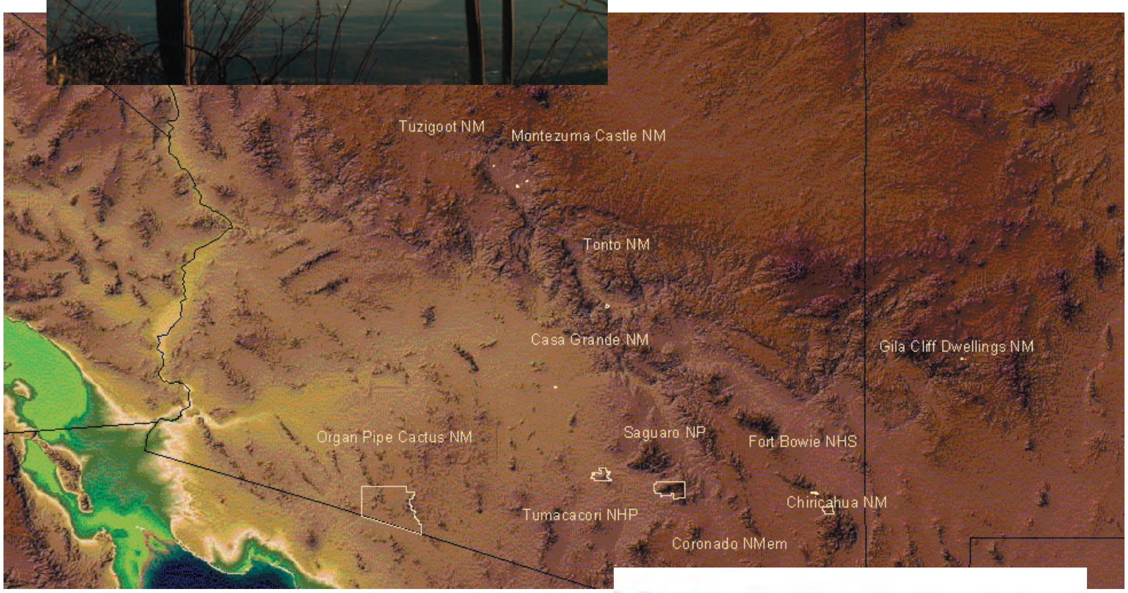
National Park Service
U.S. Department of the Interior

Intermountain Region
Sonoran Desert Network
Tucson, Arizona

Sonoran Desert Network
Vital Signs Monitoring Plan

Natural Resources Report NPS/IMR/SODN-003



SONORAN DESERT NETWORK
Inventory and Monitoring Program

ON THE COVER
View of the Tucson mountains and Saguaro cacti; sampling agaves at Coronado National Memorial.
Photographs by Jeff Balmat.

Sonoran Desert Network
Vital Signs Monitoring Plan

Technical Report NPS/IMR/SODN-003

Theresa Mau-Crimmins[1], Andy Hubbard[1], Deborah Angell[1], Colleen Filippone[2], Natasha Kline[3]

[1]Sonoran Desert Network
Inventory & Monitoring Program
7660 E. Broadway Blvd., Ste. 303
Tucson, AZ 85710

[2]Intermountain Region
7660 E. Broadway Blvd., Ste. 303
Tucson, AZ 85710

[3]Saguaro National Park
3693 South Old Spanish Trail
Tucson, AZ 85730

With contributions from:

Eric Albrecht, Kristen Beaupre, Jeff Balmat, Michael Crimmins, Emily Dellinger, Michele Girard, Keith Lombardo, Melissa Mauzy, Jeff McGovern, Cheryl McIntyre, Brian Powell, Jeff Simms, Sara Storrer, Sarah Studd, Miguel Villareal, Jason Welborn

September 2005

U.S. Department of the Interior
National Park Service
Intermountain Region
Denver, Colorado

The Intermountain Region of the National Park Service (NPS) comprises national parks and related areas in seven western states. The diversity of parks and their resources is reflected in their designations as national parks, national historic parks, historic sites, recreation areas, seashores, memorials, monuments, rivers, and trails. Biological, physical, and social science research results, natural resource inventory and monitoring data, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences related to these park units are disseminated through the NPS/IMR Technical Report and Natural Resources Report series.

Natural Resources Reports are the designated medium for information on technologies and resource management methods; "how to" resource management papers; proceedings of resource management workshops or conferences; and natural resource program descriptions and resource action plans.

Technical Reports are the designated medium for initially disseminating data and results of biological, physical, and social science research that addresses natural resource management issues; natural resource inventories and monitoring activities; scientific literature reviews; bibliographies; and peer-reviewed proceedings of technical workshops, conferences, and symposia.

This report is available as a downloadable portable document format file from the Internet at http://www.nature.nps.gov/im/units/sodn/. Print copies may also be available from the NPS Technical Information Center (TIC), Denver Service Center, PO Box 25287, Denver, CO 80225-0287. A copy charge may be involved. To order from TIC, refer to document SODN-003.

Please cite this publication as:

Mau-Crimmins, T., A. Hubbard, D. Angell, C. Filippone, N. Kline. September 2005. Sonoran Desert Network Vital Signs Monitoring Plan. Technical Report NPS/IMR/SODN-003. National Park Service. Denver, CO.

As the nation's primary conservation agency, the Department of Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historic places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS SODN-003 September 2005

Dedicated to
Eric W. Albrecht

This plan is dedicated to Eric Albrecht, our friend and colleague. Eric played an integral role in the early stages of the SODN I&M program, leading the biological inventory field efforts for several years. A talented and dedicated ecologist, Eric believed strongly in the importance of monitoring to support resource protection. Eric's contributions also helped to shape the Monitoring Plan, laying the foundation for future work. Eric's efforts in protocol development for bird monitoring served as a model for the entire program. Eric was leading the way for the network, and possibly for the nation, in determining the most effective approaches for land bird monitoring. His enthusiasm and dedication for his work, the natural world, and to his friends and family were an inspiration for everyone he encountered. Eric will be sorely missed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

This monitoring plan and the program it describes are the result of the collective efforts of several people. We would like to gratefully acknowledge their many contributions. Many thanks go to Jeff Balmat, Mike Crimmins, Emily Dellinger, Keith Lombardo, Cheryl McIntyre, Sara Storrer, Sarah Studd, Miguel Villareal, and Jason Welborn, members of the SODN Monitoring Team and Sonoran Institute interns. These individuals made key contributions to this plan and with protocol development. We also appreciate contributions from Jeff McGovern, NPS Archaeologist. Dennis Caldwell (University of Arizona) created the cover, network logo, and many of the graphics displayed in the plan. Kristen Beaupré (Sonoran Institute) assisted with GIS analysis and map production. Melissa Mauzy, Biological Technician with SODN, and Emily Dellinger, Sonoran Institute Research Assistant, deserve special acknowledgments for their tremendous efforts in designing, editing, and formatting the document.

Kathy Davis (Superintendent Montezuma Castle NM) and Bill Halvorson (USGS Sonoran Desert Field Station) have been driving forces for the network since its inception in 2001. Brian Powell and Eric Albrecht of the University of Arizona have done an outstanding job leading the SODN Biological Inventories to their successful conclusion and have been key contributors to the development of the monitoring program. Eric's passionate advocacy of resource monitoring and the crucial role he played in initiating protocol development is reflected in the dedication of this plan to his memory. He will be missed but not forgotten.

We thank the staff of other I&M networks, especially Thom O'Dell and Steve Garman (Northern Colorado Plateau Network), Cathie Jean and Rob Bennetts (Greater Yellowstone), and Bruce Bingham, IMR Regional Program Manager for their collaboration on various components of the plan and on-going cooperation on protocol development. Bryan Milstead's (Northeast Coast and Barrier Network) experience and thoughts as a transplanted desert rat have helped to frame conceptual issues in monitoring. The service-wide I&M program has provided guidance and direction for the SODN program, and Steve Fancy in particular has been an inspiration for his tireless pursuit of network development.

Michele Girard of the Southern Arizona Office played a key role in drafting the Water Quality Implementation Plan, developing water issue sections in the monitoring plan, and establishing critical links to partnering agencies. Larry Laing and Kevin Harper (Southern Arizona Office) continue to be important partners for SODN resource management issues and network development, and their vision of an integrated approach to natural and cultural resources management has been a model for network cooperation. We thank Larry Norris and the Desert Southwest CESU for their unwavering support of the SODN program, and value their experience and perspective on SODN parks.

Nina Chambers (Sonoran Institute), Jeff and Karen Simms (BLM), Dave Gori and Heather Schussman (TNC), and the many other members of the Regional Monitoring Partnership also provided technical expertise and valuable insights during program development. Nina's vision of a regional monitoring team has been central to the success of the program.

Finally, we thank the staff and management of the 11 SODN parks. Without your enthusiasm, active participation, and advocacy for the program, none of this would be possible.

EXECUTIVE SUMMARY

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "unimpaired for the enjoyment of future generations." National Park 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 basis for making decisions. The Sonoran Desert Network (SODN) is one of 32 National Park Service (NPS) Inventory & Monitoring (I&M) Networks established to meet this challenge. It is comprised of 11 National Park Service units located in southern Arizona and western New Mexico: Casa Grande Ruins National Monument, Chiricahua National Monument, Coronado National Memorial, Fort Bowie National Historic Site, Gila Cliff Dwellings National Monument, Montezuma Castle National Monument, Organ Pipe Cactus National Monument, Saguaro National Park, Tonto National Monument, Tumacacori National Historical Park, and Tuzigoot National Monument. The SODN Phase 3 Monitoring Plan summarizes the activities undertaken to develop the monitoring program, incorporates the products of the earlier phases, and serves as a draft of the final monitoring plan.

Straddling the Sonoran Desert and Apache Highlands Ecoregions, SODN park ecosystems range from low elevation desert scrub to high-elevation conifer forests atop the major mountain ranges or "sky islands" of the American Southwest. Despite this range of variability, SODN parks share similar ecological, historical and administrative characteristics. Eight of the 11 SODN parks are relatively small and were established primarily to protect cultural resources, though each contains regionally-important natural resources (unique riparian and aquatic habitat) as well. Organ Pipe Cactus National Monument, Saguaro National Park, and Chiricahua National Monument were established to protect natural resources and comprise 98% of the 184,035 hectares contained in the network. Organ Pipe Cactus National Monument alone represents nearly three-quarters of the network lands. More than 86% of the network is designated wilderness.

The primary goal of the NPS I&M Program is to assess the long-term ecological condition of the park units, evaluate resource response to management actions, and facilitate effective resource management. The service-wide I&M program was created through the Natural Resource Challenge, a congressional mandate to improve natural resource stewardship in the NPS system. The Natural Resource Challenge requires managers to know the condition of natural resources under their stewardship, monitor long-term trends in key resources or "vital signs", and to use monitoring results to improve and refine park management for the benefit of the resource. Moreover, monitoring is legally mandated through the NPS Organic Act, as well as numerous other acts and executive orders. Vital signs monitoring achieves the Category 1 goals found in the Government Performance and Results Act (GPRA), which requires that federal agencies establish operational goals and account for progress and funds expended towards meeting those goals.

Baseline biological inventories have been completed for the SODN parks and park-specific reports synthesizing the results of current field efforts with historical datasets have been generated. These inventories, coupled with detailed evaluations of abiotic factors, such as water quality and quantity characteristics, soil and landform distributions, and air quality issues, have provided an important foundation for developing the SODN monitoring program. For most SODN parks, these efforts represented the first comprehensive ecological surveys ever undertaken, and the findings have already provided guidance and direction for effective management of park resources. Additional inventories of physical factors such as geology and climate are ongoing and will be incorporated into the program as they are completed.

Management goals, concerns and key stressors were identified during Phase 1 SODN development. Detailed park-based scoping, stressor surveys, regional assessments, and consultations with the scientific community and agency partners provided a comprehensive picture of important resource management issues at park and network scales. Leading concerns included landscape fragmentation, non-native plant and animal encroachment, altered fire regimes, groundwater extraction, surface water contamination, recreational pressures, and impacts related to illegal migration and smuggling along the U.S./Mexico border. Maintenance of key ecological processes and biotic communities was the most common resource management goal shared by SODN parks. The network also completed a detailed review of the ecology of the SODN parks and broader ecoregions, and developed conceptual models to communicate this information to park staff and cooperators.

The fusion of management issues with a detailed understanding of the ecology of SODN parks provided direction for the selection of candidate vital signs during Phase 2 SODN development. Park and network staff developed a candidate vital sign selection process in 2002. Eight scientists with extensive experience in the Sonoran Desert and Apache Highlands Ecoregions developed a monitoring framework based on SODN park management issues, and the ecology of park ecosystems. This framework refined vital sign criteria and monitoring objectives developed in Phase 1, and led to the establishment of nine expert workgroups for key resource types: climate and air quality, water quantity and quality, landscape dynamics, vegetation, vertebrates, invertebrates, human dimensions, and soil/landform processes. Employing the nominal workgroup technique, experts were tasked with identifying and prioritizing candidate vital signs based on park management issues, criteria for "ideal" vital signs, and their subject-matter expertise. Results from these nine workgroups were synthesized by park staff and presented to the SODN Technical Committee in August of 2003 for evaluation and selection. The Technical Committee approved 25 candidate vital signs for the SODN program.

Strategies and approaches for effectively monitoring the 25 SODN vital signs were investigated during Phase 3. Existing protocols, datasets, and technical issues for each vital sign were evaluated, and summarized in Protocol Development Summaries (PDSs). Broad monitoring objectives began the evolution towards more detailed, measurable statements of purpose. Development of robust and effective monitoring protocols forms the backbone of any successful monitoring program, and provides focus to network infrastructure (budget, staffing, equipment needs) and programmatic (communications, reporting, administrative structure) priorities. The Phase 3 plan describes general strategies and approaches for these aspects of network development, but allows for flexibility until protocol development (2005-2006) can provide direction on these long-term commitments.

Protocol development is proceeding through the establishment of the SODN Monitoring Team, comprised of network staff, graduate interns, and partners. Cooperative approaches to monitoring are key strategy for the SODN program, and range from collaboration with the other Phase 3 network in the Intermountain Region (Greater Yellowstone and Northern Colorado Plateau Networks) to the establishment of the Greater Sonoran Desert Regional Monitoring Partnership in 2003, a consortium of regional management and research entities with interests and mandates for resource monitoring. The SODN Monitoring Team is employing a structured, iterative process that weighs technical and statistical considerations against financial, safety, and resource impact factors in a cost/benefit framework. The team approaches protocol development in a integrated fashion rather than considering each vital sign in isolation, favoring a synthetic monitoring program and reaping efficiencies in time and funds expended. A schedule has been established for completing each protocol, with the results to be incorporated into the SODN Monitoring Plan.

An effective long-term resource program must be both consistent and open to modification as problems and limitations arise. This paradox presents a challenge to that can be overcome with diligence and persistent, active involvement by park and network staff, management, partners, and the agency as a whole. Therefore, the SODN Monitoring Plan is intended both to provide a foundation for the development and direction of the vital signs program, and to be an evolving, living document to be revisited and amended as the program progresses.

CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1. Park Stewardship and Natural Resource Monitoring

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's ability to manage park resources "unimpaired for the enjoyment of future generations." National Park 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 basis for making decisions, and for working with other agencies and the public for the benefit of park resources.

Natural resource *monitoring* offers site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need for change in 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 threats to these systems (Roman and Barrett 1999).

"*Vital signs*," as defined by the NPS, 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. 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. Because of the need to maximize the use and relevance of monitoring results for making management decisions, vital signs selected by parks may include elements that were selected because they have important human values (e.g., harvested or charismatic species) or because of some known or hypothesized threat or stressor/response relationship within a particular park resource. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource *inventories*, management, and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.1). Natural resource inventories are extensive point-in-time efforts to determine the location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Monitoring differs from inventories by adding the dimension of time; the general purpose of monitoring is to detect changes or trends in a resource. 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 a change or trend may trigger a management action, or it may generate a new line of inquiry. Research is generally defined as the systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the

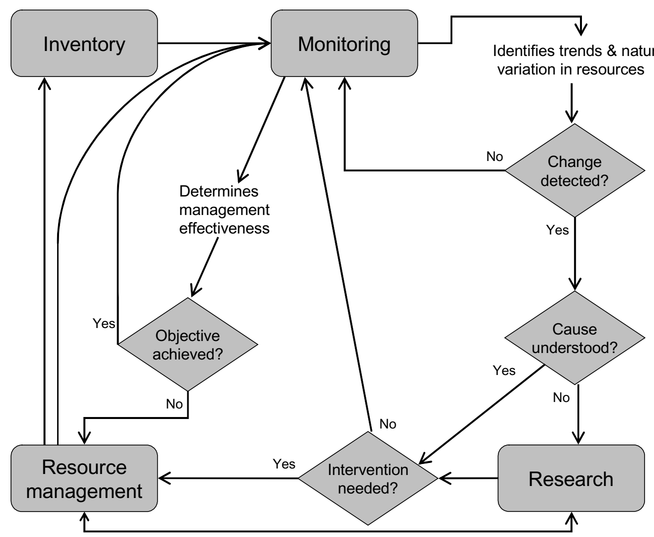
MONITORING:
The collection and analysis of repeated observations or measurements to evaluate changes in condition (trends) and progress toward a management objective.

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.

INVENTORY:
An extensive point-in-time effort to determine the location or condition of a resource.

probable cause of an observation is tested in situations with and without the specified cause. A research design is usually required to determine the cause of changes observed by monitoring. The development of monitoring protocols also involves a research component to determine the appropriate spatial and temporal scale for monitoring.

Figure 1.1. Stewardship of natural resources in national parks involves the interconnected activities of inventories, monitoring, research, and resource management (modified from Jenkins et al. 2002).



1.1.1. Servicewide Monitoring Goals

The overall goal of natural resource monitoring in parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems.

NPS Servicewide Vital Signs Monitoring Goals

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 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.

An effective monitoring program provides information that can be used in multiple ways. The most widely identified application of monitoring information is that of enabling managers to make better-informed management decisions (White and Bratton 1980, Croze 1982, Jones 1986, Davis 1989, Quinn and van Riper 1990). Another use of monitoring information is to document changes primarily for the sake of familiarity with resources (Croze 1982, Halvorson 1984). By gathering data over long periods, correlations between different attributes become apparent, and resource managers gain a better general understanding of the ecosystem. A third use of monitoring information may be to convince others to make decisions benefiting national parks (Johnson and Bratton 1978, Croze 1982). Monitoring sensitive species, invasive species, culturally significant species, or entire communities can provide park managers, stakeholders, and the public with an early warning of the effects of human activities before they are noticed elsewhere (Wiersma 1989, Davis 1989). Finally, a monitoring program can provide basic background information that is needed by park researchers, public information offices, interpreters, and those wanting to know more about the area around them (Johnson and Bratton 1978).

ADAPTIVE MANAGEMENT:
A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

1.1.2. Legislation, Policy, and Guidance for Natural Resource Monitoring

In establishing the first national park in 1872, Congress "dedicated and set apart (nearly 1,000,000 acres of land) as a … pleasuring ground for the benefit and enjoyment of the people" (16 U.S.C. 1 § 21). By 1900 a total of five national parks had been established, along with additional historic sites, scenic rivers, recreation areas, monuments, and other designated units. Each unit was to be administered according to its individual enabling legislation, but had been created with a common purpose of preserving the "precious" resources for people's benefit. Sixteen years later, the passage of the National Park Service Organic Act of 1916 (16 U.S.C. 1 § 1) established and defined the mission of the National Park Service, and through it, Congress implied the need to monitor natural resources and guarantee unimpaired park services:

> "The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified … by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Agave in bloom at Coronado National Memorial. June 2004.

Congress reaffirmed the declaration of the Organic Act vis-à-vis the General Authorities Act of 1970 (16 U.S.C. 1a-1a8) and effectively ensured that all park units be united into the 'National Park System' by a common purpose of preservation, regardless of title or designation. In 1978, the National Park Service's protective function was further strengthened when Congress again amended the Organic Act to state "…the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…" thus further endorsing natural resource goals of each park. A decade later, park service management policy again reiterated the importance of this protective function of the NPS to "understand, maintain, restore, and protect the inherent integrity of the natural resources," (NPS Management Policies 2001).

More recent and specific requirements for a program of inventory and monitoring park resources are found in the National Parks Omnibus Management Act of 1998 (P.L. 105-391). The intent of the Act is to create an inventory and monitoring program that may be used "to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources." Subsequently, in 2001, NPS management updated previous policy and specifically directed the Service to inventory and monitor natural systems in efforts to inform park management decisions:

> "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" (NPS Management Policies 2001).

In addition to the legislation directing the formation and function of the National Park System, there are several other pieces of legislation intended to not only protect the natural resources within national parks and other federal lands, but to address concerns over the environmental quality of life in the United States generally. Many of these federal laws also require natural resource monitoring within national park units. As NPS units are among some of the most secure areas for numerous threatened, endangered or otherwise compromised natural resources in the country, the particular guidance offered by federal environmental legislation and policy is an important component to the development and administration of a natural resource inventory and monitoring system in the National Parks.

The following legislation, policy and executive guidance all have an important and direct bearing on the development and implementation of natural resource monitoring in the National Parks. Relevant federal legal mandates are therefore summarized in the following table.

Table 1.1. Summary of Legislation, National Park Service Policy and Guidance Relevant to Development and Implementation of Natural Resources Monitoring in National Parks.

Public Laws	Significance to Inventory and Monitoring
National Park Service Organic Act (16 USC 1 et seq. [1988], Aug. 25, 1916).	The 1916 National Park Service Organic Act is the core of park service authority and the definitive statement of the purposes of the parks and of the National Park Service mission. The act establishes the purpose of national parks: "… To conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."
General Authorities Act of 1970 (16 USC 1a-1--1a-8 (1988), 84 Stat. 825, Pub. L. 91-383	The General Authorities Act amends the Organic Act to unite individual parks into the 'National Park System'. The act states that areas of the National Park System, "though distinct in character, are united through their inter-related purposes and resources into one national park system as cumulative expressions of a single national heritage; that individually and collectively, these areas derive increased national dignity and recognition of their superb environmental quality through their inclusion jointly with each other in one national park system preserved and managed for the benefit and inspiration of all the people of the United States…"
Redwood National Park Act (16 USC 79a-79q (1988), 82 Stat. 931, Pub. L. 90-545	This act includes both park-specific and system-wide provisions. This act reasserts system-wide protection standards for the National Park System. This act qualifies the provision that park protection and management "shall not be exercised in derogation of the values and purposes for which these areas have been established by adding except as may have been or shall be directed and specifically provided for by Congress." Thus, specific provisions in a park's enabling legislation allow park managers to permit activities such as hunting and grazing.

Table 1.1. continued.

Public Laws	Significance to Inventory and Monitoring
National Environmental Policy Act of 1969 (42 USC 4321-4370)	The purposes of NEPA include encouraging 'harmony between [humans] and their environment and promote efforts which will prevent or eliminate damage to the environment… and stimulate the health and welfare of [humanity].' NEPA requires a systematic analysis of major federal actions that includes a consideration of all reasonable alternatives as well as an analysis of short-term and long-term, irretrievable, irreversible, and unavoidable impacts. Within NEPA the environment includes natural, historical, cultural, and human dimensions. Within the NPS emphasis is on minimizing negative impacts and preventing "impairment" of park resources as described and interpreted in the NPS Organic Act. The results of evaluations conducted under NEPA are presented to the public, federal agencies, and public officials in document format (e.g. EAs and EISs) for consideration prior to taking official action or making official decisions.
Clean Water Act (33 USC 1251-1376)	The Clean Water Act, passed in 1972 as amendments to the Federal Water Pollution Control Act, and significantly amended in 1977 and 1987, was designed to restore and maintain the integrity of the nation's water. It furthers the objectives of restoring and maintaining the chemical, physical and biological integrity of the nation's waters and of eliminating the discharge of pollutants into navigable waters by 1985. Establishes effluent limitation for new and existing industrial discharge into U.S. waters. Authorizes states to substitute their own water quality management plans developed under S208 of the act for federal controls. Provides an enforcement procedure for water pollution abatement. Requires conformance to permit required under S404 for actions that may result in discharge of dredged or fill material into a tributary to, wetland, or associated water source for a navigable river.
Clean Air Act (42 USC 7401-7671q, as amended in 1990)	Establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards. Under the Prevention of Significant Deterioration provisions, the act requires federal officials responsible for the management of Class I Areas (national parks and wilderness areas) to protect the air quality related values of each area and to consult with permitting authorities regarding possible adverse impacts from new or modified emitting facilities. The act establishes specific programs that provide special protection for air resources and air quality related values associated with NPS units. The EPA has been charged with implementing this act.
Endangered Species Act of 1973, as amended (ESA) (16 USC 1531-1544)	The purposes of the ESA include providing "a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved. According to the ESA 'all federal departments and agencies shall seek to conserve endangered species and threatened species' and '[e]ach federal agency shall…insure that any action authorized, funded, or carried out by such agency…is not likely to jeopardize the continued existence of any endangered species or threatened species.' The USFWS (non-marine species) and the National Marine Fisheries Service (NMFS) (marine species, including anadromous fish and marine mammals) administers the ESA. The effects of any agency action that may affect endangered, threatened, or proposed species must be evaluated in consultation with either the USFWS or NMFS, as appropriate.
Environmental Quality Improvement Act of 1970 (42 U.S.C. 56 -- 4371)	Directs all Federal agencies whose activities may affect the environment to implement policies established under existing law to protect the environment.
Coastal Zone Management Act of 1972 (16 U.S.C. 33 -- 1452)	"Congress finds and declares that it is the national policy to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations."

Table 1.1. continued.

Public Laws	Significance to Inventory and Monitoring
Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 32 -- 1431)	Recognizes that the United States has historically protected special areas of its public domain, but (that) these efforts have been directed almost exclusively to land areas above the high-water mark. For this reason congress elected to recognize and protect 'Certain areas of the marine environment possess(ing) conservation, recreational, ecological, historical, scientific, educational, cultural, archeological, or esthetic qualities which give them special national, and in some cases international, significance.' Specifically this law intends to 'Improve the conservation, understanding, management, and wise and sustainable use of marine resources; (to) enhance public awareness, understanding, and appreciation of the marine environment; and (to) maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas.'
National Historic Preservation Act of 1966, as amended (16 USC 470 et seq.)	Congressional policy set forth in NHPA includes preserving 'the historical and cultural foundations of the Nation' and preserving irreplaceable examples important to our national heritage to maintain 'cultural, educational, aesthetic, inspirational, economic, and energy benefits.' NHPA also established the National Register of Historic Places composed of 'districts, sites, buildings, structures, and objects significant in American history, architecture, archeology, engineering, and culture.' NHPA requires federal agencies take into account the effects of their actions on properties eligible for or included in the National Register of Historic Places and to coordinate such actions with the State Historic Preservation Offices (SHPO).
Wilderness Act of 1964 (16 USC 1131 et seq.)	Establishes the National Wilderness Preservation System. In this act, wilderness is defined by its lack of noticeable human modification or presence; it is a place where the landscape is affected primarily by the forces of nature and where humans are visitors who do not remain. Wilderness Areas are designated by Congress and are composed of existing federal lands that have retained a wilderness character and meet the criteria found in the act. Federal officials are required to manage Wilderness Areas in a manner conducive to retention of their wilderness character and must consider the effect upon wilderness attributes from management activities on adjacent lands.
Forest and Rangeland Renewable Resources Planning Act of 1974 (16 U.S.C. 36 -- 1642	Mandates that the Secretary of Agriculture inventory and monitor renewable natural resources in National Forests, and has been cited as congressional authorization for the inventory and monitoring of natural resources on all federal lands. While this is not specifically directed in the act it is perhaps indicative of a national will to account for and manage the nations natural heritage in manner that sustains these resources in perpetuity.

Table 1.1. continued.

Public Laws	Significance to Inventory and Monitoring
Surface Mining Control and Reclamation Act	The Surface Mining Control and Reclamation Act was enacted in 1977. It establishes a nationwide program to protect the environment from adverse effects of surface coal mining operations, establishes minimum national standards for regulating surface coal mining, assists states in developing and implementing regulatory programs, and promotes reclamation of previously mined areas with inadequate reclamation. Under the Act, the Secretary of the Interior is directed to regulate the conduct of surface coal mining throughout the United States for both federally and non-federally owned rights. The Act establishes the Abandoned Mine Reclamation Fund, which is for the reclamation of land and water affected by coal mining. Eligibility for reclamation under this program requires that the land or water had been mined for coal, or affected by coal mining, and had been inadequately reclaimed prior to the enactment of this act in 1977. Both public and private lands are eligible for funding. Sections 522(e)(1) and 533(e)(3) of the act specifically prohibit surface mining within the National Park Service, National Wildlife Refuge System, National System of Trails, National Wilderness Preservation System, or Wild and Scenic Rivers System. The act also prohibits surface mining that adversely impacts any publicly-owned park or place included in the National Register of Historic Sites. These prohibitions are subject to valid existing rights at the time of the Act, the exact definition of which remains the subject of administrative and legal action. How valid existing rights are ultimately defined will affect the ability of mineral owners to mine in the Recreation Area.
Geothermal Steam Act 1988	This act specifically calls for a monitoring program for certain parks with thermal resources: (1) The Secretary shall maintain a monitoring program for significant thermal features within units of the National Park System. (2) As part of the monitoring program required by paragraph (1), the Secretary shall establish a research program to collect and assess data on the geothermal resources within units of the National Park System with significant thermal features. Such program shall be carried out by the National Park Service in cooperation with the U.S. Geological Survey and shall begin with the collection and assessment of data for significant thermal features near current or proposed geothermal development and shall also include such features near areas of potential geothermal development.
Federal Advisory Committee Act	Creates a formal process for federal agencies to seek advice and assistance from citizens. Any council, panel, conference, task force or similar group used by federal officials to obtain consensus advice or recommendations on issues or policies fall under the purview of FACA.
National Parks Omnibus Management Act, 1998 (P.L. 105-391)	Requires Secretary of Interior to continually improve NPS' ability to provide state-of-the-art management, protection, and interpretation of and research on NPS resources. Secretary shall assure the full and proper utilization of the results of scientific study for park management decisions. In each case where an NPS action may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in NPS resource conditions shall be a significant factor in superintendent's annual performance evaluations. Section 5939 states that the purpose of this legislation is to: (1) More effectively achieve the mission of the National Park Service; (2) Enhance management and protection of national park resources by providing clear authority and direction for the conduct of scientific study in the National Park System and to use the information gathered for management purposes; (3) Ensure appropriate documentation of resource conditions in the National Park System; (4) Encourage others to use the National Park System for study to the benefit of park management as well as broader scientific value, and (5) Encourage the publication and dissemination of information derived from studies in the National Park System.

Table 1.1. continued.

Public Laws	Significance to Inventory and Monitoring
Government Performance and Results Act (GPRA)	Requires the NPS to set goals (strategic and annual performance plans) and report results (annual performance reports). The NPS Strategic Plan contains four GPRA goal categories: park resources, park visitors, external partnership programs, and organizational effectiveness. In 1997, the NPS published its first GPRA-style strategic plan, focused on measurable outcomes or quantifiable results.
Executive Orders	**Significance to Inventory and Monitoring**
Off-Road Vehicle Use (Executive Orders 11644 and 11989)	Executive Order 11644, enacted February 8, 1972 and amended by Executive Order 11989 on May 24, 1977, regulates off-road vehicle use. If the enabling legislation allows the use of off-road vehicles, NPS is required to designate specific areas for off-road vehicle use. These areas must be 'located to minimize damage to soil, watershed, vegetation, or other resources' (Section (3)(a)(1)). If it is determined that such use is adverse to resources, the NPS is to immediately close such areas or trails until the impacts have been corrected.
Floodplain Management (Executive Order 11988)	Executive Order 11988 was enacted May 24, 1977. It requires all federal agencies to 'reduce the risk of flood loss,... minimize the impacts of floods on human safety, health and welfare, and ... restore and preserve the natural and beneficial values served by flood plains.' To the extent possible, park facilities, such as campgrounds and rest areas, should be located outside floodplain areas. Executive Order 11988 is implemented in the National Park Service through the *Floodplain Management Guidelines* (National Park Service, 1993b). It is the policy of the National Park Service to 1) restore and preserve natural floodplain values; 2) to the extent possible, avoid environmental impacts to the floodplain by discouraging floodplain development; 3) minimize the risks to life and property when structures and facilities must be located on a floodplain; and, 4) encourage nonstructural over structural methods of flood hazard mitigation.
Protection of Wetlands (Executive Order 11990)	Executive Order 11990 was enacted May 24, 1977. It requires all federal agencies to "minimize the destruction, loss, or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands." Unless no practical alternative exists, federal agencies must avoid any activities that have the potential to adversely affect wetland ecosystem integrity. NPS guidance pertaining to this Executive Order is stated in *Floodplain and Wetland Protection Guidelines* (National Park Service, 1980).
Executive Order 13112 on Invasive Species	This executive order was signed into law on February 3, 1999, to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause. This Executive Order established the National Invasive Species Council and required the preparation of a National Invasive Species Management Plan to recommend specific, performance-oriented goals and objectives and specific measures of success for Federal agency efforts concerning invasive species.
NPS Policies and Guidance	**Significance to Inventory and Monitoring**
NPS Management Policies 2001 (NPS Directives System)	This is the basic NPS servicewide policy document. It is the highest of three levels of guidance documents in the NPS Directives System. The Directives System is designed to provide NPS management and staff with clear and continuously updated information on NPS policy and required and/or recommended actions, as well as any other information that will help them manage parks and programs effectively.

NPS Policies and Guidance	Significance to Inventory and Monitoring
NPS Directors Orders	Second level of NPS Directives System. Directors Orders serve a vehicle to clarify or supplement *Management Policies* to meet the needs of NPS managers.
	Relevant Directors Orders:
	DO-2.1 Resource Management Planning
	DO-12 Environmental Impact Assessment
	DO-14 Resource Damage Assessment & Restoration
	DO-24 Museum Collections Management
	DO-41 Wilderness Preservation & Management
	DO-47 Sound Preservation & Noise Management
	DO-77 Natural Resource Protection
NPS Handbooks and Reference Manuals	This is the third tier in the NPS Directives System. These documents are issued by Associate Directors. These documents provide NPS field employees with a compilation of legal references, operating policies, standards, procedures, general information, recommendations and examples to assist them in carrying out *Management Policies* and Director's Orders. Level 3 documents may not impose any new servicewide requirements, unless the Director has specifically authorized them to do so.
	Relevant Handbooks and Reference Manuals:
	NPS-75 Natural Resources Inventory & Monitoring
	NPS-77 Natural Resources Management Guidelines
	NPS Guide to Fed. Advisory Committee Act
	Website: Monitoring Natural Resources in our National Parks, http://science.nature.nps.gov/im/monitor

Table 1.1. continued.

1.2. Strategic Planning and Performance Management

1.2.1. SODN Monitoring Plan and GPRA Goals

The Government Performance and Results Act (GPRA), passed by Congress in 1993, directs federal agencies to ensure that daily actions and expenditures of resources are guided by long- and short-term goal setting in pursuit of accomplishing an organization's primary mission, followed by performance measurement and evaluation. GPRA requires federal agencies to develop and use three primary documents in conducting business: a Strategic Plan, an Annual Performance Plan, and an Annual Performance Report.

The SODN Monitoring Plan is a significant and specific step towards fulfilling GPRA Goal Category I (Preserve Park Resources) for network parks. The servicewide goal pertaining to Natural Resource Inventories specifically identifies the strategic objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1). This goal tracks the basic natural resources information that is available to parks; performance is measured by what datasets are obtained. The servicewide long-term goal is to "acquire or develop 87% of the outstanding datasets identified in 1999 of basic natural resource inventories for all parks" based on the I&M

TWELVE BASIC INVENTORIES:

- Natural Resource Bibliographies
- Base Cartography Data
- Species Occurrence Inventory
- Species Distribution Inventory
- Vegetation Maps
- Soil Resources Inventory
- Geologic Information Inventory
- Water Resources Inventory
- Water Chemistry Inventory
- Air Quality Inventory
- Air Quality-Related Values Assessment
- Climate Data Inventory

Program's 12 basic datasets. The SODN Inventory Study Plan (Davis and Halvorson 2000) delineated what information exists for the network, its format and condition, and what information is missing. Information acquired from the inventories contributed to the identification of candidate vital signs for the network.

The Monitoring Plan identifies the monitoring indicators or "vital signs" of the network and presents a strategy for long-term monitoring to detect trends in resource condition (GPRA Goal Ib3). GPRA goals specific to SODN parks and relevant to the Monitoring Plan are listed in Table 1.2.

Table 1.2. GPRA goals for each park that pertain to information generated by the Inventory and Monitoring program of the Sonoran Desert Network.

GPRA Goal	Goal #	Parks with this goal
Resources maintained	Ia	CHIR, FOBO, CORO, MOCA, TUZI, ORPI, SAGU, TONT, TUMA
Disturbed lands restored	Ia01A Ia01B Ia1A Ib01A	CORO
Exotic vegetation contained	Ia1B	CHIR, CORO, FOBO, MOCA, ORPI
Natural resource inventories acquired or developed	Ib01	CORO, ORPI, SAGU
Stable federal T&E species or species of concern populations have improved status	Ia2B Ib02d	ORPI
Unknown federal T&E species or species of concern populations have improved status	Ia2D	ORPI
Improving federal T&E species or species of concern populations have improved status	Ia2A	CHIR, CORO, SAGU
Species of concern populations have improved status	Ia2X	
Air quality does not degrade	Ia3	CHIR, CORO, SAGU
Vital signs for natural resource monitoring identified	Ib3	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Water quality improvement	Ia04	MOCA, SAGU, TUZI
Geological and paleontological resources	Ib04	CORO
Improvement in resource condition of indicators	Ia12	SAGU

1.2.2. SODN Park Unit Enabling Legislation

The SODN includes one National Park, one National Historical Park, one National Memorial, one National Historic Site, and seven National Monuments. In 1970, Congress elaborated on the 1916 NPS Organic Act, clearly stating that all of these designations have equal legal standing in the National Park System.

The enabling legislation of an individual park provides insight into the natural and cultural resources and resource value for which it was created to preserve. Along with national legislation, policy and guidance, a park's enabling legislation provides justification and, in some cases, specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring. See Appendix A for a more detailed description of SODN park enabling legislation.

