular ecosystem or ecosystem component to perform desired ecosystem functions (e.g., degraded capacity for conserving soil and water resources). Human actions may degrade desired ecosystem functions directly, or they may do so indirectly by damaging the capacity of ecosystem functions to resist or recover from natural disturbances and/or anthropogenic stressors (derived from concepts of Whisenant 1999; Archer and Stokes 2000; Whitford 2002).

Disturbance—"...any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985:7). In relation to monitoring, disturbances are considered to be ecological factors that are within the evolutionary history of the ecosystem (e.g., drought). These are differentiated from anthropogenic factors that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

Driver—The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Ecological Monitoring Framework—is a National Park Service systems-based, hierarchical outline that facilitates comparisons of vital signs among parks, networks, and other programs.

Ecological integrity—a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes (http://science.nature.nps.gov/im/monitor/Glossary.htm).

Ecoregion—an area over which the climate is sufficiently uniform to permit development of similar ecosystems on sites having similar properties. Ecoregions contain many landscapes with different spatial patterns of ecosystems.

Ecosystem—a spatially explicit unit of the Earth that includes all of the

organisms, along with all components of the abiotic environment within its boundaries (Likens 1992, cited by Christensen et al.1996:670).

Ecosystem functioning—the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. Includes many ecosystem processes such as primary production, trophic transfer from plants to animals, nutrient cycling, water dynamics and heat transfer. In a broad sense, ecosystem functioning includes two components: ecosystem resource dynamics and ecosystem stability (Díaz and Cabido 2001).

Ecosystem health—a metaphor pertaining to the assessment and monitoring of ecosystem structure, function, and resilience in relation to the notion of ecosystem "sustainability" (following Rapport 1998; Costanza et al. 1998). A healthy ecosystem is sustainable (see *Sustainable ecosystem*, below).

Ecosystem integrity—see *ecological integrity*.

Ecosystem management—the process of land-use decision making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Edaphic—related to or caused by particular soil conditions, as of texture or drainage, rather than by physiographic or climate factors.

Endemic species—any species naturally confined to a particular area or region.

Endolithic—within the soil or rock layer.

Eolian—pertaining to the wind, esp. said of such deposits as loess and dune sand.

Equilibrium—a condition of balance between two opposing forces.

Evapotranspiration—the portion of precipitation returned to the area through evaporation and transpiration.

Focal resources—park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes, such as deposition rates of nitrates and sulfates in certain parks; or they may be a species that is harvested, endemic, alien, or has protected status.

Focal species / organisms—species and/or organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species and/or organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003). Encompasses concepts of keystone species, umbrella species, and ecosystem engineers.

Functional groups—groups of species that have similar effects on ecosystem processes (Chapin et al. 1996)—frequently applied interchangeably with *functional types*.

Functional types –sets of organisms sharing similar responses to environmental factors such as temperature, resource availability, and disturbance (= functional *response* types) and/or similar effects on ecosystem functions such as productivity, nutrient cycling, flammability, and resistance / resilience (= functional *effect* types) (Díaz and Cabido 2001).

Generalized Random-Tessellation Stratified (GRTS)—allows for a spatially-balanced random draw of sample units with variable inclusion

probabilities and an ordered list of sample units that can support additions and deletions of sample units while retaining spatial balance.

Genotype—the genetic constitution, latent or expressed, of an organism, the sum total of all genes present in an organism.

Geomorphic—pertaining to the shape of the earth or its surface features.

Hydrologic function (lotic and lentic systems)—capacity of an area to: dissipate energies associated with (1) high stream flow (lotic); or (2) wind action, wave action, and overland flow (lentic); thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and groundwater recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; support greater biodiversity (Prichard et al. 1998).

Hydrologic function (upland systems/soils)—capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).

Indicators—a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system (Noon 2003; http://science.nature.nps.gov/im/monitor/Glossary.htm).

Indicators of ecosystem health—measurable attributes of the environment (biotic or a biotic) that provides insights regarding (1) the functioning status of one or more key ecosystem processes, (2) the status of ecosystem properties that are clearly related to these ecosystem processes, and/or (3) the capacity of ecosystem processes or properties to resist or recover from natural disturbances and/or anthropogenic stressors (modified from Whitford 1998). In the context of ecosystem health, key ecosystem processes and properties are those that are closely associated with the capacity of the ecosystem to maintain its characteristic structural and functional atributtes over time (including natural variability).

Inventory—an extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Karst—an area of limestone formations characterized by sinks, ravines, and underground streams.