1.3. Overview of the Sonoran Desert Network (SODN)

1.3.1. Setting and Boundary

Map of NPS Inventory and Monitoring Networks, including Sonoran Desert Network.

The following sections describe the range of environmental conditions and anthropogenic influences prevalent in the Sonoran Desert Network region. A detailed account of each SODN unit and maps for each park appear in Appendix B.

The Sonoran Desert Network (SODN) is one of 32 networks in the National Park Service Inventory & Monitoring (I&M) Program. It is comprised of 11 National Park Service units located in southern Arizona and western New Mexico (Figure 1.2). Most of the park units lie within the Sonoran Desert ecoregion, but four are allied with the Apache Highlands Ecoregion (also called “Apacheria” or “Madrean Floristic”), the Sonoran and Chihuahuan Deserts, and the Sierra Madre Occidental Pine-Oak Forests Ecoregions (Olson et al. 2001, see map in Appendix C). Parks within the SODN vary in size from 144 to more than 130,000 hectares (Table 1.3), and total nearly 200,000 hectares across the network. More than 159,000 hectares are designated as wilderness.

The majority of the SODN park units were designated to protect cultural resources, although several designations included language to protect the associated natural resources (Table 1.3).

The SODN parks lie within the two largest subdivisions of the Sonoran Desert, the Lower Colorado River Valley and the Arizona Upland (Brown and Lowe 1980, see maps in Appendix C). SODN parks comprise less than 1% of the 22,339,070 ha of the Sonoran Desert, and ca. 1.4% of the Sonoran Desert contained within the United States (Marshall et al. 2000). However, SODN parks contain a wide range of biotic communities and abiotic conditions (Table 1.4), representative of the Sonoran Desert and Apache Highlands ecoregions, as well as unique resources of regional importance).

Figure 1.2. Map of Sonoran Desert Network parks.

Table 1.3.
Sonoran Desert Network parks.

Sonoran Desert Network Park	Abbreviation	State	Hectares	Wilder-ness (ha)	Originally Established For	
					Cultural Resources	Natural Resources
Casa Grande Ruins National Monument	CAGR	AZ	191		X	
Chiricahua National Monument	CHIR	AZ	4,852	3,819		X
Coronado National Memorial	CORO	AZ	1,923		X	
Fort Bowie National Historic Site	FOBO	AZ	404		X	
Gila Cliff Dwellings National Monument	GICL	NM	216		X	
Montezuma Castle National Monument	MOCA	AZ	347		X	
Organ Pipe Cactus National Monument	ORPI	AZ	133,882	126,478		X
Saguaro National Park	SAGU	AZ	41,300	28,888		X
Tonto National Monument	TONT	AZ	452		X	
Tumacacori Historical National Park	TUMA	AZ	144		X	
Tuzigoot National Monument	TUZI	AZ	324		X	

Table 1.4.
Biophysical overview of Sonoran Desert Network parks.

*NOAA 2003- Based on monthly average minimum/maximum air temperature data reported from the park meteorological station.

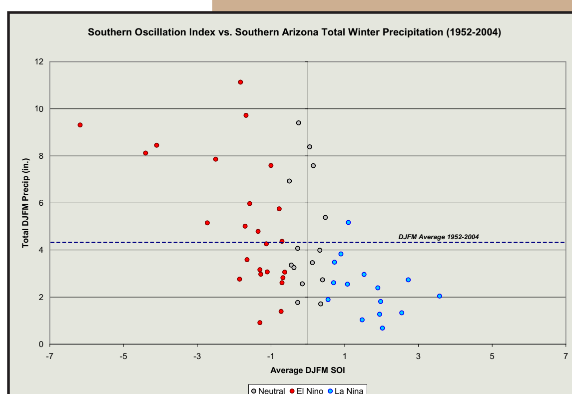
Park	Annual Precipitation (mm)*	Min./Max Air Temperature (°F)*	Elevation (m)	Major Vegetation Formations
CAGR	230	34°/107°	431 – 436	Sonoran Desertscrub, Mesquite Woodland
CHIR	494	30°/90°	1,570 – 2,385	Coniferous Forest, Madrean Evergreen Woodland and Forest, Relict Mixed-Conifer Forest, Semi-Desert Grassland, Madrean Riparian Forest, Interior Chaparral
CORO	528	33°/91°	1,433 – 2,347	Madrean Evergreen Woodland and Forest, Semi-Desert Grassland, Sonoran Riparian and Oasis Forest, Madrean Riparian Forest and Woodland
FOBO	246	27°/92°	1,417 – 1,600	Madrean Woodland, Interior Chaparral, Semi-Desert Grassland, Chihuahuan Desert Scrub, Madrean Riparian Forest and Woodland
GICL	504		2,027 – 2,079	Madrean Woodland, Coniferous Forest, Montane Riparian Forest
MOCA	332	26°/101°	963 – 1,103	Sonoran Desertscrub, Interior Perennial Riparian Forest
ORPI	245	39°/103°	305 – 1,463	Sonoran Desertscrub, Interior Chaparral, Xeroriparian Woodland, Madrean Evergreen Woodland

Park	Annual Precipitation (mm)*	Min./Max Air Temperature (°F)*	Elevation (m)	Major Vegetation Formations
SAGU	338	39°/99° at HQ; 24°/77° atop Mica Mountain	610 – 2,621	Mixed Conifer Forest, Coniferous Forest and Woodland, Madrean Evergreen Forest and Woodland, Semi-Desert Grassland/Savanna, Madrean Riparian Woodland, Lowland Perennial Riparian Forest, Xeroriparian Woodland, Sonoran Desertscrub
TONT	406	37°/102°	695 – 1,219	Xeroriparian Woodland, Interior Riparian Woodland, Interior Chaparral, Semi-Desert Grassland, Sonoran Desertscrub
TUMA	408	32°/98°	994 – 1,097	Lowland Perennial Riparian Forest and Woodland, Mesquite Bosque
TUZI	344	31°/100°	1,024 – 1,036	Lowland Perennial Riparian Forest, Southwestern Marsh Wetlands, Sonoran Desertscrub

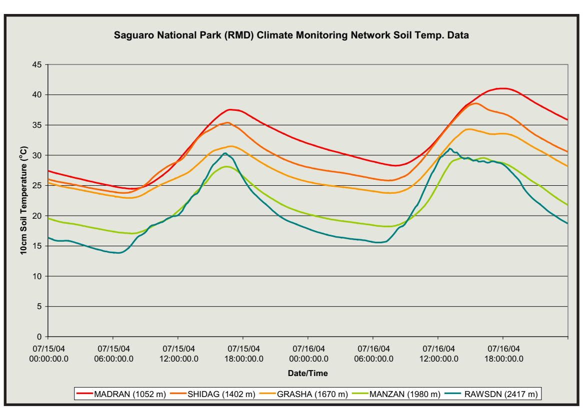
Table 1.4. continued.

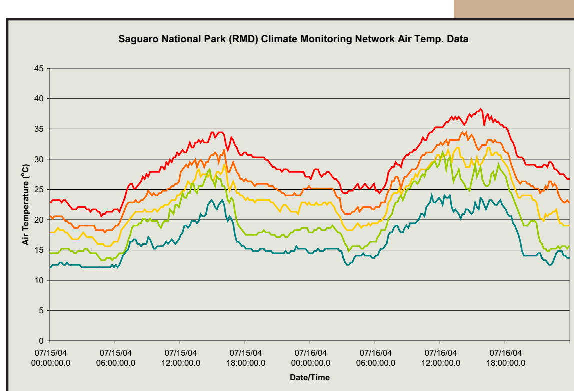
1.3.2. Climate

Perhaps no other feature defines the Sonoran Desert more than its bimodal precipitation regime (Ingram 2000). Located between the Mohave and Chihuahuan Deserts, the Sonoran Desert receives the frequent low intensity winter rains (December/January) of the former, as well as the violent summer (July/August) "monsoon" thunderstorms of the latter. These distinct rainy seasons support a broad array of warm- and cool-season flora and fauna and are the primary cause of the amazing species and lifeform diversity of the Sonoran Desert (MacMahon 1985, Nabhan 2000). Winter precipitation occurs when a low-pressure trough develops over the western United States, pushing the prevailing Pacific storm tracks south over the Sonoran Desert (Ingram 2000). During summer months, continental air masses rise as the sun heats them, drawing moist air from the Pacific Ocean. If there is sufficient moisture, violent summer thunderstorms ensue as the cool and hot air collide, creating dramatic lightning, powerful winds, and occasionally, intense downpours (Ingram 2000). Though winter and summer precipitation is roughly equivalent, there is more effective precipitation available to organisms following winter rain, as much of the summer rains evaporate or run off before they can be utilized (Ingram 2000).



ENSO-precipitation relationships for southern Arizona.



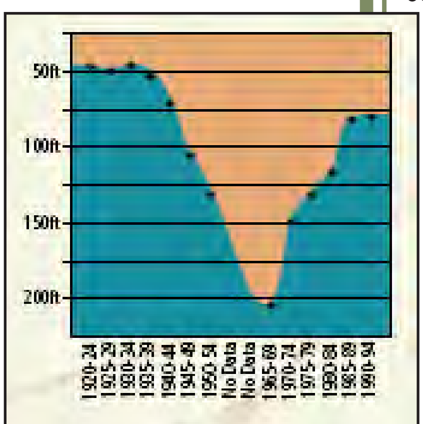


Example data from Saguaro National Park; high resolution climate monitoring network. Data from five stations are arranged along a topographic gradient.

Annual precipitation in the Sonoran Desert averages from 76-500 mm depending on location and altitude, with substantial inter-and intra-annual variability in timing and quantity (Sellers et al. 1985, Ingram 2000). Much of the spatial variation may be attributed to elevation. Precipitation typically increases with elevation due to the orographic effects of the "sky islands," where a sizeable proportion of precipitation occurrs as snowfall. It is the combination of orographic precipitation with dramatic decreases in temperature that supports the "Canadian Life Zone" flora and fauna at the uppermost elevations of the Sonoran Desert sky islands (Dimmitt 2000).

Interannual variation in precipitation throughout the region has been traced in part to El Nino and La Nina events. El Nino events occur when ocean waters in the western Pacific become unusually warm, diminishing atmospheric pressure gradients across the eastern Pacific (Ingram 2000). These shifts in global circulation patterns result in Pacific winter storms that develop farther south and east than in an average year, increasing the intensity and total precipitation of winter rainfall events in the Sonoran Desert (Ingram 2000). La Nina events occur when waters of the western Pacific are abnormally cold, and result in drought throughout the Sonoran Desert and Latin America. Climate reconstructions and modeling of potential global change consequences both suggest that the frequency and intensity of El Nino and La Nina events has been increasing since the Industrial Revolution, and is expected to accelerate with increasing CO_2 emissions (Emmanuel et al. 1985).

Finally, giant tropical storms occasionally move southeast from the North Pacific, constituting another source of interannual variation in precipitation. These storm events usually occur in early autumn. While infrequent, the storms have produced many of the largest rainfall events ever recorded in the American Southwest, resulting in widespread flooding and severe erosion throughout the region (Ingram 2000).



Mean water level (from Arizona Department of Water Resources and USGS well measurements) near Casa Grande Ruins National Monument shows remarkable decline then recovery over an 80-year period. Recent work suggests that surface subsidence resulting from future accelerated groundwater pumping could risk collapse of Casa Grande ("Great House"), the monument's 700-year old centerpiece structure.

Temperatures in the Sonoran Desert can also be quite variable. As the Sonoran is a hot desert, it should not be surprising that summer air temperatures routinely exceed 40°C, and often reach 48°C. These high near-surface temperatures interact with cool, moist air in the atmosphere to produce the violent thunderstorms of the summer monsoons (Ingram 2000). As moisture on the soil surface and near-surface air evaporates following a storm, however, temperatures may drop 10°C or more, often within a matter of minutes. Winter temperatures are mild, with valley bottoms typically free of frost, while the surrounding mountains may have dense snow cover at high elevations and on north and east aspects. During any season, diurnal swings of 15°C or more are common, as the dry atmosphere and relatively low vegetation cover facilitate reradiation of daytime heat into the atmosphere overnight.

1.3.3. Geology

The Sonoran Desert occupies approximately 260,000 km^2 of the southwestern United States and northwestern Mexico, including the southern half of Arizona, southeastern California, and most of the States of Sonora and Baja California, Mexico (Dimmitt 2000). Bounded on the north by the Mogollon Rim, the Sonoran Desert grades into the Chihuahuan Desert to the east, the Mohave Desert to the west, and the tropical forests and montane forests of central Mexico to the south (Brown and Lowe 1980, Van Devender 2000, Olson et al. 2001). Extending between 23°N and 30°N, the subtropical Sonoran Desert represents a continental scale ecotone between the tropics and temperate zones of western North America (MacMahon 1985). At a regional scale, the Sonoran Desert serves as a transition between the Sierra Madre and the Rocky Mountains, the Pacific and Gulf coasts, and the coastal lowlands of Baja and the mid-continent.

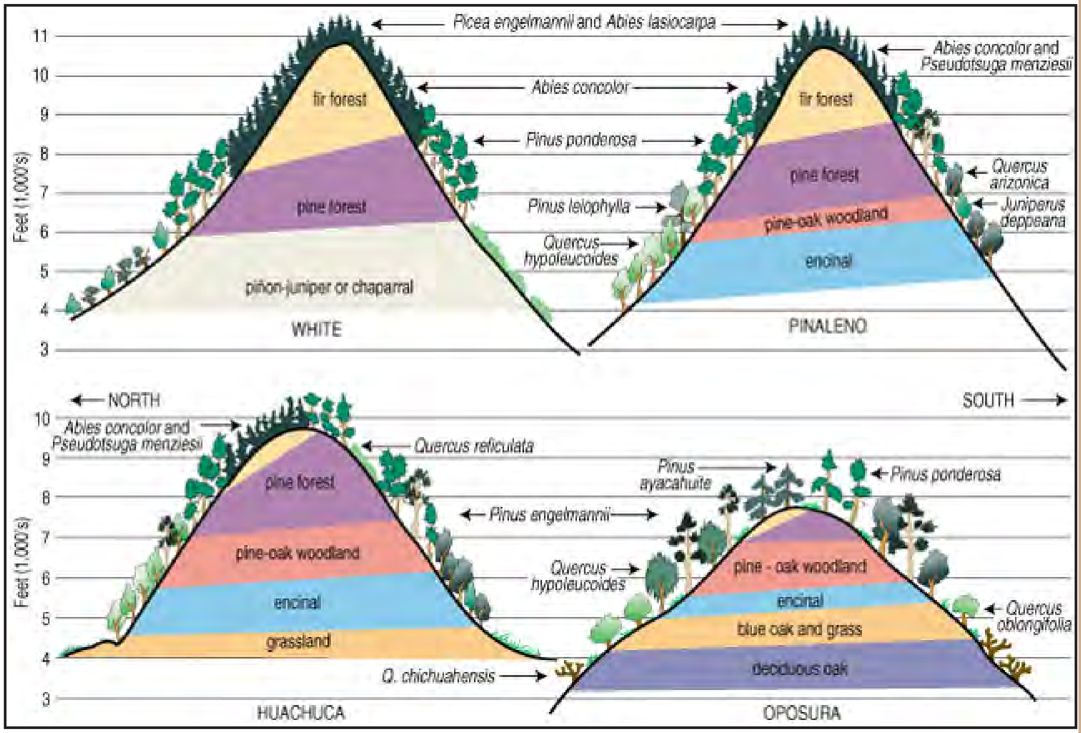
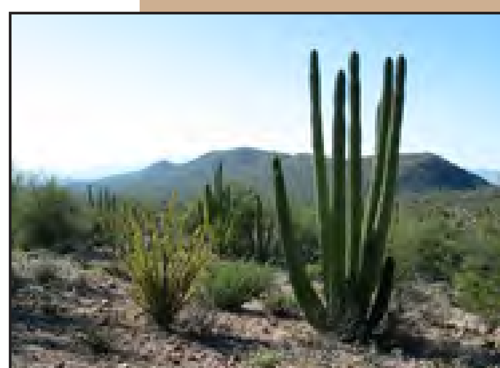


Figure 1.3. Cross-sections of four sky islands showing the stacked biotic communities (Marshall 1957).

The Sonoran Desert is composed of sedimentary, igneous, and metamorphic rocks with widely varying ages, from 2-billion year old Precambrian outcroppings in Arizona to relatively recent (ca. 700 A.D.) volcanism in the Pinacate region near the international border (MacMahon 1985). Between 20 and 40 million years ago (mya), numerous volcanoes were active in the Sonoran Desert, resulting in large calderas (basins formed by volcanic explosions), lava vents, and cinder cones (Nations and Stump 1983). Between 12 and 25 mya, the Pacific Coast became attached to the Pacific Ocean plate (Scarborough 2000), causing tremendous stress on the crusts underlying the Sonoran Desert, which were simultaneously intensely heated from below (Van Devender 2000). Scarborough (2000) compares the results of this stress to stretching a caramel candy: "…the fluid caramel (superheated lower crust) stretches while the hard coating (upper crust) shatters." These stresses caused tremendous horizontal and vertical movement, with the resulting arching and faulting producing the "basin and range" topography characteristic of the Sonoran Desert (Harris 1990, McPhee 1990).



An example of desertscrub at Organ Pipe National Monument. November 2003.

This "basin and range" topography consists of roughly parallel mountain ranges separated by broad valleys flanked by "bajadas" of coalesced alluvial fans (Scarborough 2000). Many of these ranges approach 2,700 m. This precipitous topographic relief provides for radical differences in climate along slopes, with the relatively cool and moist summits (due to orographic precipitation) containing lifezones more characteristic of Canada than those of the valley bottoms below. These montane habitats (accentuated by north and east aspects and local topography) are termed "sky islands," and from the perspective of biogeography, speciation, and landscape connectivity, are analogous to marine islands. In combination with the bimodal precipitation regime and mid-continental position, this tremendous variation in topography over relatively fine scales produces the amazing diversity of the Sonoran Desert.

An example of chaparral at Montezuma Castle National Monument. May 2004.

1.3.4. Water Resources

Surface water plays a critical role in Sonoran Desert ecosystems. Over 90 percent of all species in the region utilize riparian areas or aquatic ecosystems for some portion of their lifecycles (Phillips and Comus 2000). Some of the most unique water bodies in Sonoran Desert Network parks include Quitobaquito spring in ORPI and Montezuma's Well in MOCA. Other aquatic resources in the SODN include streams (perennial, ephemeral, and intermittent, effluent), a reservior, Tavasci Marsh (TUZI), springs, seeps, and tinajas (small bedrock pools of water). SODN parks also host perennial, ephemeral, and intermediate streams. Perennial streams are characterized by flowing water in a well-defined channel at least 90 percent of the time, intermittent streams have flow that generally occurs only during the wet season (50 percent of the time or less), and ephemeral streams have no defined channel, with flow occurring only for a short duration after extreme storms.

Aquatic habitats in the southwest are threatened, primarily through groundwater pumping for agriculture and urban water use. Water quality is also impacted by urban runoff, agricultural runoff, mine drainage, industural pollution, and other non-point source pollution.

1.3.5. Biotic Communities

Sky islands, mountain ranges isolated by intervening valleys of grass or desert, are areas of remarkable biological diversity as a result of great habitat diversity. The biotic communities found along sky island gradients include desert, thornscrub, short-grass prairies, oak savanna, deciduous riparian forest, oak-pine woodlands, and mixed conifer forests (Figure 1.3.; Marshall 1957). The sky islands of the southwestern United States are unique – this complex extends from subtropical to temperate latitudes, hosting species from the Sierra Madre of Mexico and the Rocky Mountains of the United States (Warshall 1994). Because sky islands are isolated by inhospitable territory, genetic interchange between populations is limited. Speciation is common in the area, and has resulted in high numbers of endemic species.

Desert and Thornscrub Systems

The lowest in elevation and driest biotic community, aridity is the primary determinant of desert vegetation. Net primary productivity (NPP) is relatively low, though lifeform diversity is high, with plants from all three photosynthetic pathways (C3, C4, CAM) being represented. Plants are well spaced and typically exhibit microphyllous leaf phenologies. Sonoran Desert variants of desert and thornscrub communities contain a variety of phreatophytic shrubs such as velvet mesquite (*Prosopis velutina*), acacias (*Acacia spp.*), palo verdes (*Cercidium spp.*), and creosote bush (*Larrea tridentata*), to name but a few. Succulents are ubiquitous in desert, and to a lesser degree, thornscrub, with agave (*Agave spp.*), yucca (*Yucca spp.*), barrel cactus (*Ferrocactus and Echinocactus spp.*), hedgehog cactus (*Mammalaria spp.*), and prickly pear and cholla (*Opuntia spp.*) common. Warm- and cool-season annuals, both native (e.g., *Plantago patagonica*) and introduced (e.g., *Bromus rubens*) are common following rainfall. The desert biotic community is dominant in low elevation parks including Casa Grande National Monument, parts of Organ Pipe Cactus National Monument, and Saguaro National Park.

The introduction of nonnative species such as red brome (*Bromus rubens*) and buffelgrass (*Pennisetum ciliare*) to the Sonoran Desert has had far-reaching impacts. Historically, this ecosystem rarely burns naturally; many Sonoran Desert plants are not adapted to fire (Dimmitt 2000). Following rains, introduced species grow prolifically in mats, providing ample fuel for fires to race across the desert. Drought-tolerant invasive grasses are a serious threat for this ecosystem. Burning kills native vegetation, opening up the land for further invasion by nonnatives.

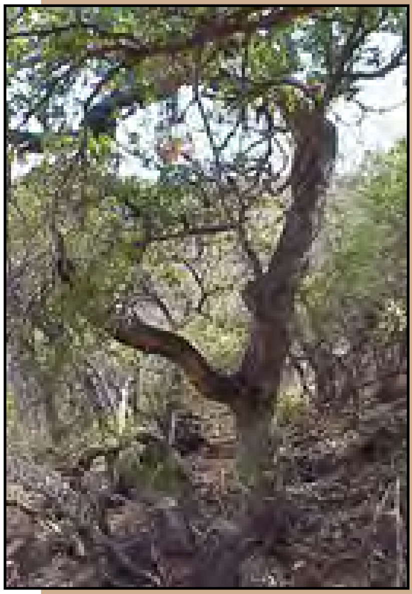
Chaparral

Chaparral is a semiarid shrub biotic community that occurs on the west coast of every continent between 30° and 40°N latitude. Chaparral in the Sonoran Desert is found along the Mogollon Rim in the upper Sonoran subdivision. This interior variety of chaparral has fewer species than the coastal variety in California. Interior chaparral is composed of dense stands of manzanita (*Arctostaphylos spp.*) and shrub live oak (*Quercus dumosa*). These species have thick sclerophyllous leaves containing large quantities of volatile compounds. The natural fire regime for chaparral includes intense, fast moving fires that are often stand-replacing. Manzanita requires charrate (burned woody material) for sexual reproduction, and each of these species sprouts vigorously following fire (Epple 1995). Chapparal is found in the vicinity of Tonto, Montezuma Castle, and Tuzigoot.

An example of semi-desert grassland at Fort Bowie National Historic Site. October 2003.

Semi-desert Grasslands

In contrast to the Great Plains, grasslands in the Sonoran Desert are semi-desert in nature, and typically composed of perennial short- and mid-grass species. Annuals and geophytes are also common, with occasional shrubs or trees. Most grasses in semi-desert grasslands use the C4 photosynthetic pathway that provide for greater water use efficiency than the C3 photosynthetic pathway of most other plants. Fire is a relatively common and necessary occurrence in semi-desert grassland, historically burning every five to ten years. Fire maintains the open structure of the ecosystem, conferring a competitive advantage to gramminoids over most woody plants. Fire suppression, intensive grazing, and soil erosion have degraded much of the grassland ecosystem in this region, leading to encroachment by woody species and drought-resistant nonnative grasses such as Lehmann lovegrass (*Eragrostis lehmanniana*). Semi-desert grasslands are an important ecosystem in several SODN parks, including Coronado National Memorial, Chiricahua National Monument, Fort Bowie National Historic Site, Tumacacori National Historical Park, the uplands at Tonto National Monument, and at mid-elevations at Saguaro National Park. Lehmann lovegrass and other exotic grasses have invaded and impacted all of these grasslands.



An example of madrean evergreen woodland at Coronado National Memorial. Summer 2002.

Woody plant abundance has increased markedly in North American grasslands over the past several centuries (Hobbs and Mooney 1986). Grazing, fires or fire suppression, and climate influence grassland production and composition both directly and through interactions.

Madrean Evergreen Woodland

Madrean evergreen woodland is the most extensive woodland type in the Sonoran Desert region, and is ubiquitous at mid-elevations throughout the Apache Highlands (Bailey 1998, McPherson 1993). Madrean evergreen woodland is characterized by evergreen oaks with thick sclerophyllous leaves, such as emory oak (*Quercus emoryii*), Arizona white oak (*Quercus arizonica*), and Mexican blue oak (*Quercus turbinella*). Mexican pinyon pine (*Pinus concolor*) and alligator juniper (*Juniperus deppeana*) are common gymnosperms in Madrean evergreen woodland. Understory grasses are usually abundant. Madrean evergreen woodland is typically bounded by semi-desert grassland.

An example of coniferous forest at Saguaro National Park. August 2002.

Coniferous Forests

Dominated by gymnosperms such as pines (*Pinus spp.*), spruces (*Picea spp.*), and firs (*Abies spp.*), coniferous forest represents the most cold-hardy biotic community in the

Sonoran Desert. Confined to cooler sites (a function of elevation, aspect, and local geomorphology) under the current warm interglacial climate, conifer forest occurs upslope from temperate deciduous forest. Most of the conifer forests in the Sonoran Desert are dominated by ponderosa pine (*Pinus ponderosa*), with a grassy understory where canopies are relatively open, and subdominant trees and shrubs where canopies coalesce. Douglas fir (*Psuedotsuga menzezii*) and true firs (*Abies spp*.) occur at higher elevations, with spruce (*Picea spp.*) at the highest elevations. Conifer forests are fire-adapted ecosystems, with natural low-intensity fires occurring every nine to fifteen years in ponderosa pine and mixed-conifer forests (Dimmitt 2000). Suppression of fires by humans has disrupted the natural cycles within many of these communities. Conifer forests occur at Chiricahua National Monument, Gila Cliff Dwellings National Monument, and Saguaro National Park.

Temperate Deciduous Forests

Temperate deciduous forests are characterized by cold deciduous woody plants such as gambel oak (*Quercus gambellii*), trembling aspen (*Populus tremuloides*), and maples and boxelder (*Acer spp.*). Occurring at high elevations, often on north-facing slopes, temperate deciduous forest is typically interspersed with coniferous forest on hills and mountains of the Sonoran Desert. Cold deciduous species are often found in the understory of coniferous forests as well. Temperate deciduous forests are found in Chiricahua National Monument, Gila Cliff Dwellings National Monument, and Saguaro National Park.

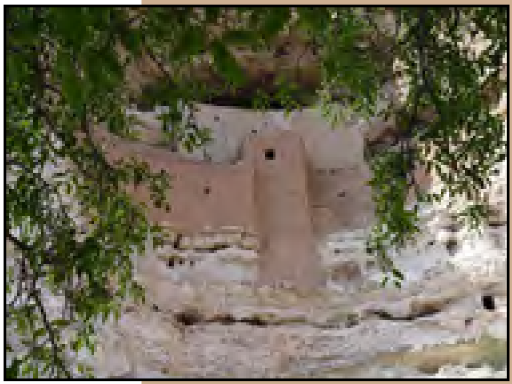
1.3.6. Biogeography

The Sonoran Desert occupies approximately 260,000 square km of the southwestern United States and northwestern Mexico, including the southern half of Arizona, southeastern California, and most of the States of Sonoran and Baja California, Mexico. Bounded on the north by the Mogollon Rim, the Sonoran Desert grades into the Chihuahuan Desert to the east, the Mohave Desert to the west, and the tropical forests and montane forests of central Mexico to the south. Extending between 23°N and 30°N, the subtropical Sonoran Desert represents a continental scale ecotone between the tropics and temperate zones of western North America.

The Sonoran Desert is composed of sedimentary, igneous and metamorphic rocks with widely varying ages, from 2-billion year old Precambrian outcroppings in Arizona to relatively recent (ca. 700 A.D.) volcanism in the Pinacate region near the international border. Between 20 and 40 million years ago, numerous volcanoes were active in the Sonoran Desert, resulting in large calderas (basins formed by volcanic explosions), lava vents, and cinder cones. Most of the flora and fauna now found within the region began colonizing the area approximately 14,000 years ago, as the last ice age ended. However, the climate of the Holocene (~11,000 years ago to present) is outside the norm when geologic time scales are considered. In fact, the Sonoran Desert region was subject to cooler temperatures and more moisture during the Pleistocene (1.8 million to 11,000 years ago). Thus the warm, arid conditions that the current flora and fauna have adapted to are in fact relatively recent and are subject to change as the planet shifts out of the recent interglacial stage (McLaughlin and Bowers 1999).

Broad-scale geologic features, climate and disturbance events have defined the framework for spatial patterns of species biodiversity in the SODN. Additionally, the interplay of three fundamental processes—evolution, extinction, and dispersal—has shaped the distribution and diversity of species that presently inhabit the Sonoran Desert, which is considered one of the most diverse deserts in the world. A bi-seasonal precipitation regime provides the region with considerable rainfall in many locations (76-500mm), while a diverse topography supplies a wide variety of habitats.

The Sonoran Desert also sits at what is generally considered the southern most edge of many temperate species ranges and at the northern most edge of many tropical species ranges. This is reflected in the relatively diverse populations seen within the region. For example, at least 60 species of mammals, more than 350 bird species, 20 amphibians, some 100 reptiles, and about 30 species of native fish are found with the region. More than 2,000 species of plants have been identified in the Sonoran Desert, and each of the three physiological groupings of vascular plants (C3, C4, and CAM photosynthetic pathways) dominate one or more major biotic communities. The great variation in flora and fauna is supplemented with a great variation in ecological behavior and response, thus as Shreve and Wiggins (1951) noted, this makes, "almost every species a distinct entity requiring separate investigation." This set of conditions has led to a unique assemblage of flora and fauna that has responded to the climatic changes of the last 14,000 years. As a result many species have established and flourished, and others have been extirpated. More recently, the influence of modern human society has played a significant role in shaping the flora and fauna of the region. Rapid extinction of some species (from the extermination of much of the megafauna 12,000 years ago to the elimination of the gray wolf in the last 100 years) and increased rate of species introductions (from the introduction of cattle and horses starting with the Columbian expeditions to the introductions of Lehmann lovegrass and buffelgrass in contemporary times) has played a significant role in the modern shaping of the biological community of the Sonoran Desert.



Montezuma Castle National Monument. April 2004.

1.3.7. Human History

Humans have influenced Sonoran Desert ecosystems in what are today the States of Arizona and Sonora for millennia (Sheridan 2000). Martin (1999) postulated that overexploitation by Stone Age Native Americans may have led to the documented extinctions of Pleistocene megafauna in North America. While Martin's theory is controversial, Paleoindians undoubtedly influenced plant and animal populations. Archaeological remains indicate that later inhabitants, the Hohokam, impacted flora and fauna by selective hunting/collecting practices and by dispersing species (particularly plants) throughout the Sonoran Desert (Nabhan 2000, Sheridan 2000). The advent of agriculture in the region some 3,000 years ago appears to have had the greatest impact in the pre-Columbian Sonoran Desert (Sheridan 2000). Early practitioners employed runoff irrigation, called Ak-Chin by the Tohono O'odham, wherein seeds of crop plants were sown near washes to capture runoff during the rainy seasons (Bowden 1977). The Hohokam constructed massive systems of irrigation canals along major river valleys, such as the Gila, before abandoning them by around the 15th century (Bowden 1977).

Tuzigoot National Monument. June 2004.

The first Europeans to arrive in the Sonoran Desert region were Spanish explorers in the early 16th century, whose primary settlements were initally focused to the south in present-day Sonora and further into Mexico (Sheridan 2000). The Spanish slowly expanded their settlements northward until halted by the Mexican-American War of 1846. Following that war, Anglo-Americans began to settle in increasing numbers in the new territories of Arizona, California and New Mexico (Marshall et al. 2000). The arrival of Europeans to the Sonoran Desert has been called an "an ecological revolution," as the introduction of Eurasian plants, animals, and microbes transformed landscapes (Sheridan 2000). Livestock grazing was the most extensive Euro-American modification of the Sonoran Desert, while mining was the most intensive land-use

Tumacacori Historical National Park. February 2004.

practice introduced to the region (Sheridan 2000). Both practices caused substantial degradation in the southern and central Sonora Desert by the mid-19th century, with numerous accounts of overgrazing and subsequent abandonment during the colonial period. These practices were not prevalent in southern Arizona since the Apache and other hostile indigenous groups greatly limited Spanish and American settlement until the late 19th century. Following the suppression of these groups, waves of miners, ranchers, and farmers settled the area. Mining and ranching activities were economically linked in a "ranch-mine settlement complex" (West 1949), wherein ranches developed around mining towns to supply the meat, timber, and fuelwood required by the mining operations. During this period, the "three C's" – cattle, copper, and cotton (grown in irrigated fields along rivercourses) dominated the economy of the region (Sheridan 2000). Pastoralism and mining peaked near the turn of the 20th century, and then began a slow decline that accelerated after the Second World War (Sheridan 2000).

Montezuma Castle National Monument, Well Unit. April 2004.

The development of modern transportation systems, the diesel pump, and the era of dam building in the U.S. (Reisner 1986, Nabhan and Holdsworth 1998) spurred a boom in irrigated agriculture beginning in the 1930s. Groundwater overdrafts were common on both the U.S. and Mexican sides of the international border, and many riparian ecosystems were rapidly converted to crop and orchard production (Sheridan 1995). Casa Grande Ruins National Monument provides a poignant example of the ecological effects of groundwater mining, as described by Nabhan and Klett (1994): "Today, the Indian ruin sits in Casa Grande National Monument right in the middle of hundreds of acres of rotting trees killed by the drawdown of groundwater below their root level."

As groundwater tables dropped and economic trends shifted, many thousands of acres of cropland were abandoned, with production continuing in areas with water developments (dams, canals), or near reliable aquifers or surface water (Reisner 1986). In Arizona, tremendous urban growth accelerated through the 1970s, transforming former orange groves and native desert into tract homes and shopping malls. After a brief slowing in the late 1980s, this trend is currently in full swing. The 1990s saw the development of manufacturing and transportation industries on both sides of the border in response to the North American Free Trade Agreement.

Gila Cliff Dwellings National Monument. April 2004.

1.3.8. Natural Disturbance

Natural disturbances are important drivers of change and are defined as any relatively discrete events in space and time that disrupt ecosystem, community, or population structure and change resources, substrate, or the physical environment (White and Pickett 1985). The key components of this definition are that disturbances are discrete in time, in contrast to chronic stress or background environmental variability, and that they cause a notable change, a perturbation, in the state of the system. Within the Sonoran Desert and Apache Highlands ecoregions, fire is the primary disturbance agent, whether as a single, discrete event or multiple events comprising a native fire regime.

Fire is a powerful force in maintaining the landscape patterns and processes of the semi-arid regions of southeastern Arizona (Bahre 1991, McPherson 1997). While the characteristics of a native fire regime may work to shape plant communities, the long-term native fire regime is likely a result of, more than a cause of, vegetation patterns. Native species in the American Southwest have evolved in concert with periodic fires and thus have evolved beneficial adaptations to fires that occur at a particular frequency, season, and extent. Contemporary fires, however, are often unlike the fires with which many native species have evolved and communities have developed. A century of fire suppression, along with the introduction of nonnative species, has changed the mix of species and increased fuels in many of these systems. Historically, it is believed that fires burned frequently (every 2 to 10 years) at low intensity in lower elevations and less frequently but with moderate intensity at higher elevations (Swetnam and Baisan, 1996). Fires at these intensities and frequencies allowed for much of the understory to be thinned, thus reducing the chances for high-intensity, large-scale fires. Additionally, fires in existing systems may be favoring nonnative species to a greater extent than they favor native species, thus altering the native biological composition and structure (McPherson and DeStefano 2003). As a result of these changes, single, large-scale catastrophic fires are playing an increasingly important role in ecosystem functioning in recent times. High-intensity wildfire can have catastrophic effects including erosion, loss of seed sources for natural regeneration of tree species, wildlife habitat loss, a breakdown in the proper functioning of ecosystems, and reduced future site productivity. While the implications for catastrophic wildfire are obvious, such conditions are also favorable for insect and disease epidemics. Insects are often attracted to fire-damaged or killed trees and their build-up in these weakened hosts can threaten adjacent, unburned stands.

As a result of the interactions of these forces of natural disturbance, ecosystems in the Sonoran Desert and Apache Highlands ecoregions are in a constant state of flux, creating significant natural variability at several spatial and temporal scales.

Agriculture has substantial impacts on ecosystem function.

1.3.9. Anthropogenic Threats

The dominant patterns of human use of the Sonoran Desert ecoregion pose several notable challenges to natural resource management in SODN parks. For example, dramatic urban population growth through in-migration to the region entails changing land use patterns such as the expansion of urban land uses and infrastructure. The landscape is also heavily influenced by the public ownership of over two-thirds of the U.S. portion of the Sonoran Desert ecoregion (Marshall et al. 2000). SODN staff and local experts identified the most important anthropogenic influences on park ecosystems as: population growth, intensification of urban-wildlife interfaces, landscape and habitat fragmentation, exotic/invasive plants, U.S.-Mexico border impacts, altered fire regimes, and recreation and park visitor use impacts (see Section 1.4.1. Resource Management Issues and Stressors). Additional related issues for the region identified by Nabhan and Holdsworth (1998) include human water use, grazing practices and conversion of land to agricultural uses.

Immigrant foot paths in Coronodo NM.

The SODN parks are located in what is known as the “Sunbelt” region in the southwestern United States. The Sunbelt, a metaphor for rising opportunities, is known for its growth in economic activity and population spurred by in-migration of people and industry to the region in the post-World War II era. Its population nearly doubled between 1970 and 1990 to 6.9 million (Nabhan and Holdsworth 1998). Between the years 1990 and 2000, the State of Arizona tolerated a population growth rate of 40%, second nationally to neighboring Nevada which can also be included in the Sunbelt region. The eleven SODN parks are juxtaposed in the landscape with the major metropolitan Sunbelt center of Phoenix-Mesa, Arizona (2000 population of 3.2 million) which experienced a 1990-2000 45.3% growth rate encompassing over 1 million new urbanites (8th nationally). Other urban areas such as Tucson, Arizona, with an estimated current population of 870,000 (26% growth rate 1990-2000), and numerous smaller – but rapidly growing – communities like Yuma, Arizona, (49.7% growth rate 1990-2000; 3rd nationally), and Santa Cruz County, Arizona (29% growth rate 1990-2000), both adjacent to the U.S.-Mexico border. These urban areas are also loci of population movement and growth influenced heavily by commercial and social interactions with Mexico (population totals and estimates from US Bureau of the Census).

Population growth and urbanization have entailed an intensification of urban-wildlife interfaces in the region through associated changes in land use, recreation and travel patterns. Some of the increases in interfaces occur within park boundaries through increases in visitation or in commuter traffic through park lands. Many more occur outside park boundaries but affect wildlife populations with ranges and/or migration routes intersecting with population centers and roads. Highway mortality of amphibians and large mammals is one example (Fahrig et al. 1995, Forman and Alexander 1998).

Changes in adjacent land uses also contribute to fragmentation of habitats and landscapes. For example, human-intensive land use practices such as the conversion of land to agricultural and urban uses over time affect land cover across the Sonoran Desert (Nabhan and Holdsworth 1998, Nabhan 2000). Many of these changes occur largely outside of park boundaries so that parks themselves serve as refuges for many animal and plant species. Nonetheless, the fragmentation that occurs regionally interrupts habitat connections between parks and other conservation areas. Thus species/population movements throughout their range can become severely limited (as in the case of pronghorn). Road and trail construction represents another extremely important cause of fragmentation, both within and outside of SODN units, by eliminating habitat, creating "edge" habitats, and creating barriers to wildlife movement corridors.

Erodium cicutarium, a common exotic species in SODN parks.

The introduction and spread of exotic invasive plant species pose a significant challenge to ecosystem management within several SODN parks. In a recent inventory of Montezuma Castle National Monument and Tuzigoot National Monument, thirty-three out of fifty target species of nonnative plants were encountered (Mau-Crimmins et al. 2004). Some estimate that over 60 percent of the Sonoran Desert surface is dominated by nonnative species introduced by people and livestock (Nabhan 2000). Of particular concern to the region are nonnative grasses such as buffelgrass (*Pennisetum ciliare*) and Lehmann lovegrass (*Eragrostis lehmanniana*) introduced through cattle grazing practices, which are now well-established and continue to spread via cattle and other animals, vehicles and humans. At Organ Pipe Cactus National Monument, a recent eradication project removed nearly 100 tons of buffelgrass from a 25 square mile area of the park over a period of two years (Marshall et al. 2000).

Further human impacts to SODN ecosystems are now associated with the flows of people across the U.S.-Mexico border and border enforcement activities. Under the current political and policy scenario, the relatively recent intensification of these impacts over the last ten years are some of the most high profile human impacts in the southernmost network parks including Organ Pipe Cactus National Monument and Coronodo National Memorial and in adjacent public and tribal lands. Although not directly adjacent to the international border, Chiricahua National Monument, Tumacacori Historical National Park and Fort Bowie National Historic Site also experience some border-related traffic and enforcement impacts. Current evidence of traffic flows/enforcement includes tire tracks, footpaths, discarded belongings, informal campsites, traffic barriers, and other law enforcement constructions. Potential impacts include soil compaction, vegetation trampling, deterioration of water quality, and disturbance of wildlife and wildlife habitats.

Visitors use park resources for recreation.

The large-scale alteration of historical fire regimes across the southwest and in northern Mexico, through changes in fire management, climatic and other ecosystem factors, has played a part in numerous fire events and ecosystem disturbance at SODN parks throughout the twentieth century. In spite of the important role that fire plays in ecosystem maintenance, increases in human population in the region have intensified the pressure for fire suppression and the potential financial/human costs. Likewise, since many of these fires take place in the region's unique "sky island" habitats they may exact an especially high ecological cost because of the growing scarcity of such habitats. Because so much of the Sonoran Desert is managed publicly and because of the proximity to Mexico, interagency and cross-border coordination has become a crucial component of SODN fire management.

With local population growth and steady tourist flows from outside the region, visitation to SODN parks and changes in recreation activity patterns are of special concern. These patterns result in changing demands on park resources and infrastructure from year to year. In addition, because of the unique SODN climate, recreation patterns vary dramatically throughout the year, with peaks in visitation during cooler months.

Of specific interest to park managers are potential impacts to park resources such as trampling effects on soils, vegetation, disturbance to aquatic resources, behavioral disturbances to wildlife, and damage to cultural resources. Visitor use densities vary widely among the parks. For instance, Montezuma Castle National Monument (one of the smaller network parks with under 2,000 acres) and Saguaro National Park (one of the larger units with 91,440 acres) are the two SODN parks with the highest number annual visitors measured in 2003, both at about 637,000 (NPS Statistical Abstract 2003).

1.4. Park Natural Resources and Management Priorities

1.4.1. Resource Management Issues and Stressors

Important management issues for SODN parks were identified through a variety of methods, including an initial issue/stressor survey, broad scoping meetings, a survey of park planning documents, and park-based scoping sessions. Additionally, regionally important issues were identified through a perusal of documents produced by other land management agencies. Copies of relevant surveys and scoping documents appear in the appendices to this document.

1.4.2. Issue/Stressor Survey

In summer 2001, SODN parks individually completed a survey of park management issues and stressors (see Appendix D). The primary benefit of this exercise was to focus park staff on resource-management and monitoring issues. The survey was of limited value, however, for network-wide scoping because the results were incongruous; with limited instructions and feedback, each park tended to create their own approach to issue selection, specificity, and scale. As this effort occurred prior to hiring a Network Coordinator or Data Manager, it was unrealistic to expect park staff (with numerous other commitments) to "self-organize" this survey.

1.4.3. Broad Scoping Meetings

In late 2001-2002, three broad scoping meetings were conducted to identify and evaluate management issues and concerns. Participants included SODN park resource management staff (Southern Arizona Parks Resource Managers) and experts from the NPS Water Resources Division, U.S. Geological Survey (USGS) Biological Resource Division and Water Resources Division, Arizona Department of Environmental Quality, University of Arizona, Colorado State University, Pima County, the Sonoran Institute, and the Arizona-Sonora Desert Museum.

Vital sign scoping meeting. May 2003.

These scoping meetings identified five leading resource management issues for SODN parks:

- urban/park interface issues such as landscape/habitat fragmentation
- encroachment of exotic plants
- border impacts, particularly undocumented migration and narcotics smuggling
- altered fire regimes (results of fire suppression at high elevations, increased fire frequency at low elevations)
- visitor impacts

These meetings played an important role in the vital signs signs process by identifying resources management issues common to several SODN parks.

1.4.4. Issues Identified in Park Planning Documents

A extensive review of park planning documents was completed in 2003. This review included General Management Plans (GMPs), Resource Management Plans (RMPs), Fire Management Plans (FMPs), administrative histories, and enabling legislation (often as interpreted through planning documents) for all eleven SODN parks. A summary of park planning documents relevant to monitoring appears in Appendix E. This approach was very useful as park-specific information that had received multiple layers of review and evaluation were identified and aggregated to the network scale. In addition, these documents set the local mandates for management in these units, and are therefore directly relevant to ecological monitoring. Issues identified in these documents were typically vague (e.g., "maintain natural ecosystem processes"), and park interviews indicated that issues were often out of date.

1.4.5. Regional Assessments

Nabhan and Holdsworth (1998) surveyed 54 field scientists with a comprehensive knowledge of the Sonoran Desert (average field research experience was ca. 20 years) to identify and prioritize "threats" to ecological systems of the region. As patterns of land use and human development in the region have shifted dramatically since the mid-20th century, respondents were asked to focus on the most significant threats since 1975. The top ten threats identified (in priority order) were:

- urbanization's aggravation of habitat conversion and fragmentation;
- the high rate of in-migration of newcomers to reside, work and recreate in the region, and their contribution to population growth and resource consumption;
- surface water impoundment and diversion from places where native vegetation and wildlife have access to it;
- inappropriate grazing of vegetation by livestock, especially when combined with conversion of plant cover to exotic pasture grasses;
- aquifer mining and salinization, the drop in water table, and their long-term effects on riparian vegetation and wildlife;
- lack of planning for growth;
- exotic [non-native] grass planting;
- conversion to farmlands;
- recreational impacts; and
- biological invasions.

The results from this study have gained wide acceptance with regional policymakers and scientists, and serve as the basis for a primary conservation planning effort in the Sonoran Desert (Marshall et al. 2000). The approach is useful for placing parks in a regional/bi-national context and reflects a broad range of ecological disciplines and mandates. Further, it substantiates many of the management issues and stressors identified through the other approaches. However, the broad application likely misses some of the key local issues facing park managers, and addressing many of these issues may be beyond the realm of an individual park or even the network as a whole.

1.4.6. Issues Identified in Park-Based Scoping

To complement the preceding efforts, "park-based" scoping was initiated in autumn of 2002. Each park was visited individually during late 2002-early 2003 by SODN staff for a three part scoping session:

A. A review and discussion of basic inventory datasets and existing ecological data; the group then set priorities for addressing gaps in these fundamental datasets.

B. Exhaustive dialogue to identify and "flesh out" park management goals, concerns, and ecological stressors.

C. A group discussion and evaluation of existing monitoring and potential vital signs.

A modified version of the nominal group technique (Moore 1994) was used to conduct the scoping meetings. Parks were asked to review the stressor surveys they completed in 2001 and 2002 and to discuss these monitoring issues amongst themselves prior to the scoping meeting. Park management and staff other than resource managers were encouraged to attend, particularly Superintendents and Division Chiefs. The input from these staff members (many of whom had not attended any prior network meetings) greatly refined the scoping process, particularly the identification of park goals and concerns. Park partners were invited to participate as well. The UA Biological Inventory, USGS- Sonoran Desert Field Station, Desert Southwest Cooperative Ecosystem Studies Unit, Sonoran Institute, and UA-Water Resources Research Center played active roles in this scoping effort. Table 1.5 provides a summary of scoping results (Appendix F). Material on current park monitoring projects is presented in existing monitoring in SODN parks. The results of this dialogue have provided direction and focus to the monitoring design process.

1.5. Designing an Integrated Monitoring Program for the SODN

Should vital signs monitoring focus on the effects of known threats to park resources or on general properties of ecosystem status? Woodley et al. (1993), Woodward et al. (1999), Jenkins et al. (2002) and others have described some of the advantages and disadvantages of various monitoring approaches, including a strictly threats-based monitoring program, or alternate taxonomic, integrative, reductionist, or hypothesis-testing monitoring designs (Woodley et al. 1993, Woodward et al. 1999). The approach adopted by SODN agrees with the assertion that the best way to meet the challenges of monitoring in national parks and other protected areas is to achieve a balance among different monitoring approaches (termed the "hybrid approach" by Noon 2003), while recognizing that the program will not succeed without also considering political issues. A multi-faceted approach for monitoring park resources was adapted, based on both integrated and threat-specific monitoring approaches and building upon concepts presented originally for the Canadian national parks (Figure 1.4, Woodley et al. 1993). This system segretates indicators into one or more of four broad categories.

(1) ecosystem drivers that fundamentally affect park ecosystems,

(2) stressors and their ecological effects,

(3) focal resources of parks, and

(4) key properties and processes of ecosystem integrity.

Table 1.5. Summary of resource management concerns expressed in park Vital Signs scoping sessions.

	Topic	CAGR	CHIR	CORO	FOBO	GICL	MOCA	ORPI	SAGU	TONT	TUMA	TUZI
General	Adjacent land use (residential)	X	X	X	X		X		X		X	X
	Adjacent land use (non-residential)[a]	X	X		X				X	X	X	X
	Border impacts		X	X	X			X	X		X	
	Recreation impacts		X		X			X	X		X	
Specific	Non-native flora	X	X	X	X	X	X	X	X	X	X	X
	Water quality	X	X	X	X	X	X	X	X	X	X	X
	Water quantity[b]	X	X	X	X		X	X	X	X	X	X
	Altered wildlife habitat use/fragmentation	X		X			X	X	X	X	X	X
	Non-native fauna[c]	X		X		X	X	X	X		X	X
	Erosion		X	X	X		X	X	X	X		
	Altered fire regimes	X	X	X	X	X		X	X		X	
	Trespass/poaching[d]	X	X	X			X	X	X		X	
	Viewscapes		X	X			X		X		X	X
	Overflights/vibration hazards[e]	X		X	X		X		X			
	T&E Species issues		X	X				X	X		X	
	Noise pollution	X			X		X	X	X			
	Trash	X		X				X			X	
	Columnar cacti regen.							X	X	X		
	Light pollution		X		X				X			
	Nuisance animal populations	X					X			X		
	Bark beetle		X			X			X			
	Roadkill							X	X	X		
	Vegetation removal	X						X				
	Visitor safety			X				X				
	Local political concerns	X										
	Pesticide drift	X										
	Shrub encroachment				X							

[a] e.g., agriculture, pastoralism

[b] including groundwater

[c] including stray pets and trespass cattle, and dam age to cultural resources

[d] danger to ruins stability e.g., overflights, esp. helicopter

[e] of any resources e.g., firewood, potshards, cactus, etc.

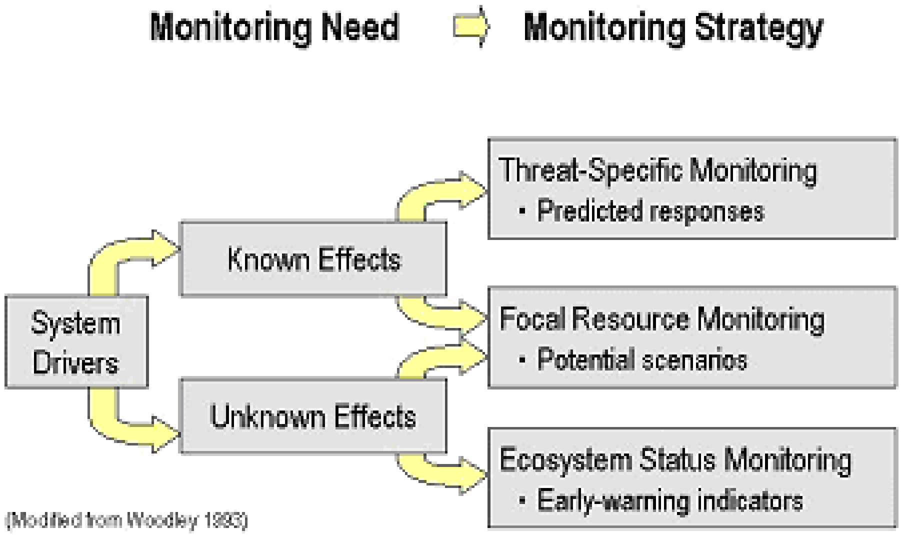
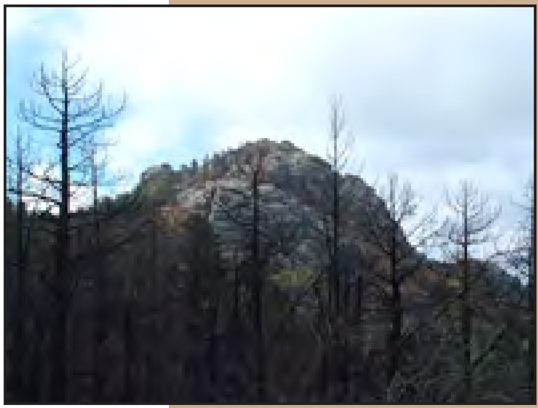


FIGURE 1.4. Conceptual approach for selecting monitoring indicators. Modified from Woodley et al. 1993.

In cases where there is a good understanding of relationships between potential effects and responses by park resources (known effects), monitoring of system drivers, stressors, and effected park resources is conducted. A set of focal resources (including ecological processes) will be monitored to address both known and unknown effects of system drivers and stressors on park resources. Key properties and processes of ecosystem status and integrity will be monitored to improve long-term understanding and potential early warning of undesirable changes in park resources.

Natural ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, and hydrologic cycles that have large scale influences on natural systems. Trends in ecosystem drivers will have corresponding effects on ecosystem components may provide early warning of presently unforeseen changes to ecosystems.



After fire effects at Saguaro National Park, one example of a natural stressor to park ecosystems. March 2004.

Stressors are 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 and Goldsmith 1976). 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. Monitoring of stressors and their effects, where known, will ensure short-term relevance of the monitoring program and provide information useful to management of current issues.

Focal resources, 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.

Collectively, these basic strategies for choosing monitoring indicators achieve the diverse monitoring goals of the National Park Service.

An immigrant foot trail in Coronado National Memorial, one example of an anthropogenic stressor to park ecosystems. November 2003.

1.5.1. Sonoran Desert Network Approach to Vital Signs Identification

The SODN has followed the basic process depicted in Figure 1.1 to select a subset of park resources and processes for monitoring. The schedule for completing the 3-phase planning and design process is shown in Table 1.6 (http://science.nature.nps.gov/im/monitor/schedule.htm).

After amassing park issues and stressors via scoping meetings, SODN developed a process for selecting monitoring parameters. To initiate the process of vital sign identification, the SODN convened a group of eight scientists in May 2003 and brainstormed potential monitoring parameters. The recommendation from this meeting was to follow up with topic-specific discussions. The SODN then hosted a series of eight workshops to discuss and prioritize candidate Vital Signs. Participants of these workshops included Park Service managers and staff, external natural resource managers, and scientists. The vital sign selection process is described in greater detail in Chapter 3. A detailed description of the workshops is included in the Sonoran Desert Network Vital Signs Workshop Summary (Appendix J). A summary of preliminary scoping workshop reports, workshop materials, an agenda, and a participant list are included with the report. The SODN Board of Directors and Technical committee then selected which parameters became candidate vital signs.

Table 1.6. Timeline for monitoring plan development and implementation.

FY01	FY01	FY02	FY02	FY03	FY03	FY04	FY04	FY05	FY05	FY06
Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar
Data gathering, internal scoping										
Inventories to support monitoring										
	Scoping workshops									
	Conceptual modeling									
				Inticator prioritization and selection						
				Protocol development, monitoring design						
				Draft Phase 1 Oct '02		Draft Phase 2 Oct '03		Draft Phase 3 Dec '04		Final Phase 3 Oct '05

1.5.2. Monitoring Objectives

The monitoring program of the Sonoran Desert Network is designed around the five broad, servicewide goals (see Servicewide Monitoring Goals, page 2). This network of park units created to protect cultural and natural resources offers unique opportunities to learn about ecological systems in the Sonoran Desert and Apache Highlands.

Within terrestrial and aquatic ecosystems, preliminary monitoring objectives and questions were nested within this framework of understanding ecosystem behavior and detecting change. Objectives and questions were developed as part of the vital signs scoping and expert workshops and revised through work with the SODN Monitoring Team. Monitoring questions may be modified or additional questions posed as protocol development continues.

Terrestrial Ecosystem Monitoring Questions and Objectives

Objective 1. Understand how terrestrial ecosystems are structured.

- How do patterns of composition and relative abundance of plant communities co-vary with soil characteristics, climate, and birds?
- What are the patterns of soil compaction, soil cover, soil stability, and biological soil crusts?
- Are there relationships between soil characteristics and trends in exotic plants, vegetation community composition, and stream channel morphology?

Objective 2. Observe structure and composition of plant communities and their spatial distribution on the landscape.

- What is the baseline spatio-temporal variation in community composition and relative abundance of native and exotic perennial plant species?
- What are the long-term trends in community composition and relative abundance of perennial plant species?
- What is the natural variation in community composition and relative abundance of perennial plant species?
- What exotic plant species exist on SODN park lands?

Objective 3. Document rates and types of change in vegetation in response to environmental factors and human effects.

- How are vegetation communities across the SODN region in responding to the primary environmental drivers of climate, natural disturbance, biotic interactions, and human activities?
- What are the trends in composition and configuration of land use on SODN park units and within the Sonoran Desert region?
- Can land cover monitoring approaches complement land use monitoring?
- When do phenological events (leaf out, flowering, leaf drop) occur? How are these events tied with ecosystem drivers such as climate, disturbance, or human activities?

Objective 4. Understand how vegetation patterns and animal distribution relate to each other.

- How are land bird species distributions changing across the SODN region in response to the primary environmental drivers of climate, natural disturbance, biotic interactions, and human activities?
- What are the long-term trends in species composition and abundance of the land bird guild in SODN park units?

Objective 5. Understand trends and patterns in landscape configuration and its impacts on animal species.

- What is the level of habitat connectivity/fragmentation in SODN parks and the greater Sonoran Desert and Apache Highlands ecoregions?
- How has habitat fragmentation changed over time?
- How is habitat structure changing, particularly herbaceous versus woody plant dominance?

Objective 6. Understand the ways humans interact with terrestrial ecosystems to affect physical and biotic components.

- What are the trends in composition (types and extent) and configuration (spatial arrangement) of key aspects of the human-ecological "footprint" within land management units (e.g. through recreation activities, visitor attendance, law enforcement activities, grazing) across the Sonoran Desert and Apache Highlands ecoregions?
- What are the key trends and spatial patterns of demographic and socioeconomic change in the Sonoran Desert ecoregion?
- What are the key patterns and trends in policymaking (environmental, economic and social) and capacitation of land management and conservation institutions on Sonoran Desert ecosystems?
- What are the key patterns and trends in natural resource use (consumption and distribution of access) and human environmental quality (pollution and disease) in the Sonoran Desert ecoregion?
- How do regional patterns of human interactions with terrestrial ecosystems translate to park-level resources?
- How do patterns of illegal road and trail development vary with associated vital signs – vegetation communities, disturbance, water quality, land use, land cover, early detection of exotic plants?
- What are the trends in the composition and configuration of illegal roads and trails in SODN parks?

Aquatic Ecosystem Monitoring Questions and Objectives

Objective 1. Understand ecological relationships and long-term changes in the physical, chemical, and biotic features of water bodies in SODN parks.

- What are baseline water quality constituent associated with primary production, including dissolved oxygen, pH, nutrients, total suspended solids, chlorophyll-a, and total organic carbon; how are they changing temporally?
- Are seasonal discharge regimes of snowmelt rivers shifting?
- What are long-term trends in water quality and quantity?
- How does seasonal and interannual climatic variability at watershed and landscape scales impact water quality and quantity?

Objective 2. Understand characteristics of channel morphology and their impact on biotic features of water bodies.

- What is the spatial and temporal variation of longitudinal and cross-sectional profiles, pebble counts, estimates of bankfull?
- Is there a relationship between soil quality trends and trends in water quantity, water quality, soil quality, climate, disturbance events, land use, vegetation communities, aquatic macroinvertebrates, and fish communities?

Objective 3. Understand how humans interact with aquatic systems to affect physical and biotic components.

- What are human uses of water bodies in SODN park units (fishing, swimming, drinking water, etc.)?
- How have human uses of water bodies impacted dissolved oxygen, pH, nutrients, total suspended solids, chlorophyll-a, and total organic carbon, macroinvertebrate community composition, and fish community composition?
- How do management activities that affect riparian communities, channel morphology, water quality, and water quantity affect the relative size structure and relative abundance of fish?
- Altered disturbance regimes: is there a correlation between drought, fire,

and other wide-scale disturbances and the relative size structure and relative abundance of fish in SODN parks?
- What are the trends in visible disease, parasites, and mutations in fish in SODN parks?
- What are the trends in exotic fish species abundance?

1.6. Summary of Current Monitoring Within and Surrounding the Network

As monitoring is defined as the collection of *repeated* observations (Elzinga et al. 1998), SODN park projects were only considered past or existing monitoring if measurements were taken at the same locations on several occasions. Seven of the SODN parks collects basic climate data (precipitation, minimum and maximum temperature, wind speed and direction). Air, water, and biological components are monitored in eight parks in the SODN network (Table 1.7.). In most parks with one or more monitoring components, only a few, legally mandated indicators are monitored. Only SAGU and ORPI currently monitor a broad range of indicators, generally vertebrates and vascular plants. Most monitoring projects have some reporting as part of the program, but detailed protocols and databases are generally lacking (Table 1.7).

1.6.1. Climate Monitoring

National Weather Service Cooperative Observer Network Stations exist in 7 SODN parks: Casa Grande NM, Chiricahua NM, Coronado NM, Montezuma Castle NM, Organ Pipe Cactus NM, Tumacacori NM, and Tuzigoot NM. Climate stations report 24-hour maximum and minimum temperatures, liquid equivalent of precipitation, snowfall, snow depth, and other special phenomena such as days with thunder, hail, etc. A single Remote Automated Weather Stations (RAWS), owned and operated by the National Interagency Fire Center (NIFC), are deployed in Saguaro NP, Chiricahua NM, and Gila Cliff Dwellings NM.

1.6.2. Air Quality Monitoring

Table 1.8. summarizes air quality monitoring taking place in SODN parks. Chiricahua NM and Saguaro NP have been designated Class I areas under the Clean Air Act. The purpose of the Clean Air Act is to "preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value." Section 169(A) of the Clean Air Act clearly identifies the goals of air quality monitoring in Class I areas:

> "Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing impairment of visibility in mandatory Class I Federal areas which impairment results from any man-made air pollution."

In accordance with its classification as a Class I area, visibility monitoring is ongoing in Chiricahua NM and Saguaro NP as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. In addition, Gila Cliff Dwellings NM, Tonto NM, and Organ Pipe Cactus NM are also IMPROVE sites. IMPROVE is composed of members from federal, state and regional agencies and has the common goal of providing information to protect visual environments under the Clean Air Act of 1977 (IMPROVE 2004). The program was initiated in 1985 to protect visibility in Class I airsheds in 156 national parks and wilderness areas. Figure 1.5 is a map of current air quality monitoring stations within the SODN.

Atmospheric deposition monitoring is ongoing in Chiricahua NM, Gila Cliff Dwellings NM, and Organ Pipe Cactus NM through the National Atmospheric Deposition

Program/National Trends Network (NADP/NTN). NADP is a multi-agency (including federal, state and local) approach to monitoring the chemistry of wet deposition throughout the country at over 200 sites.

Dry deposition of nitrogen and sulfur is monitored in Chiricahua NM through the Clean Air Status and Trends Network (CASTNet) program. CASTNet is a joint venture between the Environmental Protection Agency (EPA) and the National Park Service-Air Resources Division that operates over 70 dry acidic deposition sites throughout the U.S. (EPA 2004). These sites provide hourly ozone levels and weekly information on the concentration of sulfate, nitrate, ammonium, sulfur dioxide and nitric acid.

Ozone is being monitored in Saguaro NP by the Pima County Department of Environmental Quality and in Chiricahua NM as part of the CASTNet program. Additionally, passive ozone sensors currently exist in Organ Pipe Cactus NM, operated by NPS Air Resources Division.

1.6.3. Water Quality Monitoring

Prior to the Natural Resource Challenge, the only waters monitored in SODN parks are Quitobaquito Spring in Organ Pipe Cactus NM (park-based), and Montezuma Well in Montezuma Castle NM (USGS cooperators). Waterbodies within SODN parks listed on the State 303d list are identified in Table 1.9. No waters within SODN parks have been identified as Outstanding Natural Resource Waters. Water quality trends in SODN parks are summarized in Table 1.10.

1.6.4. Organ Pipe Ecological Monitoring Program

The Ecological Monitoring Program (EMP) was initiated at Organ Pipe Cactus NM in 1984 and as such has the distinction of being one of the longest running ecological monitoring programs in the NPS. Since the inception of the EMP, ORPI staff has monitored ten parameters covering a wide range of physical and biological characteristics (Table 1.7). A more detailed description of the ORPI EMP appears in Appendix G. However, this program was designed for a different purpose than the I&M Network. The wealth of data collected through the EMP will be valuable as SODN pursues protocol development.

1.6.5. Existing Monitoring Programs in Adjacent Park Lands

As part of SODN's cooperation with other agencies in the Sonoran Desert region to develop an ecosystem monitoring framework, SODN staff conducted a series of agency briefings. At each of these meetings, discussions focused on the partner's priorities for monitoring that responded to needs for natural resource decision making, or accomplishing their missions and mandates. Table 1.11 summarizes current and desired monitoring underway by these agencies. These efforts and datasets provide the basis for many monitoring decisions and will be invaluable in protocol development.

Table 1.7. Current monitoring projects in SODN for all physical and biological categories.

Park	Category	Monitoring Project	Reason for monitoring	Yrs data collected	Project status: Data entered in database	Detailed protocol available	Data analyzed	Consistent reporting	Notes
CAGR	All	No monitoring							
CHIR	Air	Quality	General interest	1994-	x	x	x	x	
	Water	Stream flow and temperature	General interest	1993-					
	Birds	Spotted owls (*Strix occidentalis*)	Legal requirements	1994-		x	x	x	
	Plants	Agaves (*Agave spp.*)	General interest	1994-				x	Food for lesser long-nosed bats (*Leptonycteris curasoae*)
		Fire effects	Fire effects on Spotted owls	1994-		x	x	x	
CORO	Plants	Agaves (*Agave spp.*)	General interest	1996-			x	x	Food for lesser long-nosed bats
	Amphibians	Barking frogs (*Hylactophryne augusti)*	General interest	1997-2002					
	Birds	Spotted owls	Endangered species	1998-		x	x	x	
	Mammals	Nocturnal rodents	General interest	1996-	x		x	x	Effects of fire on rodent community
		Bats	General interest	1993-	x		x	x	Use of abandoned mines and caves
FOBO	Water	Well depth	General interest	UNKN					
	Mammals	Nocturnal rodents	General interest	1997-2002	x				Effect of mesquite removal on rodents
GICL	Water	Quality near monument	Legal	UNKN	x	x	x	x	
MOCA	Water	Quality near monument on Wet Beaver Creek	Legal	UNKN	x	x	x	x	
	Atmosphere	Atmospheric deposition	LTMP	1991-	x	x	x	x	
	Air	Quality/visibility	LTMP	1991-	x	x	x	x	

Table 1.7. continued.

Park	Category	Monitoring Project	Reason for monitoring	Yrs data collected	Project status: Data entered in database	Project status: Detailed protocol available	Project status: Data analyzed	Project status: Consistent reporting	Notes
MOCA cont'd	Climate	Climate	LTMP	1991-	x	x	x	x	
	Mammals	Nector-feeding (*Leptonycteris spp.*) bats	LTMP	1991-	x	x	x	x	
		Nocturnal rodents	LTMP	1991-				x	
	Birds	Relative abundance	LTMP	1991-	x	x	x	x	
	Lizards	Abundance	LTMP	1991-	x	x	x	x	
	Fish	Quitobaquito desert pupfish (*Cyprinodon macularius eremus*)	LTMP	1975-1981, 1985-	x	x	x	x	
SAGU	Invert-ebrates	Africanized honey bees (*Apis mellifera*)	Visitor/staff safety	1993-					Monitor 4 traps around park buildings
	Amphibians	Lowland leopard frogs (*Rana yavapaiensis*)	General Interest	1995-	x	x	x	x	
	Reptiles	Tiger rattlesnakes (*Crotalus tigrus*)	General Interest	1996-2002	x			x	Monitoring effects of urban development
		Desert tortoise (*Gopherus agassizii*)	General interest-urban development	1994-	x		x	x	Monitoring effects of urban development
		Tree lizards (*Urosaurus ornatus*)	General interest	1980's-					Ongoing research projects by outside researchers
		All species	General interest	1994, 1999					Park expansion area
	Birds	Elf owls (*Micrathene whitneyi*)	General Interest	1999-			x	x	Monitoring effects of urban development
		Spotted owls	Endangered species	1994-		x	x	x	

Table 1.7. continued.

Park	Category	Monitoring Project	Reason for monitoring	Yrs data collected	Project status: Data entered in database	Detailed protocol available	Data analyzed	Consistent reporting	Notes
SAGU cont'd	Birds cont'd	Cactus ferruginous pygmy owl (*Glaucidium brasilianum*)	Endangered species	2000-		x	x	x	
	Mammals	Mountian lions (*Felix concolor*)	General interest	2000-				x	Concern over loss of species on west side of park
		Lesser long-nosed bats (*Leptonycteris curasoae)*	Endangered species	1994-				x	
		Medium-large mammal community	General interest	2000-	x			x	Exploration for monitoring using infrared-triggered cameras
		Small mammal community	General interest	1980's-					A few plots read annually for mammology class
		Game animals	General interest	2000				x	Helicopter counts conducted by Arizona Game and Fish
	Vertebrates	Roadkill	General interest	1993-2000	x	x	x	x	
	Plants	Saguaro (*Carnegeia gigantea*) plots	Flagship species	1990-	x	x	x	x	Reread every ten years, 40 plots
		Saguaro (*Carnegeia gigantea*) plots	Flagship species	Started 1960's	x	x	x	x	Original plots resurveyed in 2001
		Fire-effects plots	Fire program	8	x	x	x	x	Plots throughout east side of park
		Vegetation transects	General interest	1990-2000					Plots read every other year
		Exotics	General interest	2000-					Removal program
TONT	Birds	Spotted owls	Endangered species	1997-				x	
TUMA	All	No monitoring							
TUZI	All	No monitoring							

Figure 1.5.
Map of air quality monitoring locations.

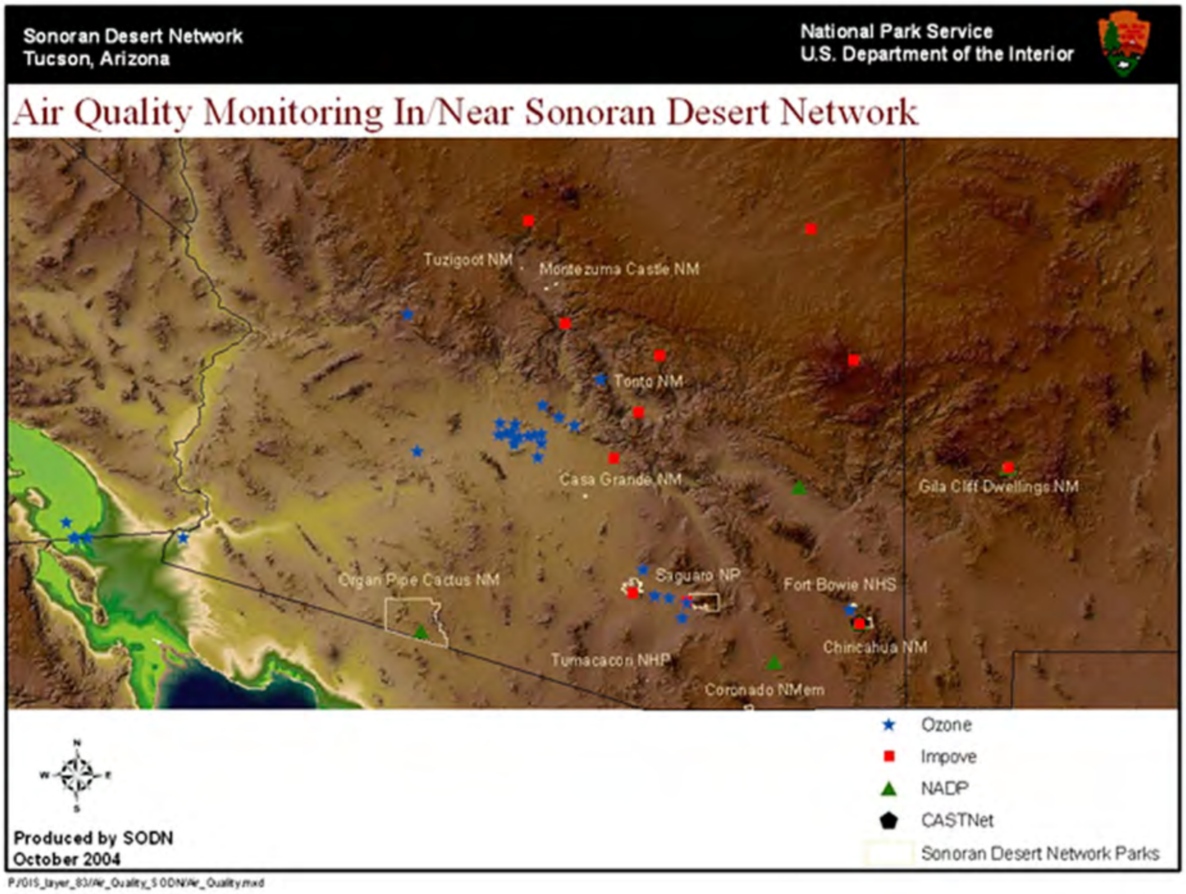


Table 1.8.
Summary of existing air quality monitoring at the eleven National Park Service units in the Sonoran Desert Inventory and Monitoring Network.

Park	State	Program	Parameters	Site Information
SAGU	AZ	Pima County Department of Environmental Quality	Ozone and meteorological variables	site #040190021 Since 1982
ORPI	AZ	NPS ARD	Ozone (passive)	
CHIR	AZ	National Atmospheric Deposition Program/National Trends Network (NADP/NTN)	Wet deposition: Ca, Mg, K, Na, NH4, NO3, Cl, SO4, pH, inorganic N	Site #AZ98 Since 1999
GICL	NM	National Atmospheric Deposition Program/National Trends Network (NADP/NTN)	Wet deposition: Ca, Mg, K, Na, NH4, NO3, Cl, SO4, pH, inorganic N	Site #NM01 Since 1985
ORPI	AZ	National Atmospheric Deposition Program/National Trends Network (NADP/NTN)	Wet deposition: Ca, Mg, K, Na, NH4, NO3, Cl, SO4, pH, inorganic N	Site #AZ06 Since 1980
CHIR	AZ	Interagency Monitoring of Protected Visual Environments (IMPROVE) program	Site #CHIR1 since 1988	Particle monitor, transmissometer
GICL	NM	Interagency Monitoring of Protected Visual Environments (IMPROVE) program	Site #GICL since 1994	Particle monitor, nephelometer
SAGU	AZ	Interagency Monitoring of Protected Visual Environments (IMPROVE) program	Site #SAGU1 since 1988	Particle monitor
TONT	AZ	Interagency Monitoring of Protected Visual Environments (IMPROVE) program	Site #TONT1 since 1988	Particle monitor, transmissometer
ORPI	AZ	Interagency Monitoring of Protected Visual Environments (IMPROVE) program	Site #ORPI1	Particle monitor
CHIR	AZ	CASTNet	Total Nitrogen and Sulfur, Ozone, meteorological variables	Site #CHA467 (CASTNet); site #040038001 (ozone) Since 1989

Table 1.9. Water quality threats in SODN parks. Sources: National Park Service, Water Resources Division summary of STORET data; SODN Phase II Water Quality Implementation Plan.