Landscape—a spatially structured mosaic of different types of ecosystems interconnected by flows of materials (e.g., water, sediments), energy, and organisms.

Lentic—referring to standing freshwater habitats, such as ponds and lakes.

Lithology —study of the physical characteristics of rocks, in particular, their color, mineralogic composition, and grain size.

Lotic—referring to running freshwater habitats.

Measures—specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all measures of water chemistry (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Membership design –Describes the method by which members of the population are assigned to panels (McDonald 2003).

Metadata—Data about data. Represents the set of instructions or documentation that describe the content, context, quality, structure, and accessibility of a data set (Michener et al. 1997).

Microclimate—A local atmospheric zone where the climate differs from the surrounding area (Wikipedia).

Monitoring—collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Natural variability—the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal (Landres et al. 1999).

Orographic—of or pertaining to mountains or mountain ranges.

Panel –A group of sample units that will always be sampled during the same sampling occasion or time period (MacDonald 2003).

Pediment—a broad gently sloping erosion surface or plain of relief, typically developed by running water, in an arid region at the base of an abrupt and receding mountain front.

Pedogenesis—the process of soil formation.

Phenology—term referring to the timing of an organisms lifecycle (e.g., producing flowers) only with certain periods of light.

Phreatophytes—a plant species which extends its roots into the saturated zone of the water table.

Piedmont—lying or formed at the base of a mountain or mountain range.

Physiography—study of the natural features of the earth's surface including land formation, climate, currents, and distribution of flora and fauna. Also known as physical geography.

Playa—a term used in the Southwestern US for a dry, barren area in the lowest part of an undrained desert basin, underlain by clay, silt, or sand and commonly by soluble salts. It may be marked by an ephemeral lake.

Protocols—are detailed study plans that provide rationale for monitoring a Vital Sign, and provide instructions for carrying out the monitoring. Protocols consist of a narrative, standard operating procedures, and supplementary materials (Oakley et al. 2003)

Resilience—the capacity of a particular ecological attribute or process to recover to its former reference state or dynamic after exposure to a temporary disturbance and/or stressor (adapted from Grimm and Wissel 1997). The ability of a natural ecosystem to restore its structure following acute or chronic disturbance (Westman 1978). Resilience is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Resistance—the capacity of a particular ecological attribute or process to remain essentially unchanged from its reference state or dynamic despite exposure to a disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resistance is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Revisit design—refers to the schedule with which panels will be sampled over time (McDonald 2003).

Riparian—pertaining to or situated on the banks of a body of water, esp. a river.

Soil / site stability—the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).

Soil quality—the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1997). From an NPS perspective, soil quality is defined by a soil's capacity to perform the following ecological functions: (a) regulate hydrologic processes; (b) capture, retain, and cycle mineral nutrients; (c) support characteristic

native communities of plants and animals. Soil quality can be regarded as having (1) an inherent component defined by the soil's inherent soil properties as determined by the five factors of soil formation, and (2) a dynamic component defined by the change in soil function that is influenced by human use and management of the soil (Seybold et al. 1999).

Split panel—a revisit design in which one panel is sampled on every occasion and remaining panels are revisited on every nth occasion (e.g., [1-0, 1-4].

Status—as used in this program, refers to the condition of a resource or vital sign at a given point in time.

Stressor—physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land use change, and air pollution (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Threshold—as applied to state-and-transition models, a threshold is a point "...in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained [dynamic] equilibrium of the state degrades beyond the point of self-repair. These processes must be actively restored before the return to the previous state is possible. In the absence of active restoration, a new state is formed" (Stringham et al. 2003). Thresholds are defined in terms of the functional status of key ecosystem processes and are crossed when capacities for resistance and resilience are exceeded. (Also see state and transition.)

Transition—as applied to state-and-transition models, a transition is a trajectory of change that is precipitated by natural events and/or management actions which degrade the integrity of one or more of the primary ecological processes responsible for maintaining the dynamic equilibrium of the state. Transitions are vectors of system change that will lead to a new state without abatement of the stressor(s) and/or disturbance(s) prior to exceeding the system's capacities for resistance and resilience (adapted from Stringham et al. 2003).

Trend—as used by this program, refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units) (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Trophic—describes the position that an organism occupies in a food chain (what it eats and what eats it).

Variable—any quantitative aspect of an object of concern.

Vital signs—a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes) (http://science.nature.nps.gov/im/monitor/Glossary.cfm).

Watershed—a drainage basin, usually described as into a river or lake.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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