* Denotes historic data gathered in "Baseline Water Quality Inventory and Analysis Reports".

** Denotes Water Qaulity Standards and state lists

Park	Data	Threats to Water Resources	Documented problem parameters*	Waterbody legal status **
Casa Grande Ruins National Monument	1977- 1994	Drawdown of ground water by agricultural irrigators and urban users may be impacting vegetation and may cause subsidence of cultural resources and facilities.	There is a lack of observations and long-term stations in the area of the monument and no data collected within the monument.	No surface water.
Chiricahua National Monument	1946-1984	The King of Lead Mine is a potential threat to water quality in Bonita Creek. Flash flooding is a problem in ephemeral drainages. The continuing drought may pose a threat to water quantity at springs and wells.	No recent observations within the monument and therefore no conclusions were drawn concerning water quality.	No 303(d) listed waters
Coronado National Memorial	1965-1993	There are several mines in the monument that may pose a threat to water quality, some have extremely low pH and high mineral content. Soil erosion during flash floods is a potential threat. The continuing drought may pose a threat to water quantity at springs and wells.	There was insufficient data to draw definitive conclusions concerning the water quality of the memorial.	No 303(d) listed waters
Fort Bowie National Historical Site	1946-1976	Currently there are no known threats to the water quality, most activities in the vicinity are down gradient. A well was drilled in 2000. Data indicates that the well is not impacted spring flow, but additional monitoring of flow was recommended.	Lack of recent observations precludes the ability to make definitive statements about water quality.	No 303(d) listed waters
Gila Cliff Dwellings National Monument	1957-2002	Threats to water quality within the monument are minor as most of the area is designated wilderness. Wildfires and *E coli* from human activities pose potential threats. Loss of quality water resources has the potential to impact five TES/candidate species: Mexican spotted owl, bald eagle, Chiricahua leopard frog, spikedace, loach minnow and the yellow-billed cuckoo.	Data indicate that the surface waters in the monument and adjacent areas are generally of good quality, with some indications of impacts from natural and human activities. Water temperatures exceed the standards set for cold water fisheries.	West Fork (inside) & Middle Fork Gila River (outside) the monument are on the 303(d) list
Montezuma Castle National Monument	1972-2003	Threats to water quality include increasing population growth, high use of ground water, and contamination from *E coli* and agricultural chemicals. Loss of quality water resources has the potential to impact TES/candidate species: spikedace, bald eagle, loach minnow, southwestern willow flycatcher, yellow-billed cuckoo, Gila chub, and the Montezuma Well springsnail.	Surface waters within the study area generally appear to be of good quality, with some indications of impacts from human activities.	No 303(d) listed waters

Table 1.9. continued.

Park	Data	Threats to Water Resources	Documented problem parameters*	Waterbody legal status **
Organ Pipe Cactus National Monument	1917-1985	Threats to water resources include loss of spring flow from the continuing drought, contamination of water sources by human waste, and soil erosion problems from illegal smuggling and interdiction efforts. TES/candidate species dependent on water resources include: Quitabaquito desert pupfish, Sonoran mud turtle, and the lesser long-nosed bat. Quitobaquito is the only known location in the United States for the Quitobaquito tryonia snail, desert caper, and Howarth's giant white butterfly.	Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.	No 303(d) listed waters
Saguaro National Park	1975-1997	Threats to water quality and quantity include human activities and continued urban growth adjacent to park boundaries. Loss of water quantity could pose a threat to the lowland leopard frog, a species of concern.	Without adequate data it is difficult to make definitieve statements regarding recent water quality within the study area. The Santa Cruz River outside the park appears impacted by human activities.	No 303(d) listed waters
Tonto National Monument	1971-1992	Threats to water resources include a loss of spring flow due to drought and flooding, and soil erosion associated with flash floods.	Water quality appears to be generally of good quality with some impact from natural and human activities.	No 303(d) listed waters
Tumacacori Historical National Park	1941-1995	Water in the Santa Cruz River is primarily treated effluent from the Nogales International Wastewater Treatment Plant. Threats include *E coli*, *Giardia*, and cryptosporidia. Loss of quality water resources has the potential to impact TES/candidate species: Gila topminnow, southwestern willow flycatcher, and yellow-billed cuckoo.	An upstream reache of the Santa Cruz River is on the 303(d) list due to *E coli* exceedences.	Santa Cruz River outside boundary 303(d) listed.
Tuzigoot National Monument	1973-2003	Threats to water quality include increasing population growth, high use of ground water, and contamination from *E coli* and mine spoils. TES/candidate species at the monument and the adjacent areas of Tavasci Marsh and the Verde River include: spikedace, loachminnow, southwest willow flycatcher, bald eagle, Yuma clapper rail, and yellow-billed cuckoo.	Surface water quality appears to have been impacted by human activities that may include: grazing, agriculture, mining, wastewater, and urban development. Pecks Lake is near the monument and it is on the 303(d) list as impaired due to low dissolved oxygen.	No 303(d) listed waters

Table 1.10.
Water quality trends for bodies of water in SODN parks.

PARK	Baseline Water Quality Data Inventory and Analyses National Park Service, Water Resources Division	Concerns	ADEQ
CAGR	No monitoring stations were located within the park boundary. Only 93 observations collected at one monitoring station have been reported to STORET since 1979. Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.		
CHIR	The data inventories and analyses contained in this report reveal a shortage of recent observations for most parameters measured in the study area. Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.	Runoff from King of Lead Mine	
CORO	Since 1981, only 95 observations within the study area, collected during a one-time sampling effort in March 1993 at four monitoring stations near an abandoned copper mine, have been reported to STORET. Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.	There are a number of abandoned mines. Blue Waterfall Seep has extremely low pH and high mineral content. Illegal aliens may be drinking water at some sites, posing health risks.	
FOBO	The data inventories and analyses contained in this report indicate a shortage of recent observations for all parameters measured in the study area. Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.		
GICL	Based on the data inventories and analyses contained in this report, surface waters within the study area generally appear to be of good quality, with some indications of impacts from human activities.	The West Fork of the Gila River is on the 303(d) list for cold water fisheries temperature exceedences.	
MOCA	Based on the data inventories and analyses contained in this report, surface waters within the study area generally appear to be of good quality, with some indications of impacts from human activities.	Maintaining the exceptional macroinvertebrate populations in Beaver Creek. Maintaining the unique aquatic communities of Montezuma Well.	Beaver Creek was listed as impaired due to turbidity on the 2002 303(d) list, and has been delisted in 2004 due to a change in turbidity standards (ADEQ 2004).
ORPI	No STORET data exist for the study area since December 1989. Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area.	Maintaining the aquatic habitat in Quitobaquito Springs. Illegal aliens may be drinking the water at some sites, posing health concerns.	

Table 1.10. continued.

PARK	Baseline Water Quality Data Inventory and Analyses National Park Service, Water Resources Division	Concerns	ADEQ
SAGU	Without adequate data it is difficult to make definitive statements regarding recent water quality within the study area; however, from the limited available data, it appears sections of the study area (outside the park along the Santa Cruz River) have been impacted by human activities. Dissolved oxygen, pH, chlorine, cadmium, copper, lead, mercury, selenium, silver, and zinc exceeded their respective EPA crieteria for the protection of freshwater aquatic life at least once in the study area.	Loss of aquatic habitat from sediment and ash following wildfires is a concern.	
TONT	Based on the data inventories and analyses contained in this report, surface waters within the study area generally appear to be of good quality, with some indications of impacts from human activities.		
TUMA	No monitoring stations are located within the park boundaries. Without adequate data it is difficult to make definitive statements regarding surface water quality throughout the study area; however, historically it appears water quality has been impacted by human activities.	Most of the surface water is from treated effluent. *E. coli, Giardia* and cryptosporidia are of the highest concern for human health risks.	Lawson (1995) analyzed data from the outlet of the Nogales International Wastewater Treatment plant downstream for 16 miles. Data showed that water quality improved downstream from the plant. ADEQ (2004) had listed several reaches of the Santa Cruz River as impaired on their 2002 list due to high *E. coli.* Some reaches, including the reach through the monument, have been recommended for delisting in 2004 because there was a change in the *E. coli* standard.

Table 1.11. Current (C) and desired (D) natural resource monitoring by agencies in southern Arizona and northern Mexico.

Level 1	Level 2	Level 3	Network Vital Sign Name	Measures	NPS	BLM	USFS	USFWS	US Army	USAF	NRCS	AGFD	AZSP	PIMA Co	IMADES	INE-MX
Air and Climate	Air Quality	Ozone	Ozone	Continuous (SAGU, CHIR) or Passive Monitors (ORPI)	X	D		D	D			D				
		Wet and dry deposition	Wet and dry deposition	Wet Deposition Rates (GICL, CHIR, ORPI), Dry Deposition Rates (CASTNet at CHIR)	X	D		D	D			D				
		Visibility and particulate matter	Visibility and particulate matter	Light-extinction, light scattering, fine particle sampling (IMPROVE - CHIR, GICL, SAGU, TONT, ORPI), automatic camera	X	D		D	D			D				
	Weather and Climate	Weather and Climate	Climate	Air Temperature, Precipitation, Total Solar Radiation, Photosynthetically Active Radiation (PAR), Surface Soil Temperature, Soil Moisture (5cm), Wind Speed, Wind Direction, Relative Humidity	X	C		C	C						C	
Geology and Soils	Geomorphology	Stream / river channel characteristics	Channel Morphology	Channel cross sectional profile, longitudinal profile, pebble counts, bankfull estimates	X	C	C					C				
	Soil Quality	Soil function and dynamics	Biological Soil Crusts	Soil darkness index,% cover by guild	X		D		C							
			Soil Aggregate Stability	Stability class (Herrick et al. 2001), percent aggregate stability	X		D		C							
			Soil Compaction	Cone indices, energy per unit depth, force per base area	X		D		C							
			Soil Cover	% cover of soil surface by ground cover type (e.g., soil, rock, plants, lichen, litter)	X		D		C							
Water	Hydrology	Groundwater dynamics	Groundwater Depth	Depth to groundwater level as measured in monitoring wells	X				C							
		Surface water dynamics	Surface Water Quantity	cubic feet per second of flow, volume of static water bodies, (tinijas, sloughs, sinkholes, marshes)	X	C			C			C	C			
	Water Quality	Water chemistry	Core Water Quality Parameters	water temperature, dissolved oxygen, conductivity, pH, turbidity	X	C	C						C			
		Nutrient dynamics	Water Quality - Nutrient Loading	concentrations of ammonia, nitrate, nitrite, total phosphorus	X	C	C						C			
		Toxics	Water Quality - Pollutant Metals	concentrations of EPA priority pollutant metals (Sb, As, Be, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Ti, Zn)	X	C	C						C			
		Microorganisms	Water Quality - Biological Condition	Biological oxygen demand, concentration of E. coli	X	C	C						C			
		Aquatic macroinvertebrates and algae	Aquatic Macroinvertebrates	community indices of water quality (AZ State Standards), abundance of exotic crayfish	X	C	C						C			

Table 1.11. continued.

Level 1	Level 2	Level 3	Network Vital Sign Name	Measures	NPS	BLM	USFS	USFWS	US Army	USAF	NRCS	AGFD	AZSP	PIMA Co	IMADES	INE-MX
Biological Integrity	Invasive Species	Invasive/Exotic plants	Exotic Plants - Early Detection	percent area occupied, distribution, density, percent cover relative to native flora	X	C	C	C	C	C					C	
			Exotic Plants - Status and Trends	percent foliar cover, cover classes, density, basal area, size class, phenology, abundance relative to native flora	X	C	C	C	C	C					C	
	Focal Species or Communities	Desert communities	Vegetation Community Structure and Demography	percent foliar cover, cover classes, density, basal area, size class, phenology	X				C		C				C	
		Fishes	Fish Communities and Habitat	relative abundance of fish species, size structure (relative), disease/parasites/mutations - visible	X	C	C					C				
		Birds	Landbirds	Relative Abundance, Species Richness, Density, Distribution	X	C	C	C	C	C		C	C			C
Human use	Point-Source Human Effects	Point-source human effects	Border Issues	area of illegal roads/trails, distribution of illegal roads/trails, number of illlegal roads/trails	X	D	D	C	D	C						
	Visitor and Recreation Use	Visitor usage	Visitor Use	monthly visitation, park recreational use patterns	X	C		C		D					D	
Ecosystem Pattern and Processes	Land Cover / Land Use	Land cover / Land use	Land Cover	area and distribution of broad land cover types (vegetation formations, developed areas) over park and adjacent landscape, area and distribution of lifeforms (woody, herbaceous, bare, developed) within land cover types	X	D		D	D	D						
			Proximate Land Use	proportion of nearby lands in various categories of human uses (e.g., agriculture, pastoralism, mining, urban, exurban)	X	D		D	D	D						

"Precious" resources can be considered to include those of cultural, natural, historic, national, etc. importance.

[2] The human-ecological footprint concept is usually applied to measure aggregate resource use of a particular human population, often against an index. In this case, we use "footprint" more narrowly to refer to a measurable pattern of relatively direct human impacts to small-scale ecosystems, e.g. through soil compaction (the most literal type of footprint), road-building, wildlife encounters, or transportation of invasive plant or animal species.

CHAPTER 2: CONCEPTUAL MODELS

2.1. Introduction and Approach

A conceptual model is a structure to organize complex information – a visual or narrative summary that describes the important components of an ecosystem and the interactions among them. These interactions include how agents of change (drivers and stressors) influence the structure or function of natural systems. Conceptual models provide a framework that places issue-specific information into a broader context. Investigations and discussions that accompany the design, construction, and revision of the models contribute to a shared understanding of complex system dynamics and appreciation of the diversity of information needed to identify an appropriate suite of ecosystem indicators. Throughout the life of a monitoring plan, conceptual models can contribute to communication. Once the program is underway, articulation of explicit key linkages in conceptual models is essential to justifying and interpreting ecological measurements and monitoring data (Kurtz et al. 2001).

Well-designed conceptual models:

- Formalize current understanding of system processes and dynamics
- Identify linkages of processes across disciplinary boundaries
- Identify the bounds and scope of the system of interest

Conceptual models do not represent finished products; the process of thinking about, developing, discussing, and revising conceptual models provides the greatest benefit to the users. Conceptual models are based on concepts that can and will change as monitoring provides new knowledge about ecosystem interactions. A critical role of the conceptual models developed for the SODN was to identify the principal drivers of natural and anthropogenic change in network ecosystems. The increased understanding the relationships between ecosystem components gained through this effort aided in the identification of parameters which could, through monitoring, offer the greatest insights into ecosystem trajectories.

2.2. Sonoran Desert Network Approach to Conceptual Models

The conceptual models developed for the SODN are not intended to explain all possible relationships or all factors that influence the ecosystems; they are intended to simplify and highlight the most relevant, influential, and important components and processes of the systems. Two main types of models were developed: traditional box-and-arrow diagrams which depict key system drivers; and conceptual diagrams, which are pictorial diagrams used to show ecosystem components on the landscape and their relationship to SODN vital signs. The conceptual diagrams aid in interpretation of the information to less technical audiences. Additionally, models were built at two levels: generalized ecosystem models and more detailed, system-specific models.

2.2.1. General Theoretical Framework

A general theoretical framework model (Figure 2.1) was designed to guide the development of system-specific models and to provide insights applicable to the selection of vital signs. Major drivers, stressors, and ecosystem attributes specific to the Sonoran Desert and Apache Highlands ecoregions were identified and are further described below. A pictorial conceptual diagram of the components of the system was also developed to aid in interpretation of the information for non-technical audiences (Figure 2.2). The eight attribute pools identified in Figure 2.1 formed the basis of eight corresponding expert workgroups during vital signs selection (see Chapter 3).

2.2.2. Description of Ecosystem Drivers

Ecosystem drivers are major external driving forces such as climate, fire cycles, biological processes, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large scale influences on natural systems. Ecosystem drivers listed below are the product of network Vital Signs scoping workshops and represent the dominant external forces for the SODN. Natural disturbance regimes are considered as part of each driver category.

Solar and Seasonal Cycles

Cycles in daylight result from the rotation of Earth on its axis, and cycles in seasons are the result of Earth's revolution around the sun. Diurnal and seasonal cycles have direct influence over the movement and activities of plants, animals, and entire communities. For example, kangaroo rats avoid the heat of the desert sun through nocturnal habits, which are synchronized with lunar phases. Some flowers open during the day and close at night. Deciduous plants lose their leaves to reduce transpiration rates during winter months. Both solar and lunar cycles influence ecosystem dynamics at varied spatial and temporal scales.

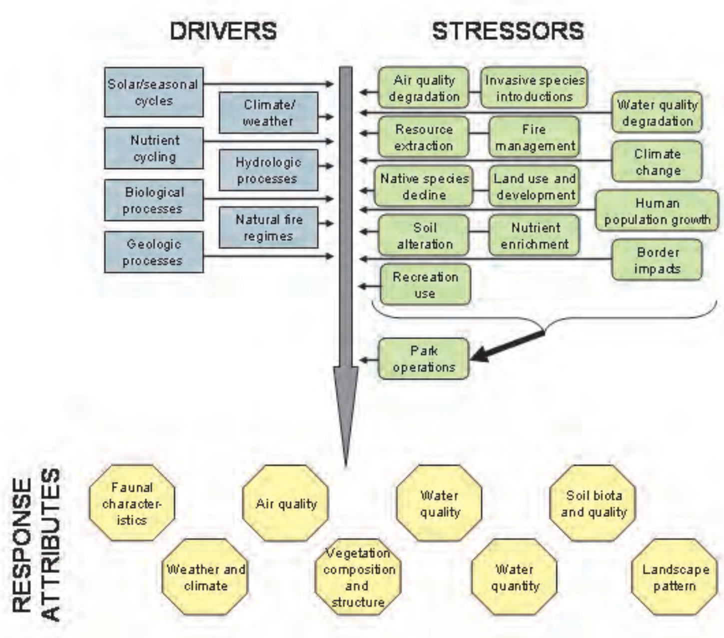
Symbols for driver (rectangle), stressor (rectangle with curved corners), attribute (octagon)

Drivers are major, naturally occurring forces of change such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., drought) that have large-scale influences on the attributes of a natural system.

Stressors are 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). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include air pollution, water withdrawl, and land use change.

Attributes are living or nonliving features or processes of the environment that can be measured or estimated and that provide insight into the state of the ecosystem.

FIGURE 2.1.
General ecosystem model for the Sonoran Desert Network.



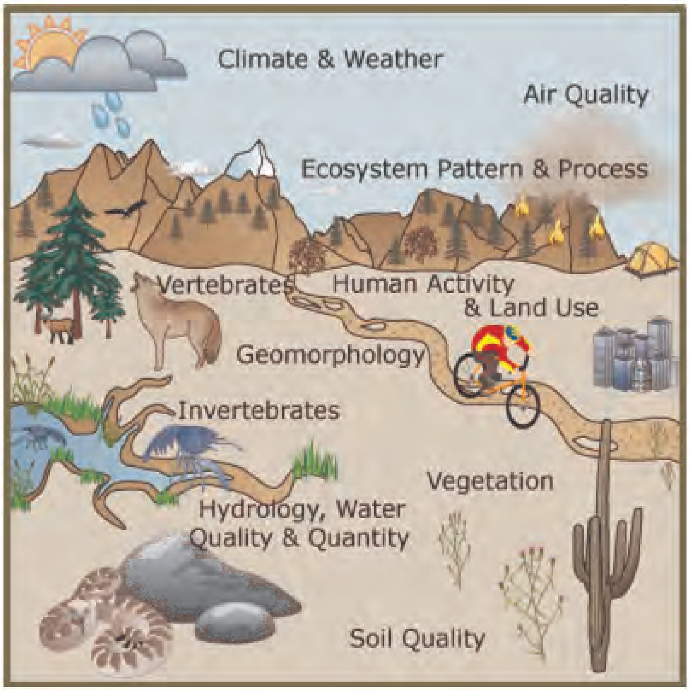


Figure 2.2.
General conceptual diagram for the Sonoran Desert Network.

Climate/Weather

Climate is associated with the broad-scale, long-term patterns of weather which drive the distribution and abundance of biota in a given region or biome. For the SODN, the temperature and precipitation patterns governing the flora and fauna are characterized by low desert extremes, a unique bimodal precipitation regime and steep topographic gradients (Sheppard et al. 2002). This diversity in climatic conditions in turn supports a high level of biological diversity. On a geologic time scale, climate does change and with it the organisms representative of a given biome also change. In contrast, weather is so variable from year to year that detection of significant change is difficult and requires long-term monitoring. Changes in weather events, growing season changes, and other aspects of natural disturbance regimes may alter natural communities and facilitate general change in species/habitat distributions (Neilson 1986, Spellerberg 1991). For instance, recurring Pacific Decadal Oscillation or El Niño-Southern Oscillation events affect temperature and precipitation patterns and produce significant changes in abiotic and biotic ecosystem components (Thurman 1988, Swetnam and Betancourt 1990, Swetnam and Betancourt 1998). These changes are within the natural range of variation, although human activities may be altering the frequency and intensity of these events (NAST 2001). Potential impacts to sensitive ecosystems, endemic species, and threatened or endangered species are of particular concern. A long-term meteorological monitoring program is essential to evaluate how meteorological agents of change within the natural range of variation influence the functioning of ecosystems.

Weather monitoring at Saguaro NP.

Geologic Processes

Tectonic, volcanic, surficial, and geomorphic processes are examples of geologic processes. While felt less than once per decade in the Sonoran Desert, earthquakes expose new rock surfaces and minerals through uplift and rock shearing. Volcanic activity brings minerals and rock to the Earth's surface from its interior. The calderas in the Chiricahua Mountains are the result of collapsing volcanoes from 40 to 20 million years ago and the basalt fields of the Sonoran Desert were formed through volcanic activity 10 million years ago. Mass movement works to break down geologic materials on a range of spatial scales from erosion of stream bank material to large landslides. Mass movement of rock, debris and sediment may occur slowly (i.e. slumping, creep, or slip) or suddenly (i.e. debris avalanches, lahars, rock falls and slides, or debris flows.) Other natural forces such as wind, water, and fire can affect the rate and magnitude of mass movement. Heavy rain causes vegetation, mud and rock to quickly tumble down narrow canyons in the mountains spilling out at the foot of the mountains to form alluvial fans which join together to form bajadas (Scarborough 2000). Geologic processes set and reset the stage for colonization and establishment by diverse biological communities.

Geologic formations at Coronado NM.

Nutrient Cycling

Nutrient cycling involves the input of nutrients (from weathering of rocks, fixation of atmospheric nitrogen, and atmospheric deposition from rain, wind and gases), the loss of nutrients through various ecological processes (such as leaching, emissions, wind erosion, and fire) and the transfer of nutrients between the soils and vegetation within the ecosystem. In arid ecosystems, the spatial pattern of nutrients is highly variable as patches of nutrient rich soils are often surrounded by a matrix of nutrient poor soils. These "islands of fertility" are formed as existing vegetation creates a patch of nutrient rich soil as litter is deposited in the immediate area surrounding the plant. This will often allow for the recruitment of other individuals, which perpetuates the process (Aguiar and Sala 1999). The rate at which nutrients are absorbed and utilized is highly dependent upon the species and the nutrient supply. As a result, changes in biotic or abiotic conditions may lead to changes in the nutrient cycling regime of an ecosystem (Chapin et al. 2002).

Hydrologic Processes

The Sonoran Desert and Apache Highlands ecoregions receive infrequent and undependable rainfall, with much moisture falling in a few infrequent events. Water is critical to sustain life, therefore, species inhabiting this region have evolved many adaptations to take advantage of the sparse precipitation. Rain events shape the landscape, directly affecting the arrangement of soils, dispersing seeds, and nutrient cycling. Perennial streams and rivers sustain unique biotic communities within the narrow ribbons of riparian habitat. Intermittent and ephemeral streams and pools provide important short-lived aquatic habitat and drinking water for wildlife. Flooding events play an important role in reshaping channel morphology, nutrient availability, and seedbeds.

Natural Fire Regimes

Naturally occurring wildland fire is a major ecological driver in many arid environments. Most vegetation communities of the Sonoran Desert and Apache Highlands, particularly those growing above 4000 feet, are adapted to frequent, low-intensity fires. Climate patterns entrain fire occurrence (e.g., Swetnam and Betancourt 1990), weather determines lightning strike density, and the existing vegetation mosaic as well as topography and weather influence fire spread. Fire influences ecosystem dynamics by liberating limited environmental resources for use by surviving organisms. It consumes live and dead organisms, releasing nutrients held in biomass and reducing competition while increasing available sunlight and soil moisture. Fire thereby produces immediate changes in ecosystem species composition, structure, and function while also influencing the long-term dynamics of these ecosystem components. The mixed conifer forests of the Sky Islands, for example, rely on periodic fires (<10 year return interval in SAGU and CHIR, Swetnam and Baisan 1996) to maintain relatively open forests.

Fire has historically been rare in desert scrub communities where plants are not typically fire-adapted, though human activity has increased occurrence probabilities (McPherson 1997). Additionally, the establishment and spread of non- native vegetation has been shown to alter native fire regimes, even in areas where fire has been historically absent (D'Antonio and Vitousek 1992). Management activities such as suppression, logging, and prescribed burning also have contributed to the modification of historical fire regimes in many locations, including parks. As fire regimes move further outside their historic range of varibiablity, distinct changes in vegetation and fire occurrence become increasingly likely.

Common monkey flower (*Mimulus gottatus*).

Biological Processes

Ecosystems consist of plants, animals, and microorganisms interacting with each other and with their physical and climatic environment in a given area to form an ecological community. Communities vary naturally over time in response to changes in environmental variables, disturbance regimes, and species interactions. Within an ecosystem, relatively independent state factors (topography, parent material, climate, potential biota, and time) coupled with plant and animal interactions, such as herbivory, competition, biological invasions, predation, and mutualism, construct the structure and function of the system. These relationships allow for the flow of energy and the cycling of nutrients and other materials throughout the system (Chapin et al. 2002). Interactions between biotic and abiotic components affect communities in numerous ways, all of which may alter successional/evolutionary pathways, leading to changes in the structure and function of ecosystems (Chapin et al. 2002). For example, range expansion of a particular species may result in reductions in relative abundance or extirpation of one or more plant species, which may, in turn, alter nutrient cycles and fire regimes. Fluctuations and transitions are common as biotic and abiotic components both respond to and affect ecosystem processes. The resiliency and stability of a community are determined by the strength of the system feedback, which has the ability to create an alternate developmental pathway for the ecosystem.

2.2.3. Description of Ecosystem Stressors

Stressors are 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). Stressors cause significant changes in the ecological components, patterns and processes in natural systems.

Climate Change

The greenhouse effect, which warms the Earth's atmosphere, results from the interaction of solar radiation with accumulated greenhouse gases (e.g., carbon dioxide, methane, chlorofluorocarbons, and water vapor) in the atmosphere. This warming effect has been enhanced over the past century by increased contributions of these gases, particularly carbon dioxide, from anthropogenic sources (NAST 2001). Potential consequences of this enhancement are rising seasonal temperatures, altered dates for first and last frost, increased drought occurrences, increased storm/flooding severity and frequency, increased biological invasions, and decreased predictability of weather patterns, all of which directly affect ecosystems. These changes may also alter natural ecosystem disturbance regimes (including fire) and can facilitate exotic species invasions. Most climate models suggest that the southwest United States will get warmer and wetter over the next 100 years. Increased and more intense precipitation would also increase erosion and flood events at all of the parks, which are characterized as erosible soils. A rise in temperatures may also be more conducive to the invasion of non-native species, both aquatic and terrestrial, and range extensions of native species leading to hybridization and increased competition.

Air Quality Degradation

Air quality is impacted by a variety of pollutants, including sulfur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds, as well as sulfates, nitrates, and ozone. Sources include power plants, industrial facilities, factories and dry cleaners, vehicles, fires, and volcanoes. Concentrations of pollutants in the air can have detrimental impacts on plant communities, water quality, nutrient cycling, vertebrates, and invertebrates. Impacts can be magnified throughout the system, influencing the potential for non-native species invasions and the disturbance regime. For instance, elevated ozone levels cause considerable impacts on vegetation, affecting biochemical and physiological processes. Deposition of sulfur and nitrogen changes water chemistry, affecting algae, fish, submerged vegetation, amphibians, and aquatic invertebrate communities. Particulate matter reduces visibility and can combine with tropospheric ozone to produce photochemical smog. Photochemical smog has been linked to respiratory ailments in fauna and reduced vigor in floral species (Chappelka et al. 1999).

Water Quality Degradation

Several threats to water quality occur in the Sonoran Desert and Apache Highlands Ecoregions, with substantial implications for human health, riparian vegetation, wildlife populations, and overall ecosystem processes. Discharge of treated effluent from municipal and septic wastewater treatment systems, pastoral and agricultural activities, and improper disposal of human waste for illegal border activities and recreation can result in nutrient loading and *E. coli* contamination of the sparse surface waters of the region. Toxic metal pollution is a common result of the long and extensive history of mining in the region, as well as more recent shifts towards high-technology industries and urbanization. Water quality impacts are also linked to increased sedimentation due to human use activities in upland portions of aridland watersheds.

Most perennial water bodies of the Sonoran Desert and Apache Highlands Ecoregions are static (at least for much of the year), and water quantity fluctuates considerably due to both natural and human influences. Contaminants become concentrated as water levels drop in tinajas and springs due to evapotranspiration or extraction for human uses, whereas major flow events can dilute or transport contaminants within a watershed. Water quantity and water quality stressors therefore interact to determine water quality conditions.

Human Population Increase

Preserving biologically and geologically diverse habitats and their associated species, as well as providing opportunities for recreation, education and aesthetic enjoyment to a growing population of urbanites in the SODN region is a difficult balancing act. Population increases inevitably result in land use change. For the parks, this includes pressures from adjacent lands, as well as possible intensification of activities by visitors inside parks, such as trampling of sensitive plant communities, compaction of soils, creation of social trails, and excessive impact on riparian areas and other sensitive ecosystems. As part of the general trend of rapid population growth in Western states, Arizona's population grew 40% between 1990 and 2000, second nationally only to neighboring Nevada. The major metropolitan center of Phoenix-Mesa, Arizona (2000 population of 3.2 million) experienced a 45.3% growth rate encompassing over 1 million new urbanites between 1990 and 2000 (8th nationally). In the same time period, Tucson, Arizona, with an estimated current population of 870,000, grew 26%. Overall, population growth and urbanization tend to intensify urban-wildlife interfaces in the region through associated changes in land use, recreation and travel patterns, contributing to highway mortality of wildlife and fragmentation of habitats and landscapes. Both within and outside of SODN park units, road and trail construction in response to population and growth-related demands for expanded infrastructure contribute to fragmentation by eliminating habitat, creating "edge" habitats, and creating barriers to wildlife movement corridors. Population and economically induced conversion of land to agricultural and urban uses over time affect land cover across the Sonoran Desert (Nabhan and Holdsworth 1998, Nabhan 2000). Increases in human population in the region have also affected important ecosystems by intensifying the pressure for fire suppression by raising the potential financial/human/political costs of wildfires.

Land Use and Development

Land use dynamics in the western United States have shifted over the past century from livestock grazing, agriculture and mining to urban and suburban development (Bahre 1991, Hansen et al. 2002). Urbanization and suburbanization, driven by growing populations in the Southwest, are a major force in land conversion and have considerable impacts on biodiversity in parks and neighboring ecosystems (U.S. GAO 1994, Hansen et al. 2002). In the Southwest, roads and trails associated with undocumented immigration, narcotic smuggling and border patrol activities on lands near the international border can modify the quality and character of existing land cover.

Habitat fragmentation is a common consequence of land use change from development, urbanization and border activities. Fragmentation diminishes habitat quality, quantity and distribution of habitat, reduces predator and prey densities, influences pathogen outbreaks and promotes distribution of exotic species (Trombulak and Frissell 2000). Road construction, from footpaths to unpaved 4 wheel drive roads to highways, represents the most ubiquitous cause of fragmentation (McGarigal et al. 2001, Riitters and Wickham 2003). In addition to physically fragmenting habitat, road construction has been linked to changes in soil characteristics, species composition, as well as serving as a direct source of mortality for organisms (Norse et al. 1986, Fahrig et al. 1995, Forman and Alexander 1998, Trombulak and Frissell 2000).

Photographs of atmospheric haze taken from Chiricahua NM, looking north towards the Rincon Mountains.

Land use dynamics associated with livestock grazing and agriculture in areas around parks can impact park ecosystems. Direct and indirect effects of livestock grazing and agriculture on native ecosystems include damage to soil resources, alteration of the hydrological cycle and disruption of disturbance regimes. High concentrations of livestock on arid rangelands in the past and present increase woody seed dispersal and encroachment of woody plants and exotics, reduce native herbaceous biomass and diversity, reduce soil water holding capacity and increase soil erosion (West 1992, Archer 1995, Asner et al. 2003).

Resource Extraction

Resource extraction results from mining, timber harvesting, harvesting of animals and herbaceous plants, recreational and commercial fishing, and withdrawal of limited water resources. Significant management issues from resource extraction are contamination, erosion, species loss, alteration of habitat, reduced water quality and quantity, and impacts from construction and access. Mineral and soil extraction can increase pollutant concentrations associated with extractive by-products or can increase sedimentation of downstream water bodies. Extracting water, river rock, sand and gravel can alter habitat by reducing bank stability, changing sediment deposition and changing flow volume and patterns (Rosgen 1996). Water table changes may also occur as a result of mining and well drilling. Timber harvesting and poaching are problems for park biota within and adjacent to parks.

Soil Alteration

Soils and biological soil crusts are important to ecosystem integrity because they provide the primary media and components for vegetation growth and for most nutrient cycles. Soils can be altered by climate change, altered precipitation patterns, water quality and quantity alteration, resource extraction, development activities, atmospheric deposition, and changes in disturbance regimes. Erosion, soil compaction, changes in soil carbon and organic matter content, loss of soil biotic diversity, and altered soil chemistry can result from soil stressors. Soil compaction reduces soil strength, water infiltration, and site productivity and increases runoff and erosion potential (Jones and Kunze 2004). Significant alterations in soil biota will inevitably affect nutrient cycling and ecosystem functions. Disturbance of biological soil crusts dramatically reduces the crust's ability to provide nitrogen and soil stability (Belnap et al. 2001). Reduction in soil stability makes the soil more susceptible to wind and water erosion. Changes in soil organic matter affect infiltration, erodibility, water retention and community productivity (Durgin 1980).

Copper mining is common in southern Arizona. Photo: Roy Matthews, 2001.

Nutrient Enrichment

Nutrient enrichment (excess nitrogen and phosphorus concentrations) can affect aquatic ecosystems. Typically, nutrient enrichment results from excessive erosion, agricultural and commercial fertilizers, and runoff. Elevated concentrations of nitrogen and phosphorus cause dramatic shifts in vegetation and macroinvertebrate communities, paving the way for non-native species invasions and reduced biodiversity. Nutrient-loading in aquatic systems can lead to shifts in the dominant primary producers, amplified occurrences of noxious and toxic algal blooms, and increased turbidity, all of which can lead to the loss of submerged aquatic vegetation, oxygen deficiency, disruption of ecosystem functioning, loss of habitat and biodiversity, and shifts in food webs which can lead to modification of the benthic community structure and function (Rabalais 2002).

Park Development and Operations

Based on local population growth and steady tourist flows from outside the region, increases in park visitation and changes in recreation activity patterns can cause a strain on SODN parks. These patterns result in changing demands on existing park resources and infrastructure from year to year, and may also necessitate new expansions in infrastructure and operations. For instance, park roads may need to be resurfaced or extended, parking lots may need to be expanded, visitor and interpretive centers, campgrounds, and other facilities may need to be built or upgraded. Interpretive media may need to be maintained more often or relocated. Increased visitation and park development may also create a need for staff to more actively monitor trail and road traffic, permit issuance, and overall visitor usage patterns in order to determine visitor thresholds and management actions to protect sensitive park ecosystems.

Recreational Use

Demographic changes can dramatically increase park visitation and recreational use, sometimes to unsustainable levels. This visitation pressure extends to trails and backcountry resources. This high level of visitor use creates demands for continued park development, or upgrade of existing development, particularly of trails, which fragment wildlife habitat, bring people into sensitive areas, and contribute to off-trail use in these sensitive areas (National Park Service 1997). Recreational uses in SODN parks have the potential to impact park resources through trampling effects on soils, vegetation, disturbance to aquatic resources, behavioral disturbances to wildlife, and damage to cultural resources. In addition, the introduction and spread of exotic invasive plant species by visitors poses a significant challenge to ecosystem management within several SODN parks. The actual levels of impacts depend on variables such as overall visitor use densities and the densities of specific activities (such as hiking, camping, creation of social trails, horseback riding, swimming, vandalism, etc.) throughout a park unit and/or in proximity to especially sensitive habitats or cultural resources.

Fire Management

Fire can be a useful tool for managing ecosystems adapted to fire disturbance regimes and controlling fuel loads. Although prescribed (human-managed) fire does not completely mimic natural fire, prescribed fire has proven to aid in the amelioration of the effects of a century of fire suppression in higher elevation forests, which has led to unnaturally dense and catastrophic fire-prone forests. However, the increase in non-native plant species that thrive in fire-prone environments, particularly in lower elevations, has complicated fire management plans. Fire suppression and prescription carry management consequences in terms of natural resource impact, as the natural fire regime of these arid bionetworks plays a critical role in maintaining ecosystem structure and function (Williams and Baruch 2000).


Grasslands fire.

Border Impacts

The current state of U.S. border enforcement policies and the proximity of several of the SODN parks to the Mexico/U.S. border have fostered extensive smuggling, law enforcement, and migration activities within the parks, both in remote and developed areas. Given the recent trends and the projected continued increase for the level of illegal activities, there will be a greater increase in the number and the severity of impacts (e.g., soil erosion/compaction, degradation of water and air quality, damage to native vegetation). Located within five of the SODN parks (CORO, FOBO, ORPI, SAGU, and TUMA) are a wide range of natural and cultural resources. The parks are variously located, e.g. directly on the border adjacent to communities in Mexico (CORO and ORPI), along major and lesser public thoroughfares (FOBO, ORPI, SAGU, and TUMA), or well inland from the border (FOBO and SAGU). To date none of these parks have the resources or a plan in place to monitor and/or mitigate resources for impacts caused by illegal drug traffickers, law enforcement agencies, and illegal immigrants.

Non-native Invasive Species/Disease

Non-indigenous invasive species are a major threat to native species diversity and ecosystem function, causing economic impacts within the U.S. estimated at more than $100 billion annually (Pimentel et al. 1999). In addition to competing with and displacing native species, these introduced species can hybridize with natives and alter conditions to promote the establishment and spread of other non-native species. Invasive species have been called the "single most formidable threat of natural disaster of the 21st century" (Schnase et al. 2002). Disease, common to plants and animals, can have substantial impacts on populations. Disease is naturally occurring, but can also be exacerbated by human influences due to habitat fragmentation, genetic isolation, and stress.

A monoculture of *Bromus rubens* (red brome), a problematic invasive species in Arizona.

Native Species Decline and Extirpation

Maintenance of viable populations of native species is a fundamental part of maintaining ecological integrity. Declining native populations, then, can lead to impaired ecosystem functions such as productivity, nutrient cycling, nutrient retention, energy transfer, habitat diversity and quality, terrestrial and aquatic linkages, and hydrologic function (Tilman 1999). In some cases, declining biodiversity may be linked to functional impairment. In other instances, a loss of functionality may be related to the decline or loss of a particular species. Loss of keystone species (e.g., starfish), umbrella species (e.g., saguaro cacti), or ecosystem engineers (e.g., mountain beaver) may be indicative of a shift in ecosystem type, resulting in cascading effects on other species (Lambeck 1997).

2.3 Ecosystem Models

For conceptual modeling purposes, ecosystems within the SODN were divided into four types—aquatic, low elevation terrestrial, mid-elevation terrestrial, and high elevation terrestrial—with each ecosystem having associated subsystems or forms. Key drivers and stressors are represented in the models acting on the different ecosystems along pathways shown.

2.3.1 Low Elevation Systems

Lower elevation systems within Sonoran Desert Network parks include low desert, scrub, and chapparal and occur generally below 2,500'. These systems are dominated by succulents, woody shrubs, and annual forbs and grasses. Trees are essentially absent. These systems are characterized by low precipitation and low net primary productivity but high plant diversity. Further description of these systems appears in Appendix H.

In lower elevation systems in the Sonoran Desert Network, vegetation community structure and composition is mainly driven by climate and geology. These drivers act to influence available water and nutrients, which directly define species assemblages. The composition and structure of vegetation communities in these systems have an impact on soil nutrients as well. Net primary productivity of desert systems are limited primarily by water, unlike many other systems (Aber and Melillo 1991). Natural and human-induced fires and herbivory also play a large role in shaping these ecosystems. Low elevation desert systems do not burn naturally (Dimmitt 2000). Introduction of several nonnative grass species, including red brome (*Bromus rubens*) and buffelgrass (*Pennisetum ciliare*), has had major impacts on these systems, resulting in hot, widespread fires that favor the exotic species and kills native species. This feedback was depicted by D'Antonio and Vitousek (1992; Figure 2.3):

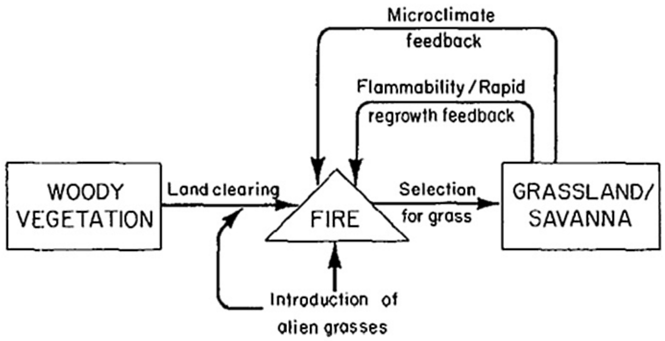


Figure 2.3. Grass/fire interaction model, D'Antonio and Vitousek (1992).

Anthropogenic effects also play an indirect role in shaping low elevation systems through trampling, introduction of exotic plant and animal species, harvesting, and multiple types of park operations. Other stressors and drivers also have indirect influences on low elevation systems; these are depicted outside of the system in Figure 2.4.

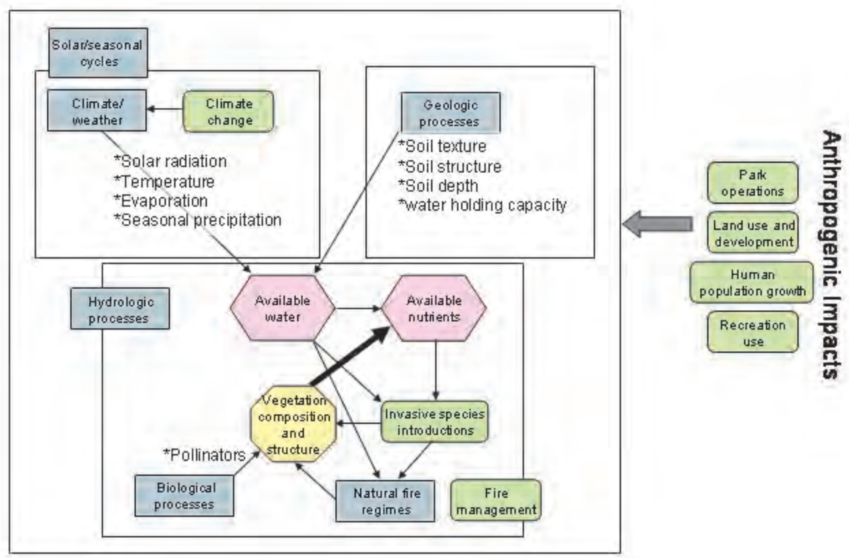


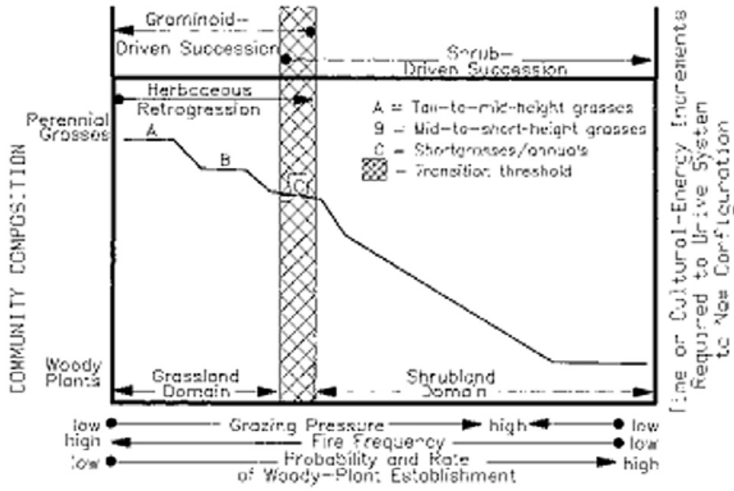
Figure 2.4. Sonoran Desert Network low elevation ecosystem model. Potential vital signs are depicted as *.

2.3.2. Mid-Elevation Systems

Mid-elevation systems in Sonoran Desert Network parks include semi-desert grasslands, shrublands, savannas, and Madrean evergreen woodland and generally occur between 2,500' and 6,000'. Grass understories are a key feature of these systems; savannas and evergreen woodlands are characterized by sparse to complete tree canopies. In these systems, water and nutrients, primarily nitrogen, are approximately equally limiting. Many soil characteristics, including presence and composition of biological soil crusts, soil depth, texture, and water holding capacity influence available soil nutrients. These characteristics are impacted through human activities which alter soil distribution, crusts, and compaction.

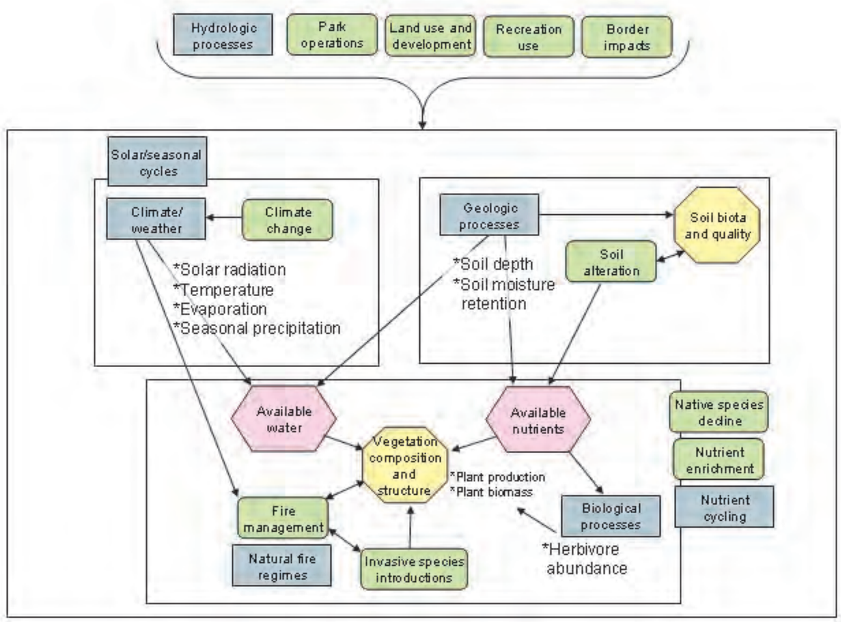
Fire is a relatively common and necessary occurrence in these systems, historically burning every 5-10 years. Fire maintains the open structure of the ecosystem, conferring a competitive advantage to graminoids over most woody plants. Fire suppression, intensive grazing, and soil erosion have degraded much of the grassland ecosystem in this region, leading to encroachment by woody species and drought-resistant nonnative grasses such as Lehmann lovegrass (*Eragrostis lehmanniana*). Archer (1989) depicted the shift from grasslands to grasslands dominated by woody species under a variety of pressures (Figure 2.5):

Figure 2.5. Herb/woody domination, Archer 1989.



Anthropogenic effects indirectly affect mid-elevation systems through trampling, introduction of exotic plant and animal species, harvesting, and multiple types of park operations. Other stressors and drivers depicted outside of the system in Figure 2.6 also have indirect influences on mid-elevation systems.

Figure 2.6. Sonoran Desert Network mid-elevation ecosystem model (modified from Scholes and Walker 1993). Potential vital signs are depicted as *.



2.3.3. High Elevation Systems

High elevation systems in the Sonoran Desert Network include temperate deciduous forests and conifer forests. These systems are dominated by tree species and generally occur above 6,000'. High elevation meadows and savannas also occur in SODN park units; these communities are characterized by grass understories and few trees.

Historically, fire was frequent in these systems but has been controlled for the past 100 years through management (Swetnam et al. 1999). Recent changes in management beliefs have resulted in the slow restoration of fire to these systems within SODN parks.

Like lower elevation systems, upper elevation systems in the Sonoran Desert region are mainly influenced by characteristics of climate and geology, through the availability of moisture and nutrients (Figure 2.7). The presence and introduction of nonnative species and fire management also play key roles in shaping the vegetation and soil biota composition, structure, and function of these systems. Additionally, climate change threatens to have major detrimental impacts on higher elevation systems. Predicted temperature increases combined with changes in precipitation patterns are expected to result in major shifts in species assemblages and upslope shifts in communities (IPCC 2001).

Human uses also impact characteristics of these systems to varying degrees through recreational uses, proximate land use changes and development, and various park operations.

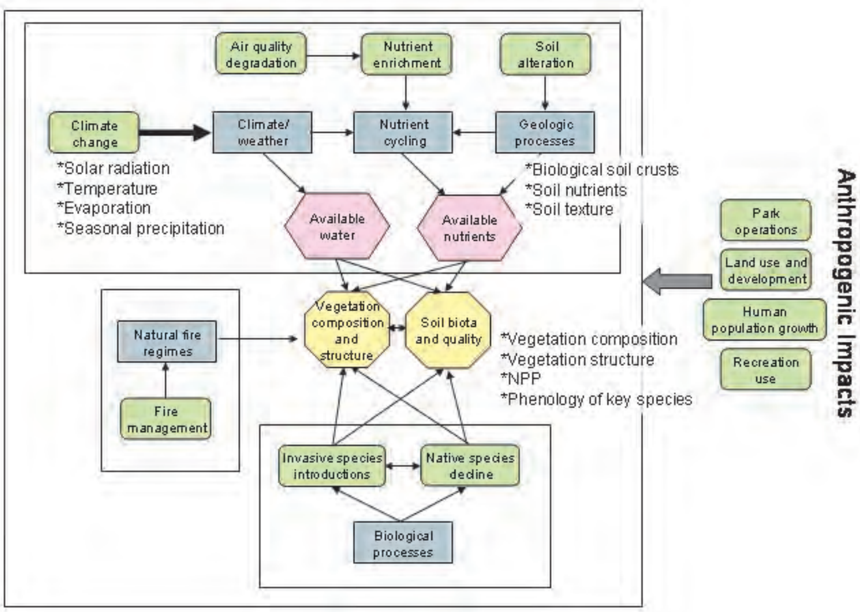


FIGURE 2.7.
Sonoran Desert Network high elevation ecosystem model. Potential vital signs are depicted as *.

2.3.4. Aquatic Systems

Within aquatic systems, five broad categories of variables have major influence on water quality: chemical variables and nutrients, energy inputs, characteristics of habitat structure, biotic factors, and characteristics of the flow regime (Karr et al. 1986; Figure 2.8). Various aspects of chemical and nutrient inputs can be measured directly, including pH, hardness, and organics. Energy inputs include incoming solar radiation, mainly a function of daily and seasonal cycles. Water quantity, a more general term for flow regime, is a function of long-term climatic patterns, short-term weather events, and hydrologic processes and can be measured through precipitation, groundwater levels, and stream velocity. Water quantity is important in its own right in desert ecosystems, limiting many biological processes. In addition, water quantity is directly related to water quality. Many aspects of biological processes have direct impact on water quality, including shifts in canopy composition, structure, and cover.

The stressors and drivers discussed above are those which have the most direct impacts on water quality and quantity, however, many of the other stressors and drivers discussed above also can influence aquatic systems to varying degrees. For this reason, these system influences are also depicted in the aquatic system conceptual model, but are shown as external to the main system.

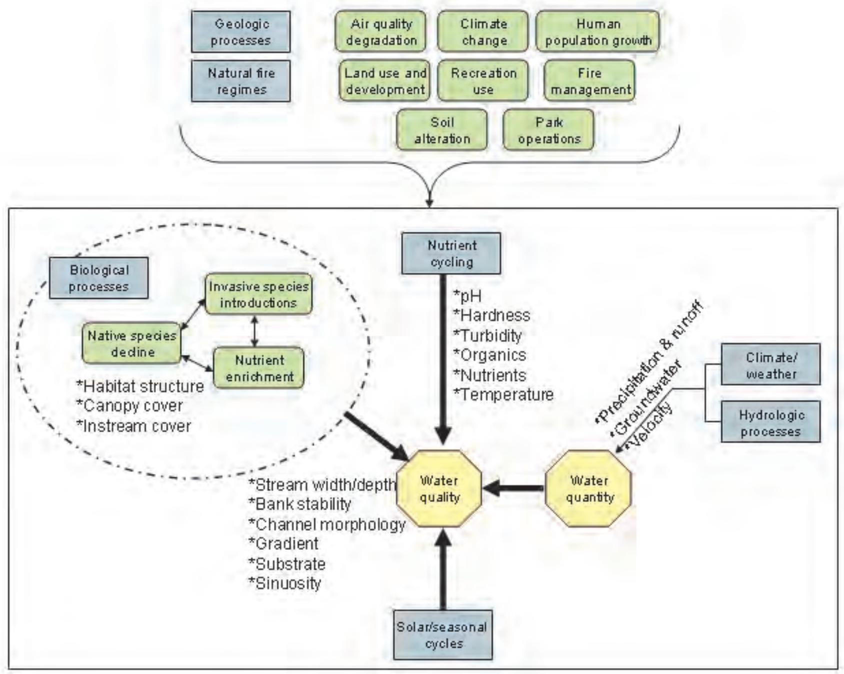


Figure 2.8. Sonoran Desert Network aquatic ecosystem model (modified from Karr et al. 1986). Potential vital signs are depicted as *.

2.4 Sonoran Desert Network Conceptual Diagrams

To facilitate translation of ecosystem complexity to non-technical audiences, a series of system-specific conceptual diagrams were developed. These diagrams were developed based on the agents of resource change: climate and air quality, soil and geomorphology, water quality and quantity, flora and fauna, and landscape and human use. These diagrams pictorially demonstrate the relationships between ecosystem components and SODN vital signs. These diagrams have been integrated into the SODN monitoring website (http://www.nature.nps.gov/im/units/sodn/conceptualmodels/fr-index.html) and can be used to interactively explore the synergistic relationships between ecosystem components. Additionally, users can access information on the selection and development of monitoring protocols for each of the vital signs from this website, including monitoring objectives, the protocol development approach being undertaken, progress to-date, and related products. The five pictorial conceptual diagrams are presented in Appendix H.

CHAPTER 3: VITAL SIGNS

3.1. Overview of the 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 will meet the most critical information needs of each park and produce scientifically credible data that are accessible to managers and researchers in a timely manner. The investment in planning and design also ensures that monitoring will build upon existing information and understanding of park ecosystems and make maximum use of partnerships with other agencies and academia. Collectively, the information used to build the monitoring program also functions as ideal criteria by which ecological indicators can be compared and selected for inclusion in the network's vital signs monitoring program. Although the networks are not required to follow set methodologies for selecting indicators, it is understood that selection of vital signs is an iterative process. Selected vital signs are subject to change as fiscal resources and management issues change. Adjustments to the monitoring program also may occur as subsequent monitoring program reviews conducted approximately every five years provide feedback on the efficacy of the selected indicators (Chapter 8). The following sections briefly explain the SODN vital sign selection and prioritization process.

3.1.1. SODN Vital Signs Selection Process

The SODN employed a three-part process to identify specific management goals and concerns for SODN parks and partners, develop an overall monitoring framework, and select and prioritize candidate vital signs (Figure 3.1). The three components included park-based scoping to determine park management goals and issues; identify monitoring objectives appropriate within the broader ecosystem context; and articulate potential monitoring indicators through interviews of experts in specific fields.

For each of the three phases, a modified version of the nominal group technique (NGT) was employed. The SODN Board of Directors selected the NGT in October 2002 as a preferred method to broad scoping meetings or the Delphi process (Crance 1987).

The main steps in the NGT (Moore 1994) are:

1. silent generation of ideas in writing
2. round-robin recording of ideas
3. serial discussion of the list of ideas
4. voting

These basic steps of NGT were followed in each of the work groups, which consisted of seven to twelve people. Each workgroup was facilitated by the same group of SODN staff, and each group was provided the same background and introductory information at the start of the meeting. Participants were provided background information prior to the meeting, and the silent generation of ideas occurred, in some cases, prior to the meeting. In addition, all work groups worked under the same criteria for identifying indicators. The following sections give greater details for each of the three steps.

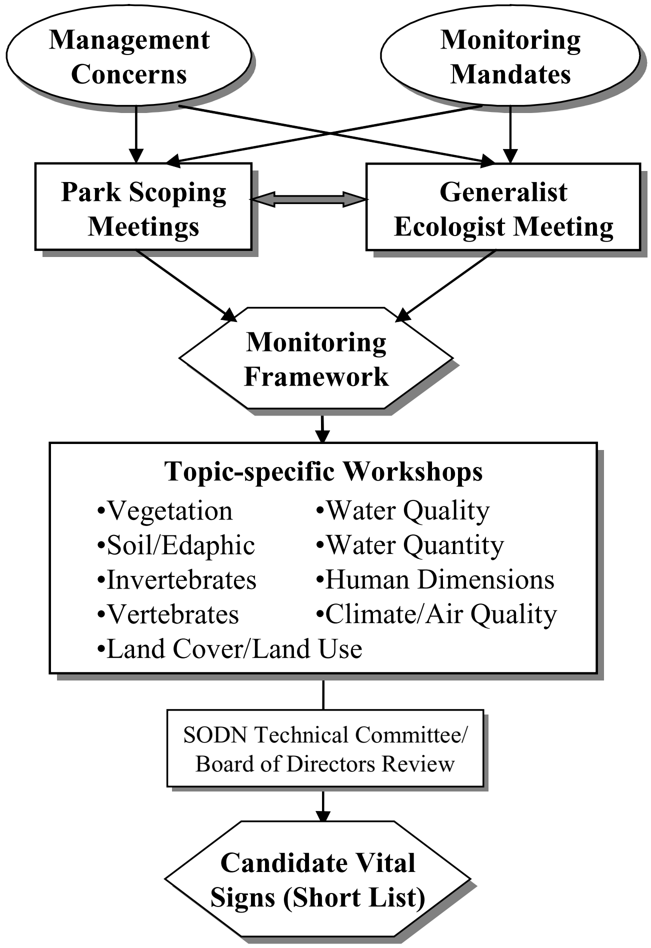


Figure 3.1.
Process diagram of the SODN approach to candidate vital sign selection.

1. Park-Based Scoping

Objective: Define park management goals and issues for monitoring

A series of eight park-based workshops were held in 2002 and 2003 to better articulate park management goals and issues to be considered in the design of a monitoring plan (Table 3.1). Several topics were covered in each workshop:

- Status of baseline inventory and assessment
- Resource stressors and management concerns
- Desired future conditions for park resources
- Past or present monitoring activities
- Specific monitoring interests
- Past management decisions made using natural resource monitoring information

A list of workshop participants and a more detailed discussion of issues addressed appears in Appendix F.

Park	Date(s)
CAGR	August 26, 2002
TONT	January 13, 2003
TUMA	January 27, 2003
SAGU	March 3-4, 2003
GICL	March 10, 2003
CORO	March 17, 2003
MOCA/TUZI	April 29, 2003
ORPI	May 5, 2003
CHIR/FOBO	May 19, 2003

Table 3.1.
Dates for park-based vital signs scoping workshops.

2. Development of a Monitoring Framework

Objective: Set monitoring objectives; define monitoring criteria; establish expert workgroups

An initial expert workshop was held May 8, 2003 with eight scientists from the United States and Mexico. At this meeting, participants described the appropriate goals and conceptual framework for a regional ecosystem monitoring program, identified criteria that monitoring indicators must meet, and proposed main themes for monitoring in the Sonoran Desert.

The scientists were selected based on their unique and extensive experience with Sonoran Desert and Apache Highlands ecosystems and ecological monitoring, and represented several scientific disciplines including plant ecology, hydrology, climatology, ecosystem ecology, vertebrate ecology, sociology, and conservation biology. A list of participants and a more complete description of the process are provided in Appendix I. The framework approach was for ecological monitoring at a regional scale (i.e., the Sonoran Desert), placing Sonoran Desert Network parks within this larger context. During this facilitated workshop, participants defined the following monitoring objectives for the Sonoran Desert Network:

A. Determine the status of and detect trends in natural resources that are important for human health, safety, and economic uses (e.g., water quality).

B. Determine the status of and detect trends in biological resources (e.g., abundance).

C. Describe ecological processes that perpetuate biological diversity (e.g., natural disturbance regimes).

D. Describe physical/abiotic features that may influence biological resources (e.g., soil structure, water budgets).

E. Track known or potential anthropogenic stressors (e.g., urbanization).

Participants were then asked to establish criteria for selecting monitoring indicators. Examples from the literature (Noon et al. 1999, Dale and Beyeler 2001) were presented and discussed. After a lengthy discussion and debate, the group settled on the following characteristics of “ideal” vital signs:

- Changes parallel those of the larger component or system
- Changes quickly in response to changes in the larger component or system (“leading” indicator)

- Low inherent natural variability
- Can be estimated precisely
- Can be estimated efficiently (reasonable cost)
- Methods for estimation and field work are well established

The final task for the participants was to define the key resource groups for subsequent evaluation of monitoring parameters by subject matter experts. The group distinguished eight expert workgroups. The eight workgroups are identified and the dates for their respective meetings are summarized in Table 3.2.

Table 3.2. Subject-specific workshop dates.

Activity	Date
Vegetation Expert Vital Signs Workshop	May 8, 2003
Vertebrate Expert Vital Signs Workshop	July 11, 2003
Human Dimensions Expert Vital Signs Workshop	July 22, 2003
Invertebrate Expert Vital Signs Workshop	July 25, 2003
Hydrology and Soils Expert Vital Signs Workshop	July 28, 2003
Land Cover and Land Use Expert Vital Signs Workshop	July 29, 2003
Climate and Air Quality Expert Vital Signs Workshop	August 11, 2003
Landscape Processes and Geomorphology	October 30, 2003

3. Expert Workgroups

Objective: Discuss monitoring parameters and identify candidate vital signs

Following the recommendations of the first expert workshop, a series of scientific work groups were facilitated to identify potential monitoring indicators. Work groups were organized around the following themes: vegetation, vertebrates, invertebrates, air quality and climate, hydrology and soils, human dimensions, land use and land cover, and ecosystem processes (Table 3.2). A list of all the scientists who participated in these meetings, more detailed discussion of the selection and ranking process, and meeting handouts appear in Appendix I. Each of these scientific work groups identified potential indicators that met the criteria set out by the initial expert workshop. For each indicator, the group then justified why they thought that indicator was important to monitor; specified the appropriate geographic and temporal scale; discussed whether these data were currently being collected, and if so, by whom; identified existing protocols; and discussed potential limitations. Finally, the scientists prioritized the indicators into one of three categories: "recommended," "promising" (worthy of additional investigation), and "not recommended." For a complete list of the indicators proposed, see Appendix I.

3.2. Selected Vital Signs

"Recommended" vital signs from each workgroup were compiled into a master list and presented to the SODN Technical Committee and Board of Directors on August 22-23, 2003. Following a discussion of the relative merits and limitations of each "recommended" vital sign, the Technical Committee and Board of Directors selected 25 vital signs. These vital signs appear in Table 3.3., presented in a hierarchical framework developed by the I&M Washington Office. A ranked list of potential additional monitoring parameters by park and a description of the process used to generate the list appears in Appendix J.

Table 3.3. Candidate vital signs for the Sonoran Desert Network.

Level 1	Level 2	Vital Sign	CAGR	CHIR	CORO	FOBO	GICL	MOCA	ORPI	SAGU	TONT	TUMA	TUZI
Air and Climate	Air Quality	Ozone	--	•	--	--	--	--	•	•	--	--	--
		Wet and dry deposition	--	•	--	--	•	--	•	--	✚	--	--
		Visibility and particulate matter	--	•	--	--	•	--	•	•	•	--	--
	Weather and Climate	Broad-scale climate	•	•	•	•	•	•	•	•	•	•	•
		Meso-scale climate	--	✚	--	--	--	--	•	✚	--	--	--
Geology and Soils	Geomorphology	Channel morphology	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Upland soil movement	--	◊	◊	◊	◊	◊	◊	◊	◊	--	◊
	Soil Quality	Biological soil crusts	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Soil cover	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Soil compaction	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Soil aggregate stability	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Soil organic matter content	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
		Soil carbon and nitrogen content	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Water	Hydrology	Groundwater dynamics	✚	✚	•	•	✚	✚	•	✚	✚	✚	✚
		Surface water dynamics	--	--	◊	✚	✚	✚	•	✚	--	✚	✚
	Water Quality	Core parameters	✚	✚	✚	✚	✚	✚	•	✚	✚	✚	✚
		Nutrient dynamics	✚	--	--	--	✚	✚	--	--	✚	✚	✚
		Pollutant metals	✚	✚	✚	--	--	✚	--	✚	--	✚	✚
		Microorganisms	--	--	◊	◊	✚	✚	✚	✚	--	✚	✚
		Aquatic macroinvertebrates and algae	--	--	◊	◊	✚	✚	✚	✚	--	✚	✚
		Carcinogens and toxins	--	--	--	--	--	--	--	--	--	◊	◊
		Suspended sediments	--	--	◊	◊	◊	◊	◊	◊	--	◊	◊
Biological Integrity	Invasive Species	Exotic plants – early detection	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Exotic plants – status and trends	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
	Focal Species or Communities	Phenology of key plant species	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Vegetation life form abundance	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Vegetation community structure	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Recruitment of dominant plant species	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
		Saguaro cactus (*Carnegia gigantea*)	◊	--	--	--	--	--	◊	•	◊	--	--
		Organ pipe cactus (*Stenocereus thurberi*)	--	--	--	--	--	--	◊	--	--	--	--
		Ironwood (*Olneya tesota*)	--	--	--	--	--	--	◊	◊	--	--	--

✚ Vital signs that the SODN is working to develop monitoring plans and protocols
• Vitals signs that are monitored by a network park or another federal or state agency
◊ Vital signs with no known current or planned monitoring
-- Vital sign does not apply to the park

Table 3.3. continued.

Level 1	Level 2	Vital Sign	CAGR	CHIR	CORO	FOBO	GICL	MOCA	ORPI	SAGU	TONT	TUMA	TUZI
Biological Integrity	Focal Species or Communities	Terrestrial invertebrates	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
		Bird community dynamics	✚	✚	✚	✚	✚	✚	•	✚	✚	✚	✚
		Elf owl (*Micrathene whitneyi*)	◊	◊	◊	◊	--	◊	◊	•	◊	◊	◊
		Terrestrial lizards	◊	◊	◊	◊	--	◊	•	◊	◊	◊	◊
		Nocturnal rodents	◊	◊	•	◊	◊	◊	•	◊	◊	◊	◊
		Large mammals	--	◊	◊	◊	◊	◊	◊	•	◊	◊	◊
		Fish community dynamics	--	--	--	--	✚	✚	•	✚	--	✚	✚
		Amphibians and aquatic reptiles	--	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
	At-risk Biota	Mexican spotted owl (*Strix occidentalis*)	--	•	•	--	◊	--	--	•	•	--	--
		Cactus ferruginous pygmy owl (*Glaucidium brasilianum*)	◊	--	--	--	--	--	•	•	--	--	--
		Nectar-feeding bats (*Leptonycteris* spp.)	--	--	•	--	--	◊	•	•	◊	--	◊
		Lowland leopard frog (*Rana yavapaiensis*)	--	--	--	--	--	--	--	•	--	--	--
		Desert tortoise (*Gopherus agassizii*)	◊	--	--	--	--	◊	◊	•	◊	--	◊
		Sonoran pronghorn (*Antilocapra americana sonoriensis*)	--	--	--	--	--	--	•	--	--	--	--
		Acuña cactus (*Echinomastus erectocentrus* var. *acunensis*)	--	--	--	--	--	--	•	--	--	--	--
		Sonoyta mud turtle (*Kinosternon sonoriense longifemorale*)	--	--	--	--	--	--	•	--	--	--	--
		Desert pupfish (*Cyprinodon macularius eremus*)	--	--	--	--	--	--	•	--	--	--	--
Human Use	Visitor and Recreation Use	Visitor use	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
		Visitor use impacts	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
	Point-source Human Effects	Illegal roads and trails	--	--	✚	✚	--	--	✚	✚	--	--	--
Ecosystem Pattern & Processes	Land Use/Land Cover	Landscape dynamics	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚	✚
	Fire	Fire and fuel dynamics	--	•	◊	◊	◊	--	◊	•	--	◊	--
	Productivity	Net primary productivity	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊

✚ Vital signs that the SODN is working to develop monitoring plans and protocols
• Vitals signs that are monitored by a network park or another federal or state agency
◊ Vital signs with no known current or planned monitoring
-- Vital sign does not apply to the park

Chapter 4: SAMPLING DESIGN

4.1 Introduction

The fundamental mission of the National Park Service is to protect park resources, and an essential function of the Inventory and Monitoring Program is to characterize and determine the status and trends of these natural resources. An overall sampling design is important to ensure that individual monitoring components will be spatially integrated, to the degree possible. In addition, it is essential that data can meet the purpose for which they were collected and can withstand scrutiny. Therefore, statistical sampling designs will be selected allowing inferences to the extent of the park resources. This chapter outlines the overall statistical sampling designs adopted for SODN vital signs. Greater detail on sampling locations and methods can be found in the vital sign protocols.

4.2 Sampling Concepts and Definitions

The monitoring approaches proposed for SODN rely on concepts in finite population sampling. In finite population sampling, the area to which inferences are desired (e.g., park unit) is generally viewed as a finite collection of *sampling units*. The total collection of sample units is called the *population*. The subset of units of the population for which measurements are taken is the *sample*. *Probability sampling* is where each element in the finite population has a known probability of being included in the sample (i.e., selection probability). The selection probability can be uniform or vary among groups of elements (i.e., unequal probability sampling). Additionally, selection probabilities can vary in subsequent additions of sampling sites. Proper estimation of population parameters requires maintaining a record of the selection probability for each element for each sample-site selection event.

Water quality sampling on the Santa Cruz River at Tumacacori NHP.

Most sampling designs proposed for SODN vital signs will rotate field sampling efforts through various sets of sample units over time. A group of units that are always sampled during the sampling occasion are called a *panel*. Sample effort can be rotated among panels through time, which effectively rotates field effort among sample units and therefore space. The pattern of visits through time to all panels is the *revisit design*. Revisit designs specify the temporal sampling schedule. Proposed notation for revisit designs is represented by a pair of digits, the first of which is the number of consecutive occasions that a panel is sampled, the second of which is the number of consecutive occasions that a panel is not sampled before repeating the sequence (McDonald 2003). The total number of panels in the rotation design is normally the sum of digits in the notation. For instance, if a single panel is visited every sample occasion, its revisit design would be [1-0]. The notation [1-0, 1-5] means that units in one panel are visited every occasion while units in the other are visited once every six years. The way in which units in the population become members of a panel is called the *membership design* (McDonald 2003).

There are many ways to draw a sample with a random component, the most basic of which is a *simple random sample*. In a simple random sample, the desired number of elements is selected from a known population without regard to spatial location (Lohr 1999). A *stratified random design* is where the sampling frame is divided into mutually exclusive strata. Stratification affords increased precision and efficiency and greater information about subpopulations (Lohr 1999). Strata are typically selected such that variation within a stratum is less than among strata. Sampled elements within strata are randomly selected. The *generalized random tessellation stratified (GRTS)* is designed to produce a spatially balanced random sample (Stevens and Olsen 2004).

This method is based on creating a function that maps two-dimensional space into one-dimensional space and uses a restricted randomization algorithm to select spatially balanced, random samples. Spatial balance means that sampled areas are spread out approximately uniformly. Inherent in the GRTS scheme is the ability to assign selected sampling units to panels such that each panel is spatially balanced. There are various benefits and limitations to each of the three allocation methods. However, due to the benefits of spatially balanced samples among panels, the GRTS scheme will be used to monitor most SODN vital signs.

The SODN monitoring program emphasizes co-location and co-visitation of vital signs. *Co-location* refers to monitoring several vital signs at the same physical location. *Co-visitation* refers to recording observations for multiple vital signs during a single sampling occasion. Co-location and co-visitation increases efficiency, reduces costs, and minimizes impacts to resources. Additionally, insights can be gained through analysis of data that were collected together. First, monitoring drivers and responses aids in interpreting reasons for observed changes. Monitoring several vital signs in concert can also contribute to understanding the causes and consequences of interactive behaviors. Finally, where the lack of precision masks statistically significant change, the collective consistency in trends among vital signs can serve as a weight of evidence of change.

4.2.1. Tracking Selection Probabilities

Most SODN vital signs will be monitored using probability sampling. Factors considered in deriving a selection probability vary among vital signs, with the most common being accessibility and travel costs. Formal stratification will be avoided in most cases due to its restrictive qualities (McDonald and Geissler 2004). Instead, unequal probability sampling will be employed. This approach provides the same benefits of stratification but without the restriction of permanent strata. As time and budget allows, additional sites may be established to enhance status and trend assessments or to expand the number and types of areas sampled. With probability sampling, the selection probability of elements can be modified to reflect changes in objectives and new sampling sites added through re-sampling with replacement. Maintaining a record of selection probabilities in the original and subsequent sampling site lotteries will be essential for statistical and inferential integrity. Thus, properties of the sampling frame for each vital sign (e.g., location of elements, accessible/inaccessible designation, travel distance) and selection probability of elements will be documented for each park unit. Metadata will include the numbers and types of selected sampling units, selection procedures and outcomes, and reasons for re-sampling events. Documentation will follow National Biological Information Infrastructure Profile guidelines. Accommodating the potential for change in the initial monitoring design is essential for the long-term viability of the SODN monitoring program.

4.3. Overview of Sampling Approaches

Five fundamentally different schemes for collecting measurements on vital signs were adopted for SODN monitoring efforts. *Grid-based sampling* uses a grid of points to represent elements of a target population. A probability sample is drawn from this grid. *Network sampling* delineates elements of the target population as equal-distance elements located on network segments. From these elements, a probability sample is drawn. *List-based sampling* involves constructing a list of potential sample units and drawing a probability sample. *Index sites* are used to collect information at carefully selected, representative locations. Finally, a *census* will be taken for vital signs where information can be collected for the extent of the entire park. Each of these sampling schemes is discussed in further detail below. A summary of sampling designs, spatial allocation of samples, and revisit plan for vital signs is presented in Table 4.1.

4.4. Grid-Based Sampling

Grid-based sampling is the primary spatial sampling method for vital signs associated with vegetation, soils, and bird vital signs. The sampling frame consists of a systematic grid of points (Figure 4.1). A 50-m grid will be implemented for all SODN parks except ORPI, for which a 150-m grid will be employed. The increased grid spacing for ORPI was selected due to the unique size (over 133,000 ha, or ~97% of SODN park area) and accessibility limitations (rough terrain, few roads and trails) of the park as compared with the relatively small parks that comprise the rest of the network. Maps of park grids appear in Appendix K.

4.4.1. Vegetation Community Structure and Soil Stability

Vegetation community structure, soil aggregate stability, and soil compaction will be monitored concurrently at the same permanent plots. These three vital signs are anticipated to exhibit changes more slowly than other aspects of vegetation and soil quality. These vital signs will be monitored using more intensive sampling techniques than the other vegetation and soils vital signs. The plots will be permanent and will be revisited every 5 years, in a revisit design of [1-4]; Table 4.2. Because inter-annual variability is expected to exhibit negligible impacts on the parameters of interest, panels within parks will not be created. Rather, entire parks will be sampled within a year. Sampling locations will be generated using the GRTS technique, with accessibility being used as selection probability. Inaccessible areas, defined within the individual protocols, will be given a selection probability of 0.

4.4.2. Vegetation Life Form Abundance, Soil Quality, and Exotic Species Status & Trends

The remaining soil quality vital signs (soil cover and biological soil crusts) and vegetation life form abundance will be sampled together on permanently established plots. The methods used for these vital signs will be rapid, enabling many samples to be taken in a short amount of time. It is anticipated that these vital signs will respond rapidly (annually) to stressors. Because travel to sampling locations will be the greatest sampling cost for these vital signs, a two-stage sampling scheme will be employed. Status and trends of exotic plants will also be accomplished as a part of vegetation life form abundance monitoring. As target exotic species are encountered within vegetation life form abundance plots, they will be recorded. Because the location of these plots will have a random component, they will enable park-wide inference for both life form abundance and exotic plant species status.

An initial estimate of temporal allocation for larger SODN parks and parks with difficult access (SAGU, ORPI, CHIR, CORO) is a split-panel design with a revisit design of [2-4,1-6] (Table 4.1). This design provides the ability to evaluate inter-annual variability and balances the ability to address status and trends. Plots sampled as part of the [2-4] revisit design will be oriented to minimize spatial variability, so that changes observed from one year to the next can be attributed primarily to inter-annual variability. Each panel within the [1-6] revisit design will be comprised of plots evenly distributed across park units, resulting in better spatial coverage and yielding status and trends information.

The first stage of sampling locations will be located in a spatially-balanced design using GRTS. Selection probability will be based mainly on accessibility, with inaccessible areas given a probability of 0. Sampling locations will then be oriented in regular clusters surrounding these locations.

Table 4.1.
Proposed sampling design, spatial allocation of samples, and revisit plan for SODN Vital Signs.

Level 1	Level 2	Vital Sign	Sample Design	Spatial Allocation	Proposed Revisit Plan
Air and Climate	Air Quality	Ozone	Index Sites	N/A	Continuous
		Wet and dry deposition	Index Sites	N/A	Continuous
		Visibility and particulate matter	Index Sites	N/A	Continuous
	Weather and Climate	Broad-scale climate	Index Sites	N/A	Continuous
		Meso-scale climate	Index Sites	N/A	Continuous
Geology and Soils	Geomorphology	Channel morphology	Network Based	GRTS	[1-4]
	Soil Quality	Biological soil crusts	Grid Based	GRTS; Cluster design	[1-4]
		Soil cover	Grid Based	GRTS; Cluster design	[2-4,1-6]
		Soil compaction	Grid Based	GRTS; Cluster design	[2-4,1-6]
		Soil aggregate stability	Grid Based	GRTS	[1-4]
Water	Hydrology	Groundwater dynamics	List Based	N/A	varies
		Surface water dynamics	List Based	N/A	varies
	Water Quality	Core parameters	Network Based	GRTS	[4-0]
		Nutrient dynamics	Network Based	GRTS	4x/year; [1-2]
		Pollutant metals	Network Based	GRTS	4x/year; [1-2]
		Microorganisms	Network Based	GRTS	4x/year; [1-2]
		Aquatic macroinvertebrates and algae	Network Based	GRTS	[1-2] or annually
Biological Integrity	Invasive Species	Exotic plants – early detection	Grid Based	GRTS	[1-1]
		Exotic plants – status and trends	Grid Based	GRTS	[2-4,1-6]
	Focal Species or Communities	Phenology of key plant species	Index Sites	N/A	Continuous
		Vegetation life form abundance	Grid Based	GRTS; Cluster design	[2-4,1-6]
		Vegetation community structure	Grid Based	GRTS	[1-4]
		Bird community dynamics	Grid Based	GRTS	[1-0]
		Fish community dynamics	Network Based	GRTS	[1-0, 3-4]
Human Use	Visitor and Recreation Use	Visitor use	List Based	N/A	Commensurate with public record update
		Visitor use impacts	Network Based	GRTS	[1-4]
	Point-source Human Effects	Illegal roads and trails	Census	N/A	[1-9]
Ecosystem Pattern & Process	Land Use/Land Cover	Landscape dynamics	Census	N/A	[1-9]

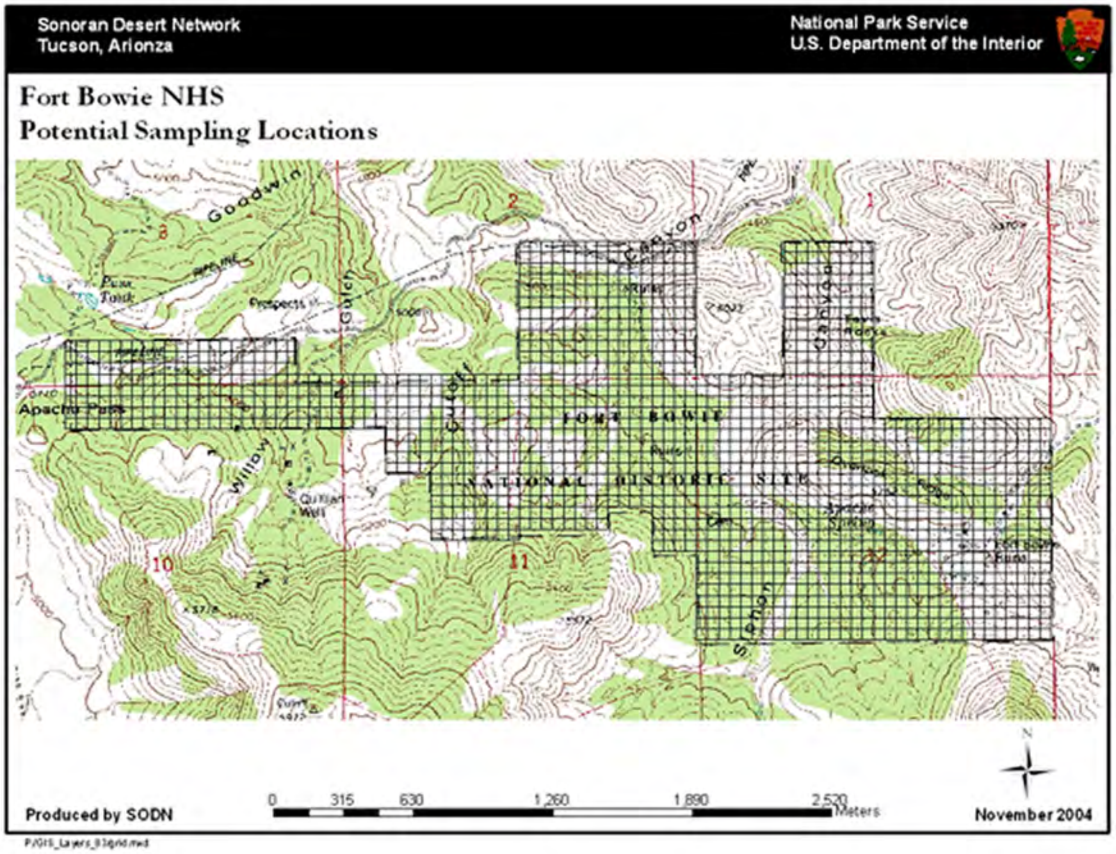


Figure 4.1. Sampling grid (50-m cells) superimposed on Fort Bowie NHS.

Table 4.2. Proposed split-panel design for monitoring vegetation community structure and soil

	Year						
Panel	1	2	3	4	5	6	7 …
1	x					x	x
2	x	x					x
3		x	x				
4			x	x			
5				x	x		
6					x	x	
1	x						
2		x					
3			x				
4				x			
5					x		
6						x	
7							x

4.4.3. Bird Community Dynamics

Bird community dynamics will be monitored on an annual basis using variable point counts (Reynolds et al. 1980) at permanently established locations. Point count locations will be selected from the subpopulation of grid points containing the vegetation and soils monitoring locations, ensuring co-location of these vital signs and enhancing data interpretation. The intended revisit design is [1-0] with no membership design since all sites will be monitored annually.

At each of the sampling locations, a timed visual and aural survey is performed. Observations of birds by sight or call are recorded along with the estimated distance from point center to the first detection of an individual. The histogram of these detection distances will allow a function to be estimated which will adjust overall counts for decreased probability of detection at large distances. Estimation of the detection function and density of each species will be performed using the Distance program (Buckland et al. 2001). Given the tendency for a limited number of observations of these species, however, transect observations generally provide status rather than trend information.

4.4.4. Exotic Plants Early Detection

Predictive models of likely distributions will be built at the park level for each target species. These models will then guide sampling. For each species, areas of each park unit that are of high risk of invasion will be identified through modeling. These areas constitute the sampling population. From this population, sampling locations will be identified using the GRTS approach. Sampling will likely involve a two-stage or cluster sampling approach, to minimize travel time between sites.

Parks will be monitored biennially, resulting in a revisit design of [1-1]. Rather than creating panels within parks, entire high-risk areas within parks will be sampled within a year.

4.5. Network Sampling

Network sampling will be implemented for SODN riparian and visitor use impacts vital signs. This sampling design operates by delineating elements of the target population as equal-distance elements located on network segments and then from these elements, drawing a probability sample.

4.5.1. Aquatic Vital Signs within Perennial Streams

Aquatic and riparian vital signs monitoring will be highly integrated on SODN parks where perennial waters exist. Several vital signs including channel morphology, aquatic macroinvertebrates, riparian vegetation, core water quality parameters, water chemistry constituents (nutrient levels, pollutant metals), and microorganisms will be co-located. When possible, these vital signs will be sampled concurrently to increase data collection efficiency and to enhance data interpretation and integration.

To ensure spatial accuracy, perennial channels in all park units will be mapped using GPS and handheld PCs. The sampling frame for a park unit consists of all perennial stream segments within the park unit and a distance of 100 m upstream and downstream of the park boundary. Sampling locations will be selected using GRTS. Beginning with the first sampling location selected by the GRTS algorithm, a sampling reach will be established as 40 times the wetted width of the stream, as recommended by the EPA EMAP program for monitoring wadeable perennial streams (Kaufmann et al. 1999). The GRTS point will then be used to locate the center point for the sampling reach; the endpoints of the reach will then be established at 20 times the distance of the wetted width both up and downstream of the GRTS point. The second sampling reach will be established using the second GRTS point in this same manner, provided that the two reaches are separated by at least 25 meters if located within a park boundary or by at least 150 meters if outside a park boundary. If this criterion can not be met, the next GRTS point will be used. Sampling reaches will be established in this manner until no additional sampling reaches could be established which did not overlap with other sampling reaches.

The reach will be divided into 10 equally-sized segments. Aquatic macroinvertebrates will be sampled at the end of each segment, resulting in 11 equally-spaced sampling locations. Three channel morphology cross-sections will be located at the top of the nearest riffle to the top, middle, and bottom of the sampling reach. Water quality parameter samples will be taken at the midpoint of the reach, and a vegetation community structure plot will be located on either bank at the midpoint of the reach. This design results in the nesting and co-location of seven vital signs (Table 4.3).

Table 4.3. Proposed nested sampling design for aquatic vital signs within perennial streams.

		Location along sampling reach										
		1-1	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**
Geology and Soils	Stream channel morphology	[1-4]					[1-4]					[1-4]
Water	Aquatic macroinvertebrates	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]	[1-2]
	Surface water dynamics						[1-2]					
	Core parameters						[1,0], 4x/yr					
	Nutrient dynamics						[1,0], 4x/yr					
	Microorganisms						[1-0]					
Vegetation	Vegetation community structure						[1-4]					

Channel morphology will be measured every 5 years, in a revisit design of [1-4], or immediately following a major flooding event, defined as a 10-year event. Water quality parameters will be measured four times a year. Aquatic macroinvertebrates will be measured each spring. As perennial waters in SODN parks are rare, few sampling reaches (i.e., five or less) will be located in any one park unit. It has not yet been decided whether all reaches within a park unit will be sampled during a sampling event or whether a panel design will be invoked. A pilot study in 2005-2006 will determine the final temporal scheme.

Fish sampling locations in perennial streams will also be nested within this design. It is anticipated that twenty-five percent of the selected sites will be revisited on an annual basis and seventy-five percent will be visited every five years on a rotating panel design. This revisit and membership design will strike a balance between power to detect trends over time and precision with estimating parameter means (McDonald 2004). The number of sampling locations is yet to be determined, pending an inventory of fish habitat (2006).

Channel morphology and vegetation community structure sampling will also take place on intermittent primary B and C stream channel types (Rosgen 1994). Using slope derived from a 10 m DEM, intermittent streams will be divided into stream channel types. One sampling reach will be randomly located within each stream channel type using GRTS. The length of the reach will be 20 times the bankfull width; bankfull measurements will be estimated from regional curves based on watershed area. Three channel cross-sections will be located within each sampling reach, one at either end and one in the center. The revisit interval for intermittent stream cross-sections will be a function of the amount of seasonal precipitation within the watershed; this is yet to be determined.

4.5.2. Visitor Use Impacts

As visitors' impacts are generally concentrated on trails or in the close vicinity of established roads and trails, this vital sign will be sampled using the network of existing roads and trails. Sampling locations will be generated using the GRTS technique, with distance from trailhead or key feature being used as selection probability. Characteristics including presence of trash, cactus vandalism, diminished recruitment of key plant species, and presence of exotic species constitute this vital sign. Related vital signs including soil cover, biological soil crusts, soil compaction, and vegetation life form abundance will be co-located and sampled concurrently with visitor use impacts sampling locations. Sites will be permanent and will be revisited every 5 years, in a revisit design of [1-4]. Panels will be created so that some portion of each park is sampled every year; sampling locations within panels will be equally distributed across park units. Visitor use sampling designs and protocols will also be applied to illegal trails resulting from trans-border smuggling activities.

4.6. List-based Sampling

List-based sampling will be the primary sampling method for visitor use and for monitoring water quality and quantity characteristics of tinajas (large "potholes" in intermittent and ephemeral drainages that store surface water for extended periods of time) and springs (point rather than linear or polygon aquatic features). In list-based sampling, the location and extent of the target population is derived from inventories and then organized as lists. The spatial and temporal allocation of samples varies by vital sign.

4.6.1. Visitor Use

Visitor use will be quantified using a variety of techniques at permanently established sites. Trail counters, counts taken at entrance stations and visitor centers, visitor registration, visitor permits, visual observation, and tracking plots are all under consideration. Where measures are currently being collected, as in the case with entrance stations, these sampling locations have already been established and will not be changed. To ascertain visitor use of specific locations, the sampling design will be monitored on an annual or more frequent basis, without a membership design. Where park-wide status and trend information are desired, the list of locations will be organized by categories (trail heads, campgrounds, etc.), selection probabilities will be generated based on park-defined criteria, and monitored areas will be selected as a GRTS sample. When appropriate, panel membership will be determined by the sequential allocation of ordered GRTS sample.

4.6.2. Aquatic Vital Signs in Tinajas and Pools

Water quality, water quantity, fish community dynamics, and aquatic macroinvertebrates will be sampled in tinajas using a list-based approach, much like the Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP; Stevens 1994). Tinajas and pools at least 3 m in size will constitute the sampling population within a park unit, where each pool is a single sampling unit. An unequal probability sample will be drawn based on accessibility using GRTS.

Springs will also be addressed with a list-based approach. Key high priority water bodies identified in the SODN Water Quality Monitoring Plan (Sprouse et al. 2004) will comprise the sampling locations for several vital signs including core water quality parameters, water quantity, fish community dynamics, and aquatic macroinvertebrates. The specific suite of vital signs measured will vary by site. Because these sampling locations were selected based on their unique characteristics and their importance to the landscape, they will not allow inference to a greater population. However, it will be possible to ascertain status and trends of conditions within the specific sites. Revisit designs will be vital-sign specific and will follow revisit designs determined for vital signs in perennial waters (see above). Some hydrologic characteristics (water level, temperature) will be measured continuously through sensors and datalogging equipment.

Table 4.4 summarizes water quality vital signs recommended for SODN park units in the SODN Water Quality Implementation Plan (Sprouse et al. 2004). Maps of potential samling locations by park units appear in Appendix L. Many of the water bodies identified as candidate water quality sampling sites in this plan are small. For small water bodies (approximately less than two square meters in surface area and less than

Table 4.4. Summary of recommended water quality vital signs for the Sonoran Desert Inventory and Monitoring Network.

1 = as needed
2= four times per year
3 = once every 1-2 years
4 = once every 5-10 years
5 = monitored in cooperation with other agencies or organizations

	WATER QUALITY						HYDROLOGY			GEOMORPHOLOGY			
Park and Water Source	Core Parameter	Major Ions	Nutrient Loading	Pollute Metals	Biological Condition	Macroinverts	Surface Flow	Groundwater Depth	Spring Discharge	Channel Morph.	Channel Substrate	Channel Type	Bank Stability
CAGR													
Wells								3					
CHIR													
King Lead Mine	2	4	4	1	4								
Shake Spring	2	4	4	4	4	1			2				
Silver Spur Sp.	2	4	4	4	4	1			2				
Bonita Creek					1		1			1	1	1	1
Rhyolite Creek							1			1	1	1	1
Wells								3					
CORO													
Mine 32	2	4	4	4	4	1			2				
Blue Waterfall	4	4	4	4	4	1			4				
Fern Grotto	2	4	4	4	4	1			2				
Texas Mine Seep	2	4	4	4	4	1			2				
Montezuma Cyn							1			1	1	1	1
Joe's Spring	1	4	1	4	1	1			1				
Wells								3					
FOBO													
Apache Spring	2	4	4	4	4	1			2				
Mine Tunnel	2	4	4	4	4	1			2				
Siphon Canyon							1			1	1	1	1
Wells								3					
GICL													
WF Gila #1	2	4	4	4	4	5	5			5	5	5	5
WF Gila #2	2	4	4	4	4	5	5			5	5	5	5
Cliff Dwell Cyn							1			1	1	1	1
Wells								3					

Table 4.4. continued.

1 = as needed
2= four times per year
3 = once every 1-2 years
4 = once every 5-10 years
5 = monitored in cooperation with other agencies or organizations

	WATER QUALITY						HYDROLOGY			GEOMORPHOLOGY			
Park and Water Source	Core Parameter	Major Ions	Nutrient Loading	Pollute Metals	Biological Condition	Macroinverts	Surface Flow	Groundwater Depth	Spring Discharge	Channel Morph.	Channel Substrate	Channel Type	Bank Stability
MOCA													
Beaver Creek	2	4	2	4	2	3	5			5	5	5	3
Wet Beaver Crk	2	4	3	4	3	3	5			5	5	5	3
Montezuma Well	2	4	3	4	3	3	5						
Wells								3					
ORPI													
Quitobaquito	2	4	4	4	4	1			3				
Dripping Spring	2	43	4	3					3				
Tinajas	2	4	3	4	3								
Aguajita Wash							1			1	1	1	1
Growler Wash							1			1	1	1	1
Kuakatch Wash							1			1	1	1	1
Wells								3					
SAGU													
Select Channels							1			1	1	1	1
Tinajas	3	4	4	4	4	1							
Madrona Pools	2	4	3	4	3	1							
Rincon Creek	2	4	4	4	4	3	5			5	5	5	5
Manning Camp	2	4	4	4	3	1							
Water Tank	2	4	4	4	4								
4 O'Clock Wash							1			1	1	1	1
Wells								3					
TONT													
Cave Canyon							1			1	1	1	1
Cholla Spring	2	4	4	4	4				3				
Wells								3					
TUMA													
St. Cruz River	5	3	3	4	3	1	1			1	1	1	1
Wells								3					
TUZI													
Tavasci Marsh	2	4	4	4	3	3	1			1	1	1	1
Shea Spring	2	4	4	4	4	1			3				
Verde River	5	5	5	5	5	5	5			5	5	5	5
Wells								3					

one meter in depth), temporal variation in water quality is believed to be potentially of greater magnitude than spatial variation. At small water bodies, a limited amount of spatial sampling using multiparameter sonde probes will be conducted during the early stages of water quality monitoring implementation. Whenever possible during the early stages of implementation, short-term (24-48 hours) continuous sampling of water bodies for core parameter variability in time will be conducted on a rotating basis (seasonally) as instrumentation availability, access, security, and staffing allow. When conditions do not allow sampling, similarity of conditions between sites that have been sampled for variability in time and sites that have not will be used to infer representativeness of samples until such time as more detailed investigations are deemed possible, or until repeated sampling has rendered more detailed investigations unnecessary.

Determination of what constitutes a representative sample for larger water bodies potentially requires sampling in both time and space. Depending on physical factors, a larger water body may be relatively well-mixed or not. Preliminary data for larger water bodies were collected through a USGS-NPS contract in 2003. Results of this study will be sued to quantifying space-time variability in the larger water bodies and implemented as resources allow.

Mean and variance of the constituents of concern are key data needed for the design of a program to obtain representative samples. Some of the sites recommended for water-quality monitoring were included in the Level 1 Baseline Water-Quality Inventory conducted in 2002-2003. Of the remaining sites, some have existing water-quality data reported in the Horizon report series, some have existing water-quality data reported elsewhere, and some have no existing water-quality data. For the purposes of preliminary estimation of parameter means and variances, existing data will be used wherever possible. Where no data exist, engineering judgment will be used to estimate means and variances until such time that sufficient data are available. This judgment may be based on data from sites judged to be similar in the network area. Depending on the availability of documentation regarding methods used for collection and analysis of existing data, levels of confidence in existing data will vary. Records of source of data input to preliminary estimation of sample statistics will be maintained.

4.7. Index Sites

Six vital signs will be monitored using index sites. These include vital signs associated with air quality and climate as well as phenology of key plant species. The use of index sites is justified due to the high cost of the equipment involved in the measurements and specific equipment requirements (e.g., electricity, access, slope). Statistical inference to a larger area is not possible with index sites due to the lack of a probability sample. However, the use of index sites is adequate when the spatial fluctuation in measures across a larger area is inconsequential for long-term monitoring purposes.

4.7.1. Climate and Air Quality

Air quality (ozone, wet and dry deposition, visibility and particulate matter) and climate vital signs will continue to be monitored at established sites. Programs external to the SODN I&M effort are currently monitoring these vital signs (Table 3.3). SODN I&M is also investigating the permanent establishment of additional climate stations to supplement existing National Oceanic & Atmospheric Administration (NOAA) and National Interagency Fire Center (NIFC) stations.

For external monitoring efforts, SODN monitoring efforts consist of the acquisition and archiving of data and performing specific analyses. Station locations were determined by the external programs in accordance with program-specific objectives and sampling frames. Target populations of these programs are regional in scope. Within larger park units, the number and location of existing stations are insufficient for park-level inference and provide only broad-scale information. Many of the climate stations have a long period of record, some dating back into the early 1900s. This long-term sample provides useful context for interpreting future climate data and ascertaining extremes and overall changes. However, many of the climate stations are located adjacent to visitor centers, for reasons of convenience. Because these biased locations do not offer park-level inference, SODN is currently exploring establishing additional climate stations at key park locations. These stations offer finer-resolution (meso-scale) climate variable information.

4.7.2. Phenology of Key Plant Species

Phenology of key plant species will be monitored by park staff and volunteers. During seasons when phenological events are expected, plants will be checked daily. Phenological monitoring locations will be established based on convenience and likelihood of remaining unaltered for long periods of time, beginning with sites located near park headquarters and visitor centers. Park-based inference is not an objective of this monitoring effort. Greater inference will be gained over time as more phenology monitoring sites are established throughout the park units. These additional sites will be established as park interest and support is fostered and more time is allotted to monitoring the sites. All sites will be monitored every year.

4.8. Census

In the case of vital signs measured using remotely sensed data, a census, rather than a sample, will be taken. Information for the variable of interest will be obtained for the entire park unit as well as the surrounding landscape.

4.8.1. Landscape Dynamics

Status and trends of land cover and land use metrics will be monitored using high-resolution multi-band satellite imagery (e.g., IKONOS, Quickbird). Metrics including subjective vegetation formation and pixel-level life form class and land use surrounding park units will be derived from imagery. Imagery will be acquired for an entire park unit and the surrounding area (several additional square kilometers, in most cases), thereby taking a census of the park rather than a sample.

The expense of imagery acquisition and processing and the rate of likely change in landscape level parameters requires a revisit design of [1-9], or once every ten years. No membership design exists, given the nature of a census. However, monitoring will likely be distributed among the 11 SODN parks such that at least one park is measured every year, for budgetary reasons.

Ground-truthing sites for land cover and land use metrics derived from remotely-sensed data will be located using a randomized approach. The methods adopted will be detailed in these protocols.

4.8.2. Illegal Roads and Trails

Status and trends of illegal roads and trails will be monitored using the same high-resolution multi-band satellite imagery as acquired for landscape dynamics. As with the case of landscape dynamics, imagery will be acquired for an entire park unit and the surrounding area (several additional square kilometers, in most cases), thereby taking a census of the park rather than a sample. The revisit design will be [1-9].

CHAPTER 5: SAMPLING PROTOCOLS

5.1 Introduction

Once a vital sign has been selected and monitoring questions and objectives have been clearly stated, the next step is to develop a monitoring protocol for that vital sign (Figure 5.1). Monitoring protocols identify methods for gathering information on a resource, outline a process to collect information, and establish how information will be analyzed and reported. Protocols are detailed study plans that are necessary to ensure that changes detected by monitoring actually are occurring in nature and do not stem from measurement variability introduced when different people or methods are used (Oakley et al. 2003). Protocols are essential for monitoring vital signs through time.

Monitoring protocols must include a narrative providing the rationale for vital sign selection, an overview of the monitoring protocol components, and a history of the development of the protocol. The narrative details protocol sampling objectives, sampling design, field methods, data analysis and reporting, staffing requirements, training procedures, and operational requirements (Oakley et al. 2003). Each of these components is discussed in much detail in standard operating procedures (SOPs).

Because data for some vital signs can be collected and analyzed in tandem, some protocols detail data collection, analysis, and reporting requirements for more than one vital sign. Table 5.1 shows how the 25 SODN vital signs are organized into 20 protocols. This table also states the expected sampling frame and sampling units for each vital sign. Justification for monitoring and monitoring objectives appear by protocol in Table 5.2, along with a list of parks where each protocol will be implemented. Within the next five years, the SODN expects to develop and implement all of the protocols that are currently under consideration. A schedule of expected implementation dates appears in Chapter 9. All SODN protocols are currently under development. Protocol Development Summaries for each protocol appear in Appendix M; links to PDSs appear in Table 5.2. Additionally, more detail regarding water quality and quantity monitoring protocols appears in Appendix N.

Sampling grassland composition at Coronado NM.

FIGURE 5.1. Process diagram for SODN Vital Sign selection and protocol development.

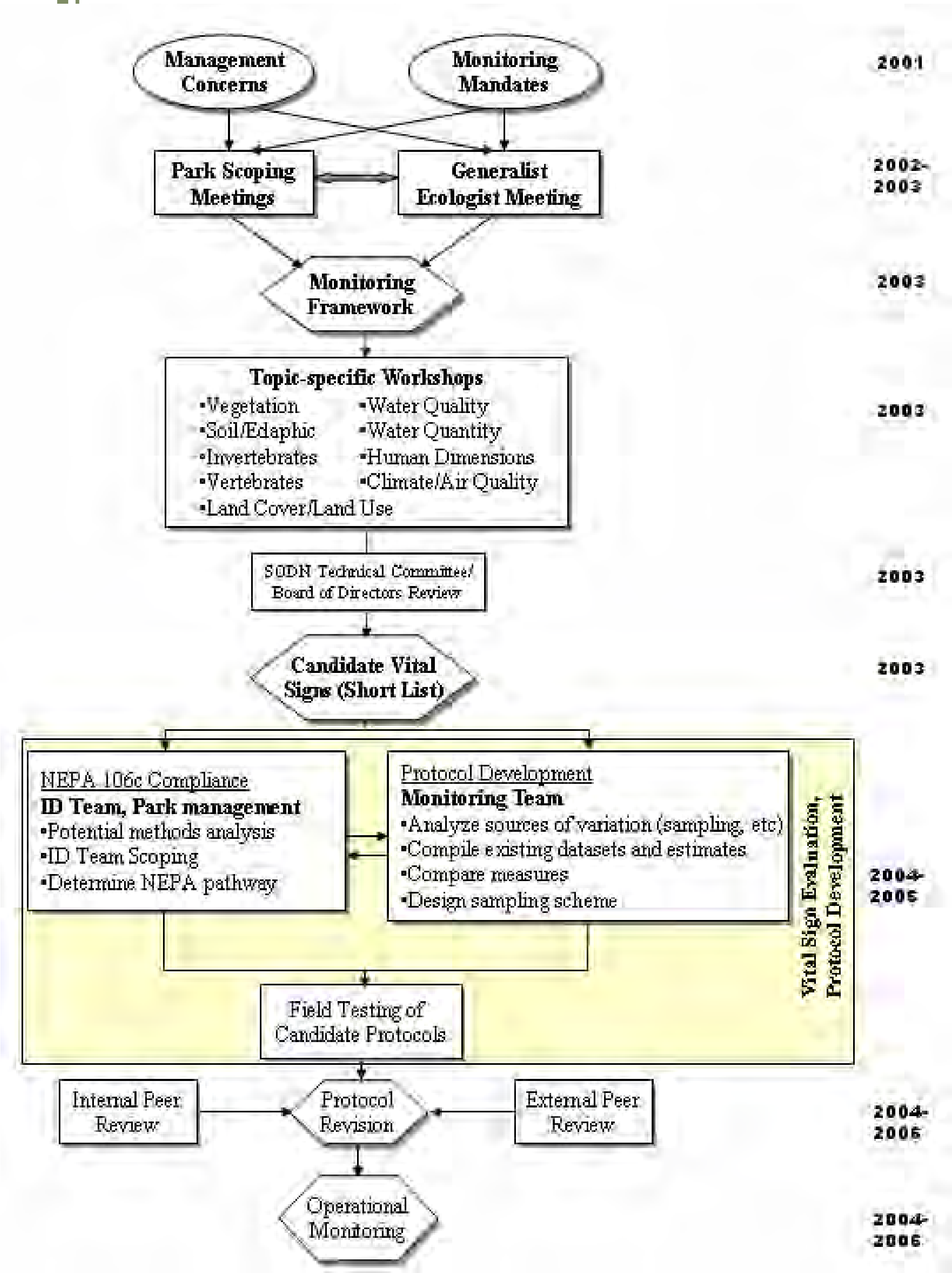


Table 5.1.
Protocols to be implemented within the next five years in the SODN.

Protocol Name	Vital Sign	Sampling Frame	Sampling Units
Air Quality	Ozone	N/A	N/A
	Wet and dry deposition	N/A	N/A
	Visibility and particulate matter	N/A	N/A
Broad-scale Climate	Broad-scale Climate	N/A	N/A
Meso-scale Climate	Meso-scale Climate	Entire park	N/A
Channel Morphology	Channel Morphology	Perennial streams; "B" and "C" type intermittent streams	Channel cross-sections; longitudinal profiles
Soil Aggregate Stability and Compaction	Soil Aggregate Stability	Entire park	Plots
	Soil Compaction	Entire park	Plot
Soil Cover and Crusts	Soil Cover	Entire park	Plot
	Biological Soil Crusts	Entire park	Plot
Water Quantity	Groundwater Dynamics	Existing wells	Well
	Surface Water Dynamics	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
Water Quality	Core Parameters	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
	Nutrient Dynamics	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
	Pollutant Metals	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
	Microorganisms	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
Aquatic Macroinvertebrates	Aquatic Macroinvertebrates and Algae	1st and 2nd order streams	Sampling points along linear stream
		seeps, springs, tinajas	Individual seeps, springs, or tinajas
Exotic Plants – Early Detection	Exotic Plants – Early Detection	Portions of park units with high risk of invasion	Quadrat
Vegetation Community Structure	Vegetation Community Structure	Entire park	Plot
Vegetation Life Form Abundance	Vegetation Life Form Abundance	Entire park	Transect
Phenology of Key Plant Species	Phenology of Key Plant Species	Index sites	Index plot
Bird Community Dynamics	Bird Community Dynamics	Entire park	Variable circular plot
Fish Community Dynamics	Fish Community Dynamics	Perennial streams	Sampling points along linear stream
		Springs, tinajas	Individual springs or tinajas
Visitor Use	Visitor Use	Index sites (e.g. trailheads)	Index site
Visitor Use Impacts	Visitor Use Impacts	Trail network	Perpendicular transect
Illegal Roads and Trails	Illegal Roads and Trails	Portion of park adjacent to international border	TBD
Landscape Dynamics	Landscape Dynamics	Park unit and surrounding region	Pixel

Table 5.2.
Justification, objectives and proposed locations for SODN Vital Sign monitoring protocols.

Protocol	Justification	Measurable Objectives	Parks Planned for Implementation
Air Quality	NPS mandates; trends of significant increase in ozone in some parks; fertilization effects from nitrogen and sulfur deposition.	1. Determine seasonal and inter-annual trends in ozone, nitrogen deposition, sulfur deposition, and visibility-reducing pollutants. 2. Detect changes in ozone, nitrogen deposition, and visibility-reducing pollutants in relation to changes in other SODN vital signs (e.g., vegetation community dynamics, phenology of key plant species, exotic plant early detection).	SAGU (Ozone, CASTNet, IMPROVE), CHIR (Ozone, NADP/NTN, CASTNet, IMPROVE), GICL (NADP/NTN, IMPROVE), ORPI (NADP/NTN, IMRPOVE), CORO (CASTNet), FOBO (CASTNet), TONT (IMPROVE)
Broad-scale Climate	The climate of a region drives ecosystem processes, dictating species' distributions, governing nutrient cycling, and driving changes in other abiotic components of the system.	1. Determine long-term trends in temperature, precipitation, and synthetic variables (PET, drought indices, etc) in the Sonoran Desert region. 2. Determine how broad-scale climate is related to other vital signs.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Meso-scale Climate	The local (meso-scale) climate within a park drives local-scale ecosystem processes, dictating species' distributions, governing nutrient cycling, and driving changes in other abiotic components of the system.	1. Evaluate spatial and temporal trends in temperature, precipitation, wind speed, wind direction, relative humidity, snow depth, and variables appropriate for understanding other vital signs in SODN parks. 2. How do local weather conditions influence biotic and abiotic processes (e.g., leaf-out, flowering, invasion by nonnative species, fire threat?) 3. How do climatic variables vary over complex topography within the scale of a park unit?	CHIR, ORPI, SAGU
Channel Morphology	Channel morphometrics integrate biotic and abiotic factors of riparian systems, thereby providing a measure of overall watershed condition. Changes in channel morphology also reflect rare, stochastic flow events that are of particular importance in ephemeral and intermittent reaches of the Sonoran Desert.	1. Determine the status and trends in the cross-sectional area, bankfull width, floodprone width, slope, and sediment composition of selected reaches of perennial and intermittent drainages in SODN parks. 2. Determine the status and detect trends in the entrenchment ratio, width/depth ratio, sinuosity, bank erodibility hazard rating, sediment supply, and Pfankuch channel stability rating (derived variables) of selected reaches of perennial, intermittent, and ephemeral drainages in SODN parks. Classify and delineate selected reaches using the Moody alterations of the Rosgen system for communication purposes. 3. Relate patterns of channel morphometrics to those of related vital signs (soil quality, vegetation community structure, water quantity, water quality, aquatic macroinvertebrate, land use, climate).	CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI

Table 5.2. continued.

Protocol	Justification	Measurable Objectives	Parks Planned for Implementation
Soil Aggregate Stability and Compaction	Soil aggregate stability has a strong influence on infiltration, soil strength, erosion, aeration, and the soil's ability to transmit liquids, solutes, gases, and heat. The loss of macro-pore space affects water and air movement and availability to roots with affects root growth.	1. Determine the spatial and temporal variation of soil aggregate stability and compaction on SODN park units. 2. Determine trends in soil aggregate stability and compaction in the context of associated vital signs (e.g., exotic plants, vegetation community structure, stream channel morphology).	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Soil Cover and Crusts	Reduction in soil stability (soil cover and biological soil crusts) makes the soil more susceptible to wind and water erosion.	1. Determine the spatial and temporal variation of soil cover and biological soil crusts on SODN park units. 2. Determine trends in soil cover and biological soil crusts in the context of associated vital signs (e.g., exotic plants, vegetation community structure, stream channel morphology).	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Water Quantity	Surface water quantity is important to maintain a healthy habitat for many aquatic organisms, riparian areas, and drinking water for wildlife.	1. Establish estimates for the range of conditions and background variability for water quantity in SODN park units. 2. Detect long-term trends in water quantity on perennial streams, springs, seeps, and tinajas in SODN park units. 3. Investigate relationships between water quantity and associated vital signs.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Water Quality	Surface water quality is important to maintain a healthy habitat for aquatic organisms and is crucial as a source of drinking water for terrestrial wildlife.	1. Establish estimates for the range of conditions and background variability for water quality vital signs in SODN park units. 2. Detect long-term trends in wter quality vital signs at perennial streams, seeps, springs, and tinajas on SODN park lands. 3. Investigate relationships between water quantity and associated vital signs.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Aquatic Macroinvertebrates	Aquatic macroinvertebrates provide a measure of riparian ecosystem function and form the basis of bioassessment monitoring.	1. Detect trends in the Warmwater Index of Biological Integrity for wadeable perennial streams and rivers at MOCA, TUZI, SAGU. 2. Detect trends in the Coldwater Index of Biological Integrity for wadeable perennial streams and rivers at GICL. 3. Investigate relationships between aquatic macroinvertebrate indices and associated SODN vital signs (e.g., water quality, fish, channel morphology).	GICL, MOCA, ORPI, SAGU, TUMA, TUZI
Exotic Plants – Early Detection	Non-native plant species are a major threat to native species diversity and ecosystem function.	1. Detect incipient populations and new introductions of invasive plant species on SODN park lands before they become established in areas of management significance. 2. Develop and update predictive models of the probability of spread and potential distribution of selected and newly identified plant species.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI

Table 5.2.
continued.

Protocol	Justification	Measurable Objectives	Parks Planned for Implementation
Vegetation Community Structure	Vegetation is a base measure of the structural and functional components of ecosystems.	1. Determine changes in community composition and relative abundance of perennial species on SODN park lands across multiple temporal and spatial scales. 2. Document the spatial and temporal variation in community composition and relative abundance of perennial plant species. 3. Identify long-term trends in community composition and relative abundance of perennial plant species. 4. Identify other environmental variables that play a key role in community composition and dynamics.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Vegetation Life Form Abundance	Annual and perennial plant species occurring in the lower canopy levels change more rapidly than overall community structure and composition, which may include trees and slow-growing species. This is component of the vegetation responds most rapidly to changes in disturbance regime, extreme weather events, drought or El Nino events.	1. What is the baseline distribution and spatio-temporal variation in life-form abundance of plants in the groundcover and lower canopy levels? 2. What are the trends in life-form abundance of plants in the groundcover and lower canopy levels? 3. How does abundance of life-forms in the groundcover and lower canopy levels vary with associated vital signs – soil aggregate stability, soil compaction, soil cover, land birds, climate?	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Phenology of Key Plant Species	The occurence of phenological events is directly related to the cumulative effect of recent weather. Seasonal variability in phenological events offer key insights into seasonal climate and how it affects vegetation condition patterns.	1. Detect temporal trends in phenological events at local scale to landscape scales of selected native and invasive plant species. 2. Determine how aggregate trends in phenological indicators compare to weather observations. 3. Develop/update models of relationships between plant phenology and climate triggers.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Bird Community Dynamics	Birds comprise a major component of biological diversity in many ecosystems, and deficiencies in the avian community can have adverse effects on ecosystem functions. Several researchers have suggested that status of bird populations may be an important indicator of overall environmental condition.	1. Determine annual changes in species composition and abundance of land birds in grassland, riparian, and upland communities in SODN parks. 2. Determine annual changes in the productivity of land birds in SODN parks. 3. Determine if trends in land bird species composition or abundance in SODN parks differ from regional trends.	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI

Table 5.2. continued.

Protocol	Justification	Measurable Objectives	Parks Planned for Implementation
Fish Community Dynamics	By monitoring the dynamics of fish communities, we are able to monitor endemic species, keystone predators of aquatic systems, and draw correlations with other aquatic variables being monitored concurrently.	1. Invasive Exotic Fish: early detection (presence and distribution). 2. Invasive Exotic Fish: status and trend (distribution over time, density, relative abundance compared with native fishes). 3. Native Fish Community: species diversity, distribution, population estimates, catch/unit effort, relative abundance, age structure, physical health.	MOCA, ORPI, SAGU, TUMA, TUZI
Visitor Use	Visitors can have impacts in the form of vegetation trampling, soil compaction, aquatic resource disturbance, behavioral disturbances to wildlife, and damage to cultural resources.	1. What is the composition (number and activity types) of recreation visits on SODN park lands over time? 2. What is the spatial configuration (distribution) of recreation visits, travel routes, and activities within each SODN park unit over time? 3. What are the seasonal and annual trends in recreation visits and activities on SODN park lands?	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Visitor Use Impacts	Visitors can have impacts in the form of vegetation trampling, soil compaction, aquatic resource disturbance, behavioral disturbances to wildlife, and damage to cultural resources.	1. What is the composition (types and extent) of recreation impacts on SODN park lands over time? 2. What is the spatial configuration (distribution) of recreation impacts within each SODN park unit over time? 3. What are the observable relationships between changes in visitor impact patterns and other SODN vital signs (e.g., visitor use, soil quality and vegetation) over time?	CAGR, CHIR, CORO, FOBO, GICL, MOCA, ORPI, SAGU, TONT, TUMA, TUZI
Illegal Roads and Trails	Illegal off-road use impacts can include vegetation trampling, soil compaction, aquatic resource disturbance, behavioral disturbances to wildlife, and damage to cultural resources.	1. What is the spatial configuration (distribution) of illegal roads and trails within each SODN park unit over time? 2. How does the number and distribution of illegal roads and trails vary with associated vital signs – soil aggregate stability, soil compaction, soil cover, vegetation, visitor use patterns?	CORO, FOBO, ORPI, SAGU

CHAPTER 6: DATA MANAGEMENT

Collecting natural resource data is the first step toward understanding the structure and function of the ecosystems within our National Parks. We analyze and synthesize these "raw" data to model various aspects of ecosystems. In turn, we use our results and interpretations to make management decisions about the Park's vital natural resources.

Any good data set – whether collected last week or 20 years ago – must be accompanied by enough explanatory documentation (e.g., why and how it was collected) so that we can understand it and use it with confidence. Therefore, our Network data management system cannot simply focus on the tables, fields, and values that make up a data set. It must also provide a process for developing, preserving, and integrating the context. Although this requires more time spent creating documentation, the end result will be a data set that will retain its value, usefulness, and interpretability for years to come.

This chapter summarizes the Sonoran Desert Network (SODN) data management system that is more completely explained in the SODN Data Management Plan (DMP). The DMP presents the overarching strategy for ensuring that Program data are documented, secure, accessible, and useful for decades into the future. The plan also refers to other guidance documents, standard operating procedures, and detailed protocols that convey more specific standards and steps for achieving our data management goals. The plan acts as a foundation upon which to build as new protocols are developed, advances in technology are adopted, and new concepts in data management philosophy are accepted.

Data and information are the basic products of scientific research. In ecological research, where field experiments and data collections can rarely be replicated under identical conditions, data represent a valuable and, often, irreplaceable resource . . . In long-term ecological studies, retention and documentation of high quality data are the foundation upon which the success of the overall project rests.
-Brunt 2000

6.1. Data and Data Management: An Overview

Collecting natural resource data is the first step toward understanding the structure and function of the evolving ecosystems within our National Parks. We use these "raw" data to analyze, synthesize, and model aspects of ecosystems. In turn, we use our results and interpretations to make management decisions about the Park's vital natural resources. Thus, data collected by researchers and maintained by the Sonoran Desert Network according to our Data Management Plan will become information through analyses, syntheses, and modeling.

Any good set of data – whether collected last week or 20 years ago – must tell us enough about itself so that we can reliably preserve and use it. Anyone using these data will need to know as much as possible about how and why they were collected. Therefore, our Network data management system cannot simply attend to the tables, fields, and values that make up a data set. It must also provide a process for developing, preserving, and integrating the context that makes data interpretable and valuable. Although this means more time spent documenting, it leads us to clearer preservation and presentation of data.

We sometimes use the term "data" in a broader sense that encompasses other products that are generated alongside primary tabular and spatial data. These products fall into five general categories: raw data, derived data, documentation, reports, and administrative (Table 6.1).

To meet I&M Program goals, and to ensure adequate context for primary data products, these categories of products all require some level of management to ensure their quality and availability. We intend to integrate the manner in which the Network creates, manages, and provides the results of our research and analysis. Thus, we will use a more "holistic view" about how natural resource data are generated, processed, finalized, and provided. All phases of data and information processing are integrated, and information about each phase and its processes must be shared through good documentation.

TABLE 6.1.
Categories of data and project products.

CATEGORY	EXAMPLES
Raw data	GPS rover files, raw field forms and notebooks, photographs and sound/video recordings, telemetry or remote-sensed data files, biological voucher specimens
Compiled/derived data	Relational databases, tabular data files, GIS layers, maps, species checklists
Documentation	Data collection protocols, data processing/analysis protocols, record of protocol changes, data dictionary, FGDC/NBII metadata, data design documentation, quality assurance report, catalog of specimens/photographs
Reports	Annual progress report, final report (technical or general audience), periodic trend analysis report, publication
Administrative records	Contracts and agreements, study plan, research permit/application, other critical administrative correspondence

There are many potential sources of important data and information about the condition of natural resources in our parks. The types of work that may generate these natural resource data include:

- Inventories
- Monitoring
- Protocol development pilot studies
- Special focus studies done by internal staff, contractors, or cooperators
- External research projects
- Monitoring or research studies done by other agencies on park or adjacent lands
- Resource impact evaluations related to park planning and compliance with regulations
- Resource management and restoration work

Because the I&M Program focuses on long-term monitoring and natural resource inventories, our first priority is to produce and curate high-quality, well-documented data that we derive from these primary efforts. However, we can easily apply our same standards, procedures, infrastructure, and attitudes about data management to other natural resource data sources. As time and resources permit, we will work toward raising the level of data management for current projects, legacy data, and data originating from outside the I&M Program. We will place the greatest emphasis on those projects that are just beginning development and implementation because inserting good data management practices into an existing project can be difficult and will generally meet with less success.

6.2. Goals and Objectives of Data Management

The data-related mission of the I&M Program is to provide scientifically and statistically sound data to support management decisions for the protection of park resources. The Program's success at identifying, cataloging, organizing, structuring, archiving, and providing relevant natural resource information will largely determine its effectiveness and standing among critics, peers, and advocates. The principal goal of the SODN Data Management Plan is to elucidate the driving concepts, principles, procedures, and processes for ensuring the quality, interpretability, security, longevity, and availability of ecological data and derived information produced by our inventory and monitoring efforts. Our objectives are centered around the five main principles:

- Quality – ensure that appropriate quality assurance measures are taken during all phases of data development: acquisition, processing, summary and analysis, reporting, documenting, and archiving.
- Interpretability – ensure that complete documentation accompanies each data set so that users will be aware of its context, applicability, and limitations.
- Security – ensure that both digital and analog data are maintained and archived in a secure environment that provides appropriate levels of access to project leaders, technicians, network staff, and other users.
- Longevity – ensure that data sets are maintained in an accessible and interpretable format, accompanied by sufficient documentation.
- Availability – ensure that the data and information from our I&M studies are made available and easily accessible to managers and other users.

6.3. Data Stewardship Roles and Responsibilities

Everyone within the SODN I&M Program uses or manages data and information, and each of us has our roles and responsibilities in this process. This new and crucial emphasis on data management, analysis, and the reporting of results will require a large investment of personnel, time, and money, and the SODN expects to invest at least thirty percent of available resources in developing and improving its data management system.

For the SODN I&M Program to work effectively, everyone within the Network will have stewardship responsibilities in the production, analysis, management, and/or end use of the data. Table 6.2 lists the roles and primary responsibilities 'from the ground up' to demonstrate the hierarchy and overlap of responsibilities.

The fundamental role of the Network data manager will be to coordinate these tasks. This requires understanding and determining program and project requirements, creating and maintaining data management infrastructure and standards, and communicating and working with all responsible individuals.

The data manager and the project leader are the personnel primarily responsible for data management. The Network coordinator also assists by ensuring that project leaders meet timelines for data entry, verification, validation, summarization/analysis, and reporting. Figure 6.1 illustrates the core data management duties of the data manager and project leader and where those duties overlap.

Table 6.2.
Roles and responsibilities for data stewardship.

Role	Data Stewardship Responsibilities
Project Crew Member	Collect, record, and verify data
Project Crew Leader	Supervise crew and organize data
Data/GIS Specialist or Technician	Process and manage data
Information Technology Specialist	Provide IT/IS support
Project Leader	Oversee and direct project operations, including data management
Resource Specialist	Validate and make decisions about data
GIS Manager	Support park management objectives with GIS and resource information management
Network Data Manager	Ensure inventory and monitoring data are organized, useful, compliant, safe, and available
Database Manager	Know and use database software and database applications
Curator	Oversee all aspects of the acquisition, documentation, preservation, and use of park collections
Statistician or Biometrician	Analyze data and present information
Network Ecologist	Integrate science in network activities
Network Coordinator	Coordinate and oversee all network activities
I&M Data Manager (National Level)	Provide Service-wide database availability and support
End Users (managers, scientists, publics)	Inform the scope and direction of science information needs and activities. Apply data and information services and products

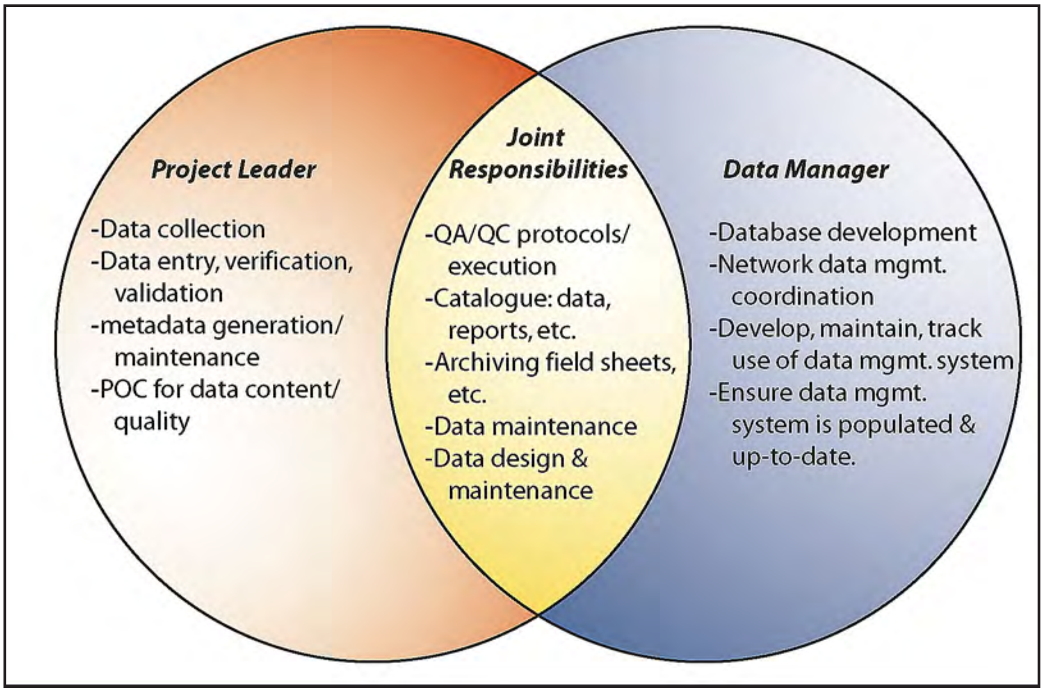


Figure 6.1.
Core data management duties of the data manager and project leader.

6.4. Data Management Infrastructure/Architecture

A modern information management infrastructure (e.g., staffing, hardware, software) represents the foundation upon which our network information system is built. Systems architecture refers to the applications, database systems, repositories, and software tools that make up the framework of our data management enterprise.

An important element of a data management system is a reliable, secure network of computers and servers maintained by national and local offsite IT specialists, assisted by network personnel. These individuals attend to hardware replacement, software installation and support, security updates, virus-protection, telecommunications networking, and server backups. Our digital infrastructure consists of a network data server and servers maintained at the national level (Figure 6.2). Each of these components hosts different parts of our natural resource information system.

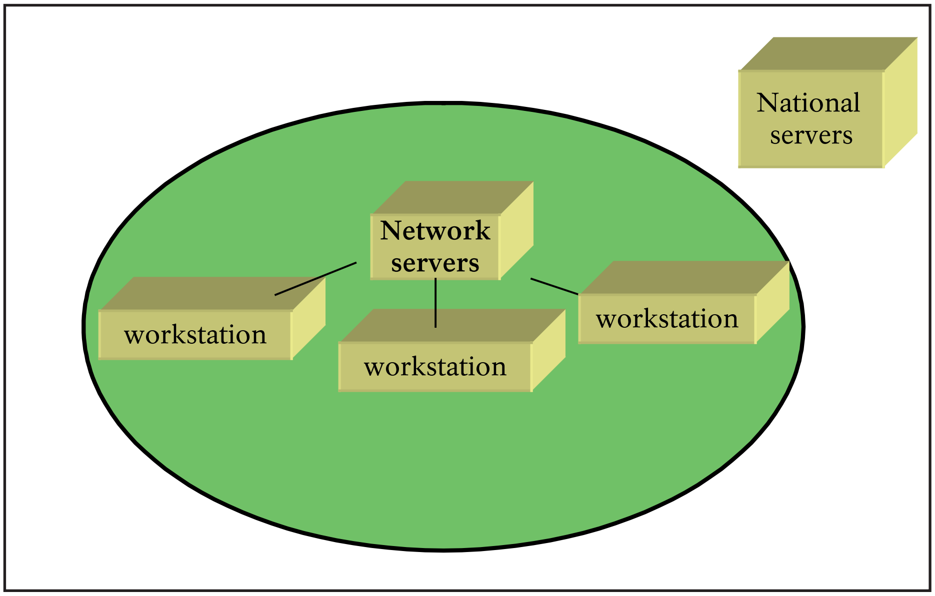


FIGURE 6.2. Schematic representing the logical layout and connectivity of computer resources.

The national servers host and maintain online applications that provide storage and access to basic natural resource data and information collected by the I&M Program (Figure 6.3):

- NatureBib is the master database for natural resource-related bibliographic references.
- NPSpecies is the master database for species that occur in or near each park and the physical or written evidence for their occurrence (e.g., vouchers, observations, and references).
- NR-GIS Metadata Database is the master metadata database for natural resource data sets. This application is currently under development; in the interim, the desktop version of the Dataset Catalog is in use.
- NR-GIS Data Store is a graphical search interface that links data set metadata to a searchable data server on which natural resource data sets are organized by NPS units, offices, and programs.

The network data servers host the following types of data and information:

- Master project databases – compiled data sets for monitoring projects and other multi-year efforts that have been certified for data quality
- Common lookup tables – e.g., parks, personnel, projects, species, etc.

•Network digital library – network repository for finished versions of products for Network projects (e.g., reports, data set documentation, data files, formal metadata, etc.)

•GIS files – base spatial data, imagery, and project-specific themes

•Working files – working databases, draft geospatial themes, draft reports, administrative records, etc.

•Project tracking application – used to track project status, contact information, product due dates

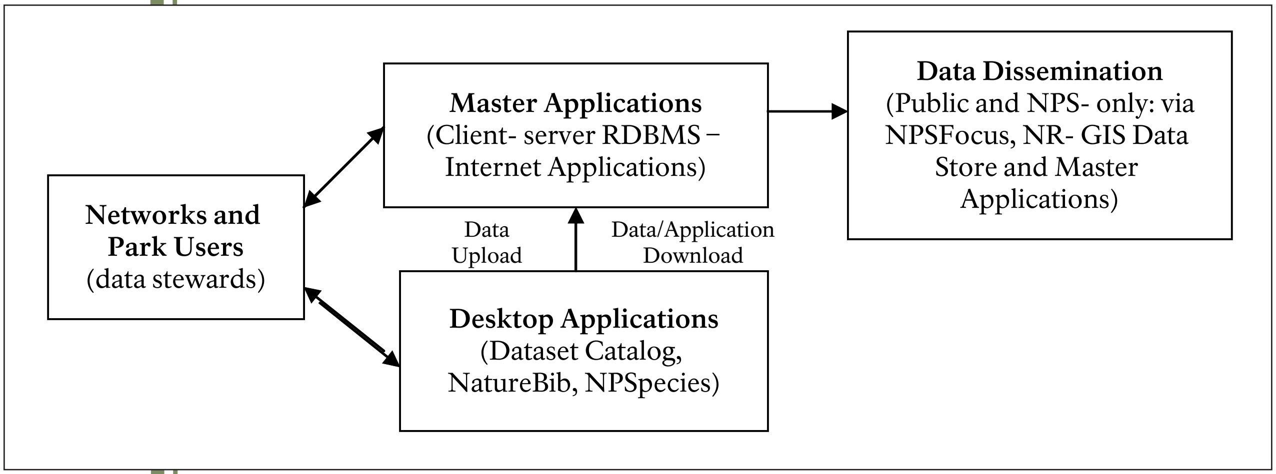


Figure 6.3. Model of the national-level application architecture.

Database Design Strategy

Rather than developing a single integrated database system, our approach uses modular, standalone project databases that share design standards and links to centralized data tables. Individual project databases are developed, maintained, and archived separately. There are several advantages to this strategy:

Data sets are modular, allowing greater flexibility in accommodating the needs of each project area. Individual project databases and protocols can be developed at different rates without a significant cost to data integration. In addition, one project database can be modified without affecting the functionality of other project databases.

By working up from modular data sets, we avoid a large initial investment in a centralized database and the concomitant difficulties of integrating among project areas with very different – and often unforeseen – structural requirements. Furthermore, the payoff for this initial investment is not always realized down the road by greater efficiency for interdisciplinary use.

Project database standards ensure compatibility among data sets, which is vital given the often unpredictable ways in which data sets will be aggregated and summarized. Well thought out standards also help to encourage sound database design and facilitate interpretability of data sets. The SODN will follow the standards for database objects used by the Natural Resource Database Template (http://science.nature.nps.gov/im/apps/template/index.htm), to the extent possible. Databases that are developed for park and network projects will all contain the following main components:

•Common lookup tables that contain lists of parks, personnel, and species

•Core tables and fields based on network and national templates that contain 'who, where, and when' for project data collection

•Project-specific fields and tables containing recorded observations

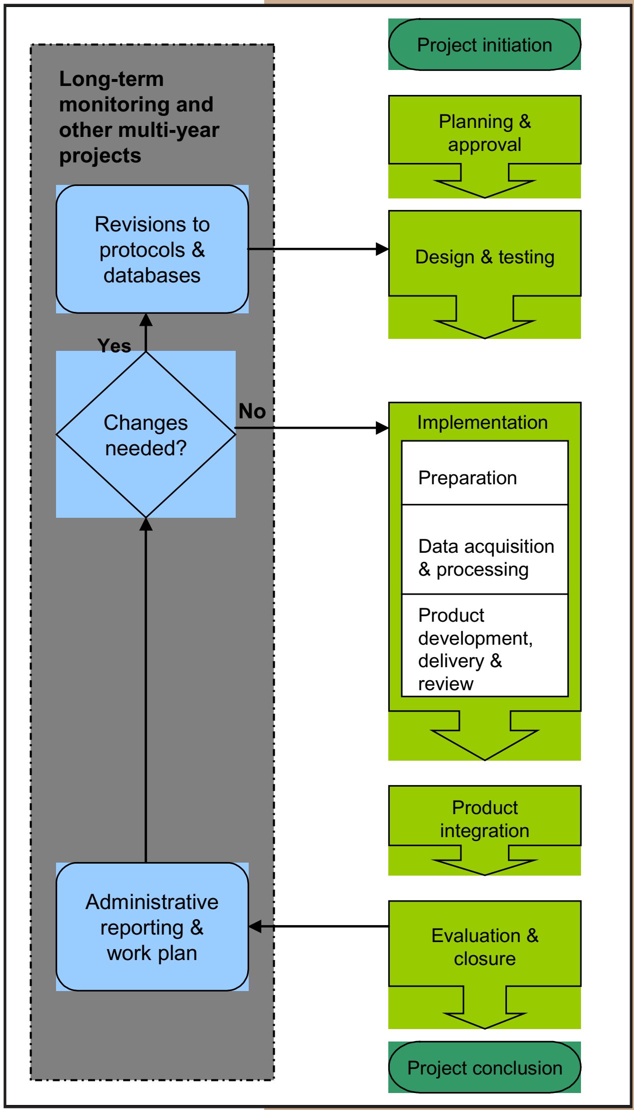
6.5. Project Work Flow

From the perspective of managing workflow, there are two main types of projects:

- Short-term projects, which may include individual park research projects, inventories, or pilot studies done in preparation for long-term monitoring.

- Long-term projects, which will primarily include the implemented monitoring studies central to the I&M Program, but may also include multi-year research projects and monitoring performed by other agencies and cooperators. Long-term projects often require a higher level of documentation, review, and infrastructure development.

FIGURE 6.4.
Five primary stages of long-term monitoring.



From a data management standpoint, a primary difference between short- and long-term projects is an increased need to adhere to standards for long-term projects to ensure internal compatibility over time. While the need to follow standards is still present for short-term projects, sometimes the cost of compliance will outweigh the benefits due to the scope, budget, and level of NPS control over the project. Nevertheless, both short-term and long-term projects share many workflow characteristics, and both generate data products that must be managed and made available.

A project can be divided into five primary stages (Figure 6.4.), each characterized by a particular set of activities carried out by staff involved with the project:

- Planning and approval – many preliminary decisions regarding project scope and objectives are made; funding sources, permits, and compliance are addressed. Although this phase lacks specific data management activities, data managers must be kept informed of projects in this phase, particularly as timelines for products are finalized.

- Design and testing – details regarding data acquisition, processing, analysis, reporting, and dissemination are worked out. Collaboration between the project leader and the data manager is critical during this phase to assure data quality and integrity. A joint effort is required to develop and document the project methods, data design, data dictionary, and the database itself.

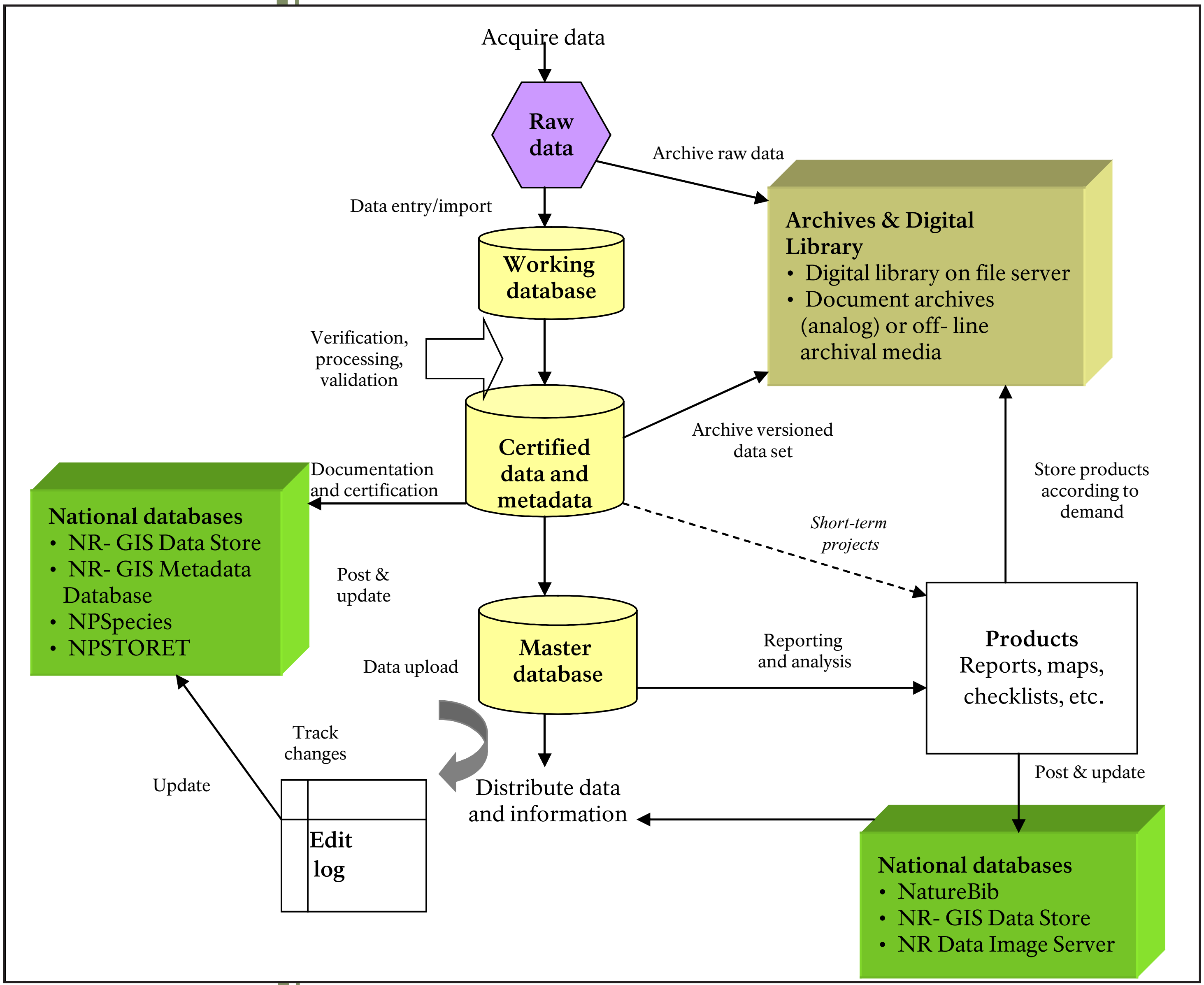
- Implementation – data are acquired, processed, error-checked, and documented; other products are developed and delivered. All aspects of this phase are overseen by the project manager; data management staff acts primarily as facilitators to support database applications, GIS, GPS, data validation, summarization, and analysis. Products are delivered to the appropriate staff, and those that do not meet program requirements will be returned to the project leader for revision.

- Product integration – Data products and other documents are integrated into national and network databases; metadata records are posted in clearinghouses, and products are made available to their intended audiences. Data from working databases are merged into master databases.

•Evaluation and closure – Project records in the project tracking database are updated to reflect completion status. The network coordinator, project leader, and data manager should work together to assess how well the project met the stated objectives and what steps might be taken to make improvements.

During various phases of a project, the data take on different forms and are maintained in different places as they are acquired, processed, documented, and archived. This data life cycle is characterized by a sequence of events, as shown in Figure 6.5.

Figure 6.5.
Project data life cycle.



Key points of this data life cycle are as follows:

•All raw data are archived intact.

•Working databases are the focal point of all modification, processing, and documentation of data collected for a given season (or other period that makes sense for a given project).

•Upon data certification, indicating that the data have passed all documentation and quality assurance requirements, the data are archived and posted or otherwise integrated with the national data applications.

- Data for long-term monitoring projects are uploaded into a master database that includes multiple years of data.
- Certified data sets are used to develop reports and other data products, which are also archived and posted to the appropriate national repositories.
- All subsequent revisions to certified data sets are documented in an edit log, which is distributed with the data upon distribution.

Specific repositories for most SODN products are indicated in Table 6.3.

Table 6.3. Repositories for SODN products.

Item	Repository
Reports	SODN digital library; posted to NR Data Image Server, linked and accessed through the catalog record in NatureBib; Park collection (hard copy)
Digital data sets (non-sensitive)	NR-GIS Data Store
Digital data, metadata, and other products • Raw and finalized data • Metadata, protocols, SOPs • Completed reports • Digital photographs, derived products	SODN data servers, digital library, and/or other cooperators for selected monitoring projects (*e.g.*, Arizona Game and Fish Department, US Environmental Protection Agency, US Forest Service, etc.)
Project materials Voucher specimens, raw data forms	Park archives and collections, or another specified collection (*e.g.*, Western Archeological and Conservation Center)
Administrative records	SODN offices and/or park offices, park archives, National Archives

6.6. Data Acquisition & Processing

The types of data handled by the I&M Program fall into three general classifications:

- Program data – produced by projects that are either initiated (funded) by the I&M Program or involve the I&M Program in another manner (e.g., natural resource inventories and vital signs monitoring projects)
- Non-program legacy/existing data – produced by NPS entities without the involvement of the I&M Program (e.g., park inventory projects)
- Non-program external data – produced by agencies or institutions other than the National Park Service (e.g., weather and water quality data)

These definitions do not in any way indicate or rank the importance of the three types of data to the I&M Program. We will base the importance or value placed on a data set on the quality, completeness, and potential usefulness of data set itself, as well as its relevance to the SODN I&M Program and parks.

Most data acquired by the Network will be collected as field data (inventories and monitoring studies) or discovered through data mining initiatives (legacy/existing data). Methods of field data collection, such as paper field data forms, field computers, automated data loggers, and GPS units will be specified in individual monitoring protocols and study plans. Field crew members will closely follow the established standard operating procedures (SOPs) in the project protocol.

The SODN will conform to NPS standards and mandates, as well as to national I&M Program standards and procedures, to facilitate program integration and data/information sharing. General and protocol-specific SOPs will provide detailed instructions for processing specific types of data.

6.7. Quality Assurance/Quality Control

The view that the data we collect during our inventory and monitoring studies is a valuable resource to be used over the long-term is justified only if we have confidence in our data. Our efforts to detect trends and patterns in ecosystem processes require data of documented quality that minimize error and bias. Data of inconsistent or poor quality can result in loss of sensitivity and lead to incorrect interpretations and conclusions. We must remember that high quality data and information are vital to the credibility and success of the I&M Program, and everyone plays a part in ensuring that our products conform to these standards.

NPS Director's Order #11B: Ensuring Quality of Information Disseminated by the National Park Service (http://www.nps.gov/policy/DOrders/11B-final.htm) specifies that information produced by the NPS must be of the highest quality and be based on reliable data sources that are accurate, timely, and representative of the most current information available. Therefore, we will establish and document procedures for quality assurance (QA) and quality control (QC) to identify and reduce the frequency and significance of errors at all stages in the data life cycle. When these procedures are followed, the progression from raw data to verified data to validated data implies increasing confidence in the quality of those data. The data manager will establish SOPs to ensure compliance with DO #11B. These procedures will document both internal and external review processes for data and information disseminated outside the network, as well as guidance for handling complaints about data quality.

Although many QA/QC procedures will depend upon the individual vital signs being monitored, some general concepts apply to all Network projects. Specific procedures to ensure data quality must be included in the protocols for each vital sign. Examples of QA/QC practices include:

- Standardized field data collection forms
- Use of field computers and automated data loggers
- Proper calibration and maintenance of equipment
- Field crew and data technician training
- Database features such as built-in pick lists and range limits to reduce data entry errors
- Automated error-checking routines

We appraise data quality by applying verification and validation procedures. Data verification checks that the digitized data match the source data, and data validation checks that the data make sense. The Data Management Plan describes several methods for verifying and validating data, and each monitoring protocol will include specific procedures for assuring data quality.

A final report on data quality will be incorporated into the documentation for each project. This will include a listing of the specific methods used to assess data quality and an assessment of overall data quality prepared by the project leader.

6.8. Data Documentation

Data documentation is a critical step toward ensuring that all data sets retain their integrity and utility well into the future. Complete, thorough, and accurate documentation should be of the highest priority for long-term studies, and since long-term data sets are continually changing, this documentation must remain up-to-date. Data documentation refers to the development of metadata, which at the most basic level can be defined as 'data about data,' or more specifically as information about the content, context, structure, quality, and other characteristics of a data set. Additionally, standardized metadata provide a means to catalog data sets within intranet and internet systems, thus making these data sets available to a broad range of potential users.

Without metadata, potential users of a data set have little or no information regarding the quality, completeness, or manipulations performed on a particular 'copy' of a data set. Such ambiguity results in lost productivity as the user must invest time in tracking down information, or, worst case scenario, renders the data set useless because answers to these and other critical questions cannot be found. As such, data documentation must include an upfront investment in planning and organization.

At a minimum, we will require the following elements for documentation of all data managed by the Network:

- Data dictionaries and Entity Relationship Diagrams (ERDs) for all tabular databases
- Formal metadata compliant with Federal Geographic Data Committee (FGDC) standards, the National Biological Information Infrastructure (NBII) Profile (where appropriate), and the NPS Metadata Profile for all geo spatial and biological data sets
- Project documentation

We will create all metadata according to NPS standards and guidelines. Formal metadata will be created using either Dataset Catalog, a NPS tool for producing abbreviated metadata, or the ArcCatalog data management application included with ArcGIS software, supplemented by the NPS Metadata Tools Extension developed by the NPS Midwest Region GIS Technical Support Center. We will publish all metadata to the online NR-GIS Metadata Database. All documentation will also be maintained with its accompanying data set(s) on the Network data server.

6.9. Support for Analysis & Reporting

Creating meaningful information from data sets through summaries and analyses is a critical component of the I&M Program and characterizes the Network's data management mission to provide useful information for park personnel. Close coordination between the project leader and data manager is important to identify opportunities and methods to streamline data extraction and exports from databases based on project objectives, protocols, and data management and analysis SOPs. Where possible, project databases will include automated summary and report routines.

To make data sets available for subsequent analysis by third parties, the Network will establish a timeline and data processing steps including error-checking, summarizing, analyzing, and distributing data. Monitoring project leaders will be responsible for their project databases, but once a year they will review and certify the data set, write an annual report, and make the data available in a common repository for others to use in syntheses and further analyses.

6.10. Data Dissemination

One of the most important goals of the Inventory and Monitoring Program is to integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision-making. To accomplish this goal, the Network will use a variety of distribution methods to make data and information collected and developed as part of the Program available to a wide community of users, including park staff, other researchers and scientists, and the public. We will ensure that:

- •Data are easily discoverable and obtainable.
- •Distributed data are accompanied by complete metadata that clearly establishes the data as a product of the NPS I&M Program.
- •Data that have not yet been subjected to full quality control will not be released by the Network, unless necessary in response to a FOIA request or unless accompanied by a data quality disclaimer.
- •Sensitive data are identified and protected from unauthorized access and inappropriate use.
- •A complete record of data distribution/dissemination is maintained.

Distribution options include the Network data server and the SODN digital libraries, along with several online interfaces. The national I&M Program has developed several web-based applications and repositories to store different types of park natural resource information:

- •NPSpecies – data on park biodiversity (species information)
- •NatureBib – park-related scientific citations
- •Biodiversity Data Store – raw or manipulated data products that document the presence/absence, distribution, and/or abundance of any taxa in NPS units
- •NR-GIS Metadata and Data Store – spatial and non-spatial metadata and accompanying data sets
- •Sonoran Desert Network Web Site – reports and metadata for all I&M data produced by the Network

Data Ownership

The NPS defines conditions for the ownership and sharing of collections, data, and results based on research funded by the United States government. All contracts and cooperative or interagency agreements should include clear provisions for data ownership and sharing as defined by the NPS:

- •All data and materials collected or generated using NPS personnel and fund become the property of the NPS.
- •Any important findings from research and educational activities should be promptly submitted for publication. Authorship must accurately reflect the contributions of those involved.
- •Investigators must share collections, data, results, and supporting materials with other researchers whenever possible. In exceptional cases, where collections or data are sensitive or fragile, access may be limited.

As such, the SODN has established guidelines for ensuring its ownership of data and other research information.

FOIA and Sensitive Data

The Freedom of Information Act (FOIA) stipulates that federal agencies, including the NPS, must provide access to agency records that are not protected from disclosure by exemptions. The NPS is directed to protect information about the nature and location of sensitive park resources under one Executive Order and four resource confidentiality laws:

- Executive Order No. 13007: Indian Sacred Sites
- National Parks Omnibus Management Act (NPOMA; 16 U.S.C. 5937)
- National Historic Preservation Act (16 U.S.C. 470w-3)
- Federal Cave Resources Protection Act (16 U.S.C. 4304)
- Archaeological Resources Protection Act (16 U.S.C. 470hh)

When any of these regulations are applicable, public access to data can be restricted. If disclosure could result in harm to natural resources, the records may be classified as 'protected' or 'sensitive' and information withheld regarding the following resources recognized as sensitive by the NPS:

- Endangered, threatened, rare, or commercially valuable National Park System resources
- Mineral or paleontological sites
- Objects of cultural patrimony
- Significant caves

The Network will comply with all FOIA restrictions regarding the release of data and information, as instructed in NPS Director's Order #66 and accompanying Reference Manuals 66A and 66B (currently in development). Managing natural resource information that is sensitive or protected requires the following steps:

- Identification of potentially sensitive resources
- Compilation of all records relating to those resources
- Determination of which data must not be released in a public forum
- Management and archival of those records to avoid their unintentional release

Classification of sensitive data will be the responsibility of Network staff, park superintendents, and project leaders. Network staff will classify sensitive data on a case-by-case, project-by-project basis and will work closely with project leaders to ensure that potentially sensitive park resources are identified, that information about these resources is tracked throughout the project, and that potentially sensitive information is removed from documents and products that will be released outside the Network.

6.11. Data Maintenance, Storage, and Archiving

Data, documents, and any other products that result from projects and activities that use Network data are all crucial pieces of information. Directions for managing these materials are provided in NPS Director's Order #19: Records Management (2001; http://www.nps.gov/policy/DOrders/DOrder19.html) and the accompanying NPS Records Disposition Schedule (NPS-19 Appendix B, revised 5-2003; http://data2int.itc.nps.gov/wapc/records/nps19app-b.pdf). This guidance states that records of natural and cultural resources are considered 'mission-critical' records (permanent records that are to be transferred to the National Archives when 30 years old) and that copies of these materials "should not, in any instance, be destroyed."

To ensure high-quality long-term management and maintenance of this information, the Network will implement procedures to protect information over time. These procedures will permit a broad range of users to easily obtain, share, and properly interpret both active and archived information, and they will ensure that digital and analog data and information are:

- Kept up-to-date in content and format so they remain easily accessible and usable
- Protected from catastrophic events (e.g., fire and flood), user error, hardware failure, software failure or corruption, security breaches, and vandalism

Technological obsolescence is a significant cause of information loss, and data can quickly become inaccessible to users if they are stored in out-of-date software programs, on outmoded media, or on deteriorating (aging) media. Effective maintenance of digital files depends on the proper management of a continuously changing infrastructure of hardware, software, file formats, and storage media. Major changes in hardware can be expected every 1-2 years and in software every 1-5 years. As software and hardware evolve, data sets must be consistently migrated to new platforms or saved in formats that are independent of specific software or platforms (e.g., ASCII delimited text files). Storage media should be refreshed (i.e., copying data sets to new media) on a regular basis, depending upon the life expectancy of the media.

Regular backups of data and off-site storage of backup sets are the most important safeguards against data loss; therefore, we will establish data maintenance and backup schedules for data stored on the network data servers. Backups of data stored on personal workstations are the responsibility of each staff member. We strongly recommend that staff members store or regularly copy important files onto the network server. Backup routines represent a significant investment in hardware, media, and staff time; however, they are just a small percentage of the overall investment that we make in Program data.

CHAPTER 7: DATA ANALYSIS AND REPORTING

7.1. Introduction

The purpose of the Sonoran Desert Network (SODN) is to provide relevant and reliable ecological monitoring data to park staff regarding resource conditions that enables them to make appropriate management decisions and protect park resources. A monitoring program is essentially an information system; interpreting and communicating derived information and their implications for effective park management to all appropriate audiences is therefore the primary product of the vital signs program. As the success of this program is ultimately based on "adaptive management," which, by definition, relies on the incorporation of timely feedback, it is crucial for the program to institutionalize effective means of communication. This chapter presents an overview of how the network proposes to analyze monitoring information and convey information internally, and exchange information with these diverse audiences.

7.2. Analysis of Monitoring Data Overview

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 that is desired or practical given natural and sampling variability. Each monitoring protocol (Chapter 5) 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 standard operating procedures (SOPs) for each prescribed analysis. It is as important to document which analyses were considered but rejected during protocol development, and the reasoning behind these decisions. This information will be captured in the Protocol Development Narratives (Chapter 5) for each vital sign. Table 7.1 summarizes the five steps of sampling from survey design through interpretation and synthesis, and identifies the personnel with substantial invovlement with each step. Personnel listed in boldface in Table 7.1 are responsible for ensuring that the step is completed within the guidelines of the corresponding protocol and program, but may not actually perform many of the functions of the step themselves. For example, the SODN Ecologist may be responsible for completing the "Data Analysis" step of Exotic Plant - Early Detection Monitoring, but may delegate some or all of the analytic procedures to research associates and interns. The Ecologist would, however, review the results in detail to confirm that the analyses would completed properly, and that the reporting products were complete and on time.

Different methods of data collection in the field.

7.3. Communications and Reporting

The ultimate goal of the vital signs program is to link focused science (monitoring) with flexible and responsive resource management in an "adaptive management" process. As adaptive management relies on the incorporation of timely feedback, it is crucial for the program to develop and institutionalize effective means of communication both within and outside of the network. Figure 7.1 illustrates the anticipated feedback process, and

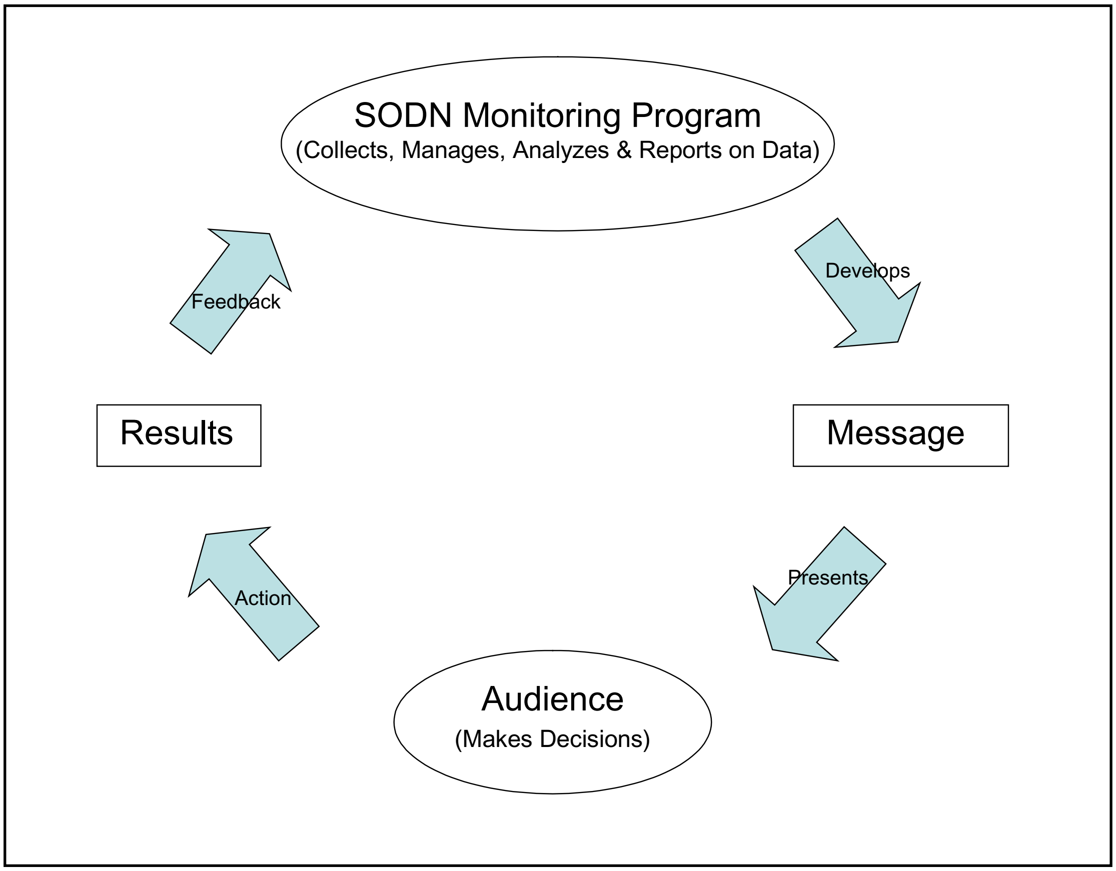


Figure 7.1. Sonoran Desert Network information exchange mechanism.

emphasizes that the SODN program is not a decision making process, but supports informed management through clear presentation of monitoring results.

7.3.1. Program Elements, Media, and Audiences

The goals of the SODN (Chapter 1) can be related to specific information and messages, as well as to target audiences (Figure 7.2). This section presents an overview of communication issues, audiences, and appropriate media. Additional detail on the relationships between program elements, communication media, and target audiences is contained in the draft SODN communication plan (Appendix O).

7.3.2. Linking Communication Types to Target Audiences

In order to fulfill all aspects of its mission, the SODN must successfully conduct five types of communication: informing, sharing, outreach, scoping and disclosure. The purpose of each communication type is to provide specific kinds of information to appropriate audiences; however, there is overlap between the communication types and the information provided. Table 7.2 summarizes these communication types along with their purpose/messages for particular audiences and provides examples of each.

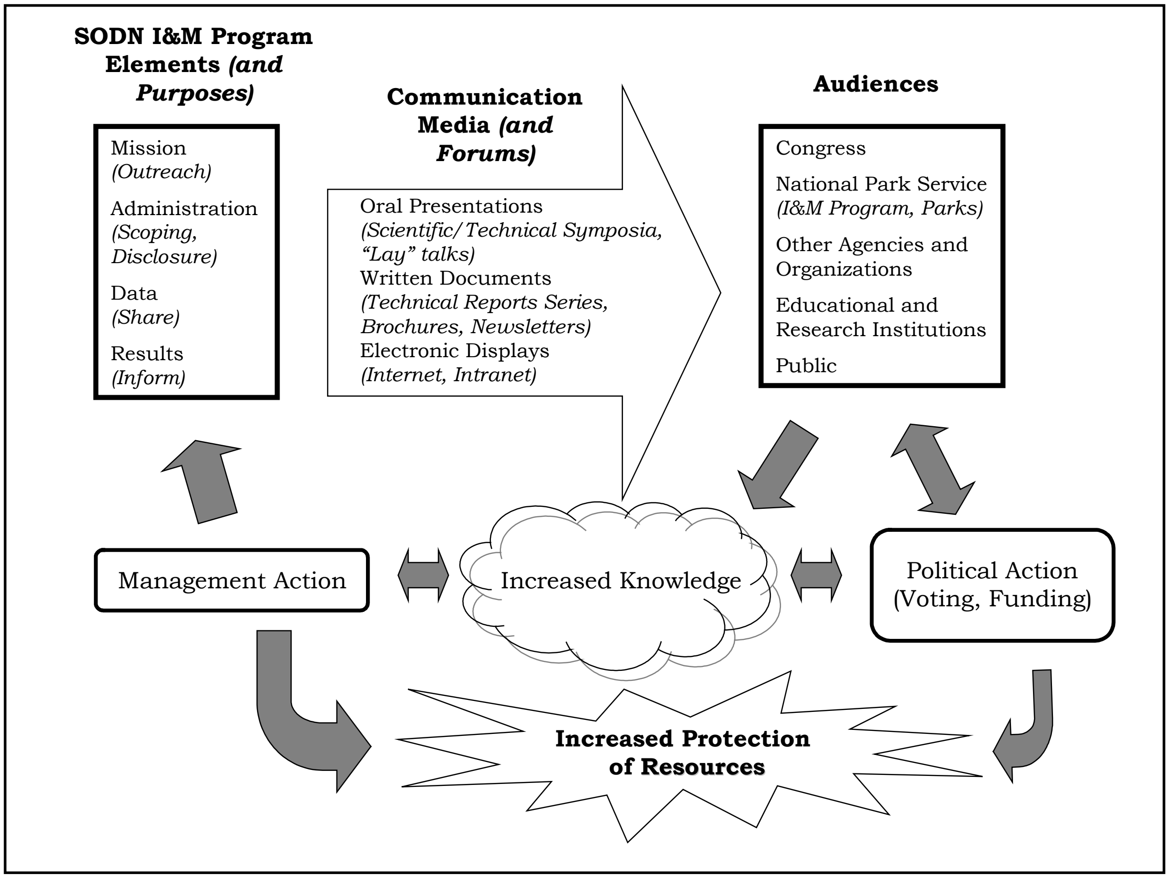


FIGURE 7.2. Schematic diagram of the Sonoran Desert Network Inventory and Monitoring Program's Communication Plan.

One of the "lessons learned" during the development of the SODN program is that one communication media for a given audience and message is often not sufficient. Written reports provide a level of detail and longevity not possible in oral presentations, but competing time commitments and limited technical knowledge often limit their utility for many audiences. Web-based information has relatively broad (and inexpensive) distribution and affords a degree of interactivity to the user. However, many audiences may be unfamiliar with internet access or unaware that monitoring information exists on the Network website, and the longevity of web-information is not assured. Multiple approaches, particularly for reporting on critical monitoring results, will be employed as described in Section 7.3.3 and the draft SODN Communications Plan (Appendix O).

7.3.3. Reporting Schedules

Clearly defined reporting schedules for periodic reports and presentations are critical for ensuring wide dissemination of monitoring results to the appropriate audiences. Table 7.3 describes periodic presentations that SODN staff will lead, whereas Table 7.4 provides an overview of written reports (including web-based materials). Additional detail on these subjects is presented in the draft SODN Communications Plan (Appendix O).

Table 7.1. Monitoring phases and personnel involved by vital sign. Underline indicates responsibility for completion. Note: See acronyms at end of table.

Level 1	Level 2	Vital Sign	Design	Data Collection	Data Management	Data Analysis	Interpretation/ Synthesis
Air and Climate	Air Quality	Ozone	NPS-Air Resources Division	NPS-Air Resources Division; Park staff	NPS-Air Resources Division; Data Manager; Data Tech	NPS-Air Resources Division	Ecologist; NPS-Air Resources Division; Regional Air Quality Specialist; ADEQ
		Wet and dry deposition					
		Visibility and particulate matter					
	Weather and Climate	Broad-scale climate	NOAA-COOP; NIFC	Automated climate networks; Park staff	NOAA-WRCC;` NIFC	UA Climate Extension Specialist (SWES); Interns	UA Climate Extension Specialist (SWES); Ecologist; Interns
		Meso-scale climate	UA Climate Extension Specialist (SWES); Interns	Physical Science Tech; Interns; Park staff	Physical Science Tech; Data Tech.; Interns	UA Climate Extension Specialist (SWES); Interns	UA Climate Extension Specialist (SWES); Ecologist; Interns
Geology and Soils	Geo-morphology	Channel morphology	Research Associate (Soils); Ecologist; Program Manager	Physical Science Tech; Interns	Research Associate (Soils); Data Manager; Data Tech; Interns	Research Associate (Soils); Program Manager & Ecologist; Interns	Program Manager; Ecologist; Research Associate (Soils);
	Soil Quality	Biological soil crusts					
		Soil cover					
		Soil compaction					
		Soil aggregate stability					

Table 7.1. continued.

Level 1	Level 2	Vital Sign	Design	Data Collection	Data Management	Data Analysis	Interpretation/ Synthesis
Water	Hydrology	Groundwater dynamics	EPA EMAP; ADEQ; Regional Hydrologist; Interns; Research Associates; Program Manager	Physical Science Tech; Interns; Park Staff; FOSCR	Physical Science Tech; Data Manager & Data Tech; Interns	Interns; Regional Hydrologist; Program Manager; Ecologist	Regional Hydrologist; Program Manager & Ecologist
		Surface water dynamics					
	Water Quality	Core parameters					
		Nutrient dynamics					
		Pollutant metals					
		Microorganisms					
		Aquatic macroinvertebrates and algae		Biotech; interns	Biotech; interns		
Biological Integrity	Invasive Species	Exotic plants – early detection	Ecologist; Research Associate (Exotic Plants); Interns	Biotech; Research Associate (Exotic Plants); Interns	Biotech; Research Associate (Exotic Plants); Data Manager & Data Tech.; Interns	Ecologist; Research Associate (Exotic Plants); Interns	Ecologist; Research Associate (Exotic Plants); Program Manager
		Exotic plants – status and trends					
	Focal Species or Communities	Fish community dynamics	UA Fisheries Scientist (SNR); BLM Aquatic Biologist; Ecologist	Biotech; Interns	Interns; Biotech, Data Manager, Data Tech	UA Fisheries Scientist (SNR)	Ecologist; Program Manager; UA Fisheries Scientist (SNR)
Biological Integrity	Focal Species or Communities	Phenology of key plant species	Ecologist; Program Manager; Interns; Research Associates	Park staff	Biotech; Data Manager; Data Tech; Interns	Ecologist; Program Manager; Interns and Research Associates	Ecologist; Program Manager
		Vegetation life form abundance		Biotech; Interns			
		Vegetation community structure					
		Bird community dynamics	UA Biologist (SNR); Ecologist	UA Biologist (SNR); UA seasonals	UA Biologist (SNR); UA seasonals; Data Manager; Data Tech	UA Biologist; Ecologist; Program Manager	Ecologist; Program Manager; UA BIologist

Table 7.1. continued.

Level 1	Level 2	Vital Sign	Design	Data Collection	Data Management	Data Analysis	Interpretation/ Synthesis
Human Use	Visitor and Recreation Use	Visitor use	Research Associates (Human Dimensions & Soils); Program Manager; Ecologist	Research Associates (Human Dimensions & Soils); Interns; Biotech; Physical Science Tech; Park Staff	Research Associates (Human Dimensions & Soils) and Interns; Data Manager; Data Tech	Research Associates (Human Dimensions & Soils); Ecologist; Program Manager	Ecologist; Program Manager; Research Associates (Human Dimensions & Soils)
		Visitor use impacts					
	Point-source Human Effects	Illegal roads and trails	UA Remote Sensing Scientist (ARSC); Program Manager	UA Remote Sensing Scientist; UA graduate students (ARSC)	UA Remote Sensing Scientist; UA graduate students; Data manager; Data Tech	UA Remote Sensing Scientist; UA graduate students; Program Manager; Ecologist	Program Manager; Ecologist; UA Remote Sensing Scientist
Ecosystem Pattern & Processes	Land Use/ Land Cover	Landscape dynamics					

ADEQ: Arizona Department of Environmental Quality
ARSC: Arizona Remote Sensing Center, Office of Arid Lands Studies, University of Arizona
Biotech: The SODN Biological Science Technician (see 8.2.1)
BLM Aquatic Biologist: Resource professional cooperating through the Regional Monitoring Partnership (see 8.3.3)
Data Manager: The SODN Data Manager (see 8.2.1)
Data Tech: The SODN Cartographic Data Technician (see 8.2.1)
Ecologist: The SODN Ecologist (see 8.2.1)
EPA EMAP: Environmental Assessment and Monitoring Program, Environmental Protection Agency
IMR: Intermountain Region, National Park Service
Interns: Graduate and undergraduate students in the SODN/SI Joint Internship Program (see 8.2.3)
FOSCR: Friends of the Santa Cruz River (non-profit)
NIFC: National Interagency Fire Center
NOAA-COOP: Cooperative Observer Program, National Oceanic and Atmospheric Administration
NOAA-WRRC: Western Regional Climate Center, National Oceanic and Atmospheric Administration
Physical Science Tech: The SODN Physical Science Technician (see 8.2.1)
Program Manager: The SODN Program Manager (see 8.2.1)
Regional Physical Scientists: The NPS- IMR Air Quality Specialist and NPS-IMR Regional Hydrologist (Arizona; see 8.3.2)
Research Associates: Monitoring professionals leading the SODN/SI Joint Internship Program (see 8.2.3)
SI: The Sonoran Institute
SNR: School of Natural Resources, University of Arizona
SODN: The Sonoran Desert Network
SWES: Department of Soil, Water, and Environmental Studies, University of Arizona
UA Scientists/Seasonals: University of Arizona subject matter experts reached through the Desert Southwest CESU (see 8.3.2-8.3.3)

Table 7.2.
Summary of SODN communication types, their purposes, and target audiences (with examples).

Communication Type	Purpose(s)	Examples	Target Audience(s)
Informing	Share Results Decision-making	Presentations at scientific symposia, park staff and TC[1] meetings, technical reports, scientific articles	Agency Staff, NGO[3] staff, Other Technical Experts, Scientists, and Students
Sharing	Share Data	Database "Clearinghouse," NPS data store	Educational/Research Institutions, Other Agencies
Outreach	Share Values Partnering	Non-technical and resource interpretation reports, website	Public, Other Agencies, Organizations and Institutions
Scoping	Solicit Input Peer Review	Workgroups, website "comment form"	Technical Experts, Public
Disclosing	Disclosure	Administrative Record, AARWP[2], Compliance Documents	Service-wide I&M Program, SODN Board of Directors, Regulatory Authorities, Congress, Public

[1]TC = SODN Technical Committee

[2] AARWP = the Annual Administrative Report and Workplan that each network produces, which (collectively) form the basis of the Service-wide I&M Report to Congress

[3]NGO = non-governmental organization

Table 7.3.
Schedule for recurring presentations of SODN results to park staff.

Type of Presentation	Purpose of Presentation	Primary Audience	Location	Frequency	Primary Presenter(s)
Technical Committee Consultation	Provide an update on network activities and findings. Receive feedback from Technical Committee on resource issues and monitoring program.	Park resource managers and partners from other agencies	Tucson	Quarterly	Ecologist, Network Coordinator, and Data Manager
Board of Directors Briefing	Update park management and NPS program managers on network operations, present draft budget and workplan. Obtain feedback and guidance on administrative and programmatic issues.	Superintendents, IMR Regional Program Manager, SOAR Resource Program Manager, DSCESU Research Coordinator	Tucson or SW Cluster location	Biennial	Network Coordinator
Park "All Hands" Meeting or Squad Meeting	Communicate network mission and results to a non-technical audience. Receive feedback on resource and monitoring issues in park operations.	Park staff and volunteers, particularly from divisions other than resource management.	At each park	Annual	Network Coordinator, Ecologist, or Data Manager
Executive Briefing	Update superintendent on park-specific findings and potential resource issue; suggest action items, where appropriate.	Individual superintendents	At each park	Annual	Network Coordinator, Ecologist

Table 7.4.
Summary of SODN written reports.

Type of report	Purpose of Report	Primary Audience	Frequency	Initiator	Review Process
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, SODN staff, regional coordinators, and Service-wide program managers; Admin. Report used for annual report to Congress.	Annual	Network coordinator	Reviewed and approved by IMR Regional Coordinator and Service-wide Program manager
Reports for Specific Protocol Development and Pilot Projects	Provide background and methods of protocol development and enhancements. Document results of pilot studies. Provide record of decision for protocol design. Includes Protocol Development Narratives (Chapter 5) that describes all methods considered during protocol development.	SODN staff, partners (Regional Monitoring Partnership), other networks with shared vital signs	Annual reports from FY05-07 with project-specific due dates, thereafter variable depending on needs	Network Coordinator and Ecologist	Peer reviewed at network level
Protocol Review Reports	Document the overall quality of a protocol, specifically in terms of the 3 key features listed below. Document where actual procedures and target levels fall short of stated expectations, recommendations for necessary changes, and changes to protocols that were implemented since the last Protocol Review Report. 1) Implementation: Document what is actually feasible to implement compared to what was specified. 2) Effectiveness: Document minimum change detection levels, and compare to expected detection levels. 3) Data Management: Document compliance with standards for data entry, QA/QC, retrieval, and archiving.	Superintendents, park resource managers, SODN staff, Service-wide Program managers, external scientists (IMR Regional Science Panel), partners (Regional Monitoring Partnership).	Within 1-3 years of protocol implementation, thereafter every 5 years.	Network Coordinator, Ecologist, Data Manager	Peer reviewed at network and regional level
Program Review Report	Document formal review of operations and products - includes the effectiveness of reports and other Network venues in communicating results to all audiences in an appropriate and useful manner, the use of results in management decision making, and the ability to engage external scientists via data sharing or in the design of complementary resource-monitoring studies.	Superintendents, park resource managers, SODN staff, Service-wide Program managers, external scientists	5-year intervals	Network Coordinator, Ecologist, Data Manager	Peer reviewed at regional and national level, SODN Board of Directors, Technical Committee
Annual Status Reports for specific protocols	Document monitoring activities for the year. Document numbers of samples by park and relevant attributes (e.g., ecological sites or riparian types). Document related data management activities (data base updates, QA/QC changes). Describe status of the resource. Document changes in monitoring protocols. Communicate monitoring efforts to resource managers.	Park resource managers, SODN staff, external scientists	Annually	Network Coordinator, Ecologist, Data Manager	Peer reviewed at Network level
Summary of Annual Reports for specific protocols	Same as Annual Reports, but summarized to highlight key points for non-technical audiences.	Park superintendents, interpreters general public, partners (Regional Monitoring Partnership)	Annually	Network Coordinator, with input from interpreters on SODN parks	Peer reviewed at network level

Table 7.4. continued.

Type of report	Purpose of Report	Primary Audience	Frequency	Initiator	Review Process
Comprehensive Trend Analysis and Synthesis Reports	*Park Level:* Describe and interpret trends of individual monitored resources. Describe and interpret relationships among resources, including relationships between drivers/stressors and responses measured at commensurate scales and measured at multiple scales. Highlight resources in need of management action, and recommend types of actions. *Network Level:* Describe and interpret trends among parks, and the role of geographic and climatic differences among park units. Interpret monitored-resource trends in the context of the network, ecoregion (Regional Monitoring Partnership), and of the region (using information from other networks).	Park resource managers, SODN staff, external scientists	Every 3-5 yrs for all monitored resources	Network Coordinator and Ecologist	Peer reviewed at the network, ecoregional level (Regional Monitoring Partnership), and regional level (IMR Science Panel).
Summary of Comprehensive Analysis and Synthesis Reports	Same as Comprehensive Analysis and Synthesis Reports, but summarized to highlight key findings and recommendations for non-technical audiences.	Park superintendents, interpreters, general public, partners (Regional Monitoring Partnership)	Commensurate with reporting frequency of Comprehensive Report	Network Coordinator and Ecologist, with input from interpreters on SODN parks	Peer reviewed at the network level
Scientific journal articles and book chapters	Document and communicate advances in knowledge.	External scientists, park resource managers	Variable	Network Coordinator, Ecologist, Data Manager	Peer reviewed by journal or book editor
Symposia, workshops, and conferences	Review and summarize information on a specific topic or subject area. Communicate latest findings to peers. Identify emerging issues and generate new ideas.	Resource managers of National Park Service and other federal and state agencies, SODN staff, external scientists	Variable, opportunities include: Bi-annual Sonoran Desert Resource Management Conference, George Wright Society, Southwest Cluster Meeting, and regional and national professional meetings.	Network Coordinator, Ecologist, Data Manager	May be peer reviewed by editor if written papers are published
SODN Newsletter	Review and summarize network activities and findings of general interest. Describe the role and purpose of the network to non-technical audiences.	Park staff, agency partners and cooperators.	Quarterly by email and on SODN website	Network Coordinator, Ecologist, Data Manager	Peer reviewed by network staff.
State of the Parks Report	Describes current conditions of park resources. Report interesting trends and highlights of monitoring activities. Identifies situations of concern. Explores future issues and directions.	Congress, budget office, NPS Leadership, superintendents, general public	Annual	Compiled by WASO from data provided by networks	Peer reviewed at national level
Web-based media	Centralized repository of all final reports in I-XII - to ensure products are easily accessible in commonly-used electronic formats	Park superintendents, resource managers, SODN staff, service-wide program managers, external scientists, students, general public	As reports complete review	Network coordinator, Ecologist, Data Manager	Only reviewed, finalized products will be posted

CHAPTER 8: ADMINISTRATION AND IMPLEMENTATION OF THE MONITORING PROGRAM

8.1. Administrative Structure of the Sonoran Desert Network

This chapter presents an overview of administrative, personnel, and program management functions of the Sonoran Desert Network. Roles and relationships between the network and internal and external partners are described. Additional detail on these functions is presented in the SODN Charter, and NPS service-wide I&M memorandums and directives.

8.1.1. Sonoran Desert Network Board of Directors

The SODN Board of Directors (BoD) provides general direction, oversight, and advocacy of network operations and ensures that inventory and monitoring activities address specific management goals and mandates for SODN parks (Table 8.1). Voting membership of the BoD is comprised of the 9 superintendents of the SODN park units, with the Southern Arizona Support Office (SOAR) Superintendent, SOAR Natural Resources Program Manager, Desert Southwest Cooperative Ecosystem Studies Unit (DSCESU) Research Coordinator, Intermountain Region (IMR) Inventory and Monitoring Program Manager, and SODN Coordinator as ex-officio members. The BoD Chairperson is elected to a two-year term from the ranks of the park superintendents. The BoD meets biannually to review and approve network workplans, evaluate administrative and operational aspects of the monitoring program, and set strategic goals and approaches for integrating monitoring results into park management. Where feasible, BoD meetings are held in concert with SODN Technical Committee meetings to facilitate interaction and discussion between these administrative bodies.

Table 8.1. Role and function of local administrative bodies of the Sonoran Desert Network.

	Role and Function in Monitoring Program
Board of Directors	•Establish monitoring objectives to address management goals and ensure monitoring results meet these goals. •Provide general direction and oversight of program development. •Advocate program integration into park operations. •Integrate monitoring results into park management. •Review and retain local approval authority for the annual administrative report and workplan (Table 7.3).
Technical Committee	•Establish monitoring objectives to address management goals and ensure monitoring results meet these goals (with BoD). •Evaluate technical considerations of program development. •Review key program development documents, monitoring protocols, and select vital signs. •Establish mechanisms to link monitoring results to management actions (adaptive management).
Science Panel	•Provide scientific peer review of network development documents, monitoring protocols, and data interpretations. •Identify shared monitoring issues across IMR networks where collaboration may result in increased efficiencies. •Suggest potential agency and research partners with common monitoring issues for membership in the Greater Sonoran Desert Regional Monitoring Partnership.

8.1.2. Sonoran Desert Network Technical Committee

The SODN Technical Committee (TC) serves as a technical review and advisory body to SODN staff and the BoD. The SODN TC reviews monitoring plan documents, evaluates potential vital signs, promotes cooperative approaches to monitoring through internal and external partnerships, and develops management alternatives and recommendations to address monitoring results (Table 8.1). The SODN TC develops, reviews, and prioritizes internal funding proposals for resource management projects through the Servicewide Combined Call (SCC). The TC is composed of natural and cultural resource managers, interpreters, and other staff from SODN parks involved with resource management. Each SODN park selects one voting representative to the TC, but meetings are open to all interested park staff. The TC Chairperson is elected to a two-year term from the ranks of the TC, and serves as a liaison between the BoD and TC. The TC meets quarterly to review and discuss inventory and monitoring approaches, results, and develop funding proposals.

8.1.3. Sonoran Desert Network Science Panel

During Phases 1-3, the SODN had a network-level Science Panel composed of academic, agency, and NGO scientists from the U.S. and Mexico. To increase the network's ability to contract with local scientists without potential conflicts of interest, facilitate inter-network cooperation, and to concentrate the rare and valuable monitoring expertise of a few key scientists, the SODN Board of Directors decided in October 2004 to disband the SODN Science Panel and replace it with an IMR Science Panel. At the time of writing (August 2005), the SODN Coordinator was working with counterparts in other IMR networks and the Regional Program Manager to initiate the IMR Science Panel.

Composed of 5 recognized monitoring experts from academic and agency research institutions, the IMR Science Panel will provide scientific review of monitoring products (including plans, draft protocols, and periodic interpretive reports) for SODN and other IMR networks (Table 8.1). The Regional Program Manager will serve as the liaison to the IMR Science Panel, with network-specific input from the SODN Coordinator. The IMR Science Panel will meet annually with staff from IMR networks to review monitoring materials and assess progress on implementing operational monitoring.

8.1.4. Regional and Servicewide Programs

Regional and service-wide programs play important roles in network development and operations (Table 8.2). The Intermountain Region (IMR) Regional Program Manager coordinates program development activities for 7 networks and facilitates integration with other IMR resource management operations. The service-wide I&M program establishes standards and guidelines based on the Natural Resource Challenge legislation and agency policy, reviews and retains approval authority for completed (Phase 3) monitoring plans and workplans, and provides technical and administrative guidance on network development. The NPS Natural Resources Program Center divisions have specific responsibilities regarding completion of baseline resource inventories and serve as a resource for subject matter expertise for particular vital signs.

	Role and Function in Monitoring Program
IMR Regional Program Manager	•Coordinates program activities for 7 IMR networks including SODN •Provides guidance on monitoring program development and facilitates integration of the SODN program with related IMR resource management operations. •Serves as an *ex-officio* member of the SODN Board of Directors •Reviews and retains approval authority for Phase 1 and 2 documents •Serves as the primary NPS point of contact for the IMR Science Panel
Service-wide Inventory and Monitoring Program	•Establishes standards and guidelines for the vital signs program based on applicable legislation and NPS policy. •Provides guidance on monitoring program development and coordinates network development at the national level. •Reviews and retains final approval authority for the final SODN Monitoring Plan and annual administrative reports and workplans. •Provides technical guidance on monitoring issues.
NRPC Offices	•Supports and guides completion of the 12 inventory datasets (Chapter 1). •Provides subject matter expertise for evaluation and protocol development of relevant vital signs.

Table 8.2.
Role and function of regional and service-wide NPS monitoring programs in the Sonoran Desert Network. IMR = NPS Intermountain Region; NRPC = Natural Resource Program Center.

8.2. Sonoran Desert Network Staff

This section presents an overview of Sonoran Desert Network staff (i.e., positions that are directly responsible for program development and funded by the SODN vital signs budget). The SODN has adopted an iterative approach to evaluating potential core staff positions as the precise kind and level of expertise required is difficult to assess without completed protocols. Options and strategies for completing anticipated tasks are discussed, and will be revisited by the core staff, SODN Technical Committee, and SODN Board of Directors, as protocol development and implementation monitoring progresses.

8.2.1. Core SODN Staff

The Network Program Manager, Ecologist, and Data Manager constitute the core permanent staff of the SODN, with an additional three positions currently being considered during the implementation phase: Data Technician, Physical Science Technician and Biological Sciences Technician. The core staff is duty stationed in Tucson, Arizona. Figure 8.1 depicts the six core staff positions approved by the SODN Board of Directors (BoD), as well as a shared Communications Specialist position that the BoD has identified as a critical staffing need that would be filled if additional funds become available in the future. Each of the initial core staff positions has critical roles and responsibilities for program development (Phases 1-3) and operational monitoring. Table 8.3 provides an overview of core staff roles and responsibilities, and indicates the lead staff member responsible for science, data management, and administration. Each of the core staff members contributes to all three program areas in an integrated fashion.

Table 8.3.
Overview of roles and responsibilities for the SODN core staff.

YELLOW= Current permanent staff
BLUE= Under consideration
ORANGE= To be hired if funding becomes available

Core Staff	Role & Responsibility	Status
Program Manager (GS-408-12/13)	The Program Manager is responsible for the overall management and supervision of the program. The Program Manager carries out these duties by developing work plans and schedules, scopes of work and coordinating network activities with the Technical Committee. The Program Manager partners with similar programs on adjacent lands and appropriate regional and national monitoring programs. The Program Manager also serves as staff to the Board of Directors and the Technical Committee.	Hired (permanent) in 2001. 1.0 FTE
Ecologist (GS-408-9/11/12)	The Ecologist is responsible for the scientific and statistical components of the program. The Ecologist designs, develops and tests long-term monitoring protocols, as well as directing data collection procedures and conducting analysis of data. The Ecologist also reports the significance of findings to park managers and interested public.	Hired (SCEP converted to permanent) in 2003. 1.0 FTE
Data Manager (GS-401-9/11)	The Data Manager is responsible for the information and data stewardship of the program. The Data Manager performs the following duties: design, development and management of complex database systems for the long-term maintenance, analysis and dissemination of natural resource data sets; and management of the GIS and database management software, GPS data dictionaries and spatial data inventories.	Hired (permanent) in 2001. 1.0 FTE
Data Technician (GS-1371-5/6/7)	The Data Technician works under the direction of the Data Manager to complete information management tasks including data entry, quality control/quality assurance procedures, generating and populating GIS maps, and GPS data dictionaries. The Data Technician manages the daily operations of the handheld computer (PDA) field data collection systems and the network infrastructure for the SODN data management program.	Hired (term) in 2005. 1.0 FTE. Currently being evaluated for permanent.
Biological Science Technician (GS-404-5/6/7)	The Biological Science Technician leads field data collection and data entry efforts for 10 vital signs (Table 7.2) under the direction of the Ecologist. The Biological Science Technician maintains field instruments and equipment, coordinates logistics for field and laboratory sample collection and processing activities, and performs routine data entry and data summarization tasks.	To be hired (term) in 2006. 1.0 FTE. Currently being evaluated for permanent.
Physical Science Technician (GS-1311-5/6/7)	The Physical Science Technician leads field data collection and data entry efforts for 10 vital signs (Table 7.2) under the direction of the Ecologist and in coordination with the IMR Regional Hydrologist (Arizona). The Physical Science Technician maintains field instruments and equipment, coordinates logistics for field and laboratory sample collection and processing activities, and performs routine data entry and data summarization tasks.	To be hired (term) in 2006. 1.0 FTE. Currently being evaluated for permanent.
Communication Specialist (GS- 401-9/11)	The Communication Specialist develops information media for communicating I&M results and mission to diverse audiences including resource professionals, Superintendents, other park staff, and the public. The Communication Specialist interprets scientific results for these groups in written and web-based media using desktop publishing, technical writing and graphic design skills.	To be hired in future if additional funds become available. 0.5 FTE (shared with other IMR network)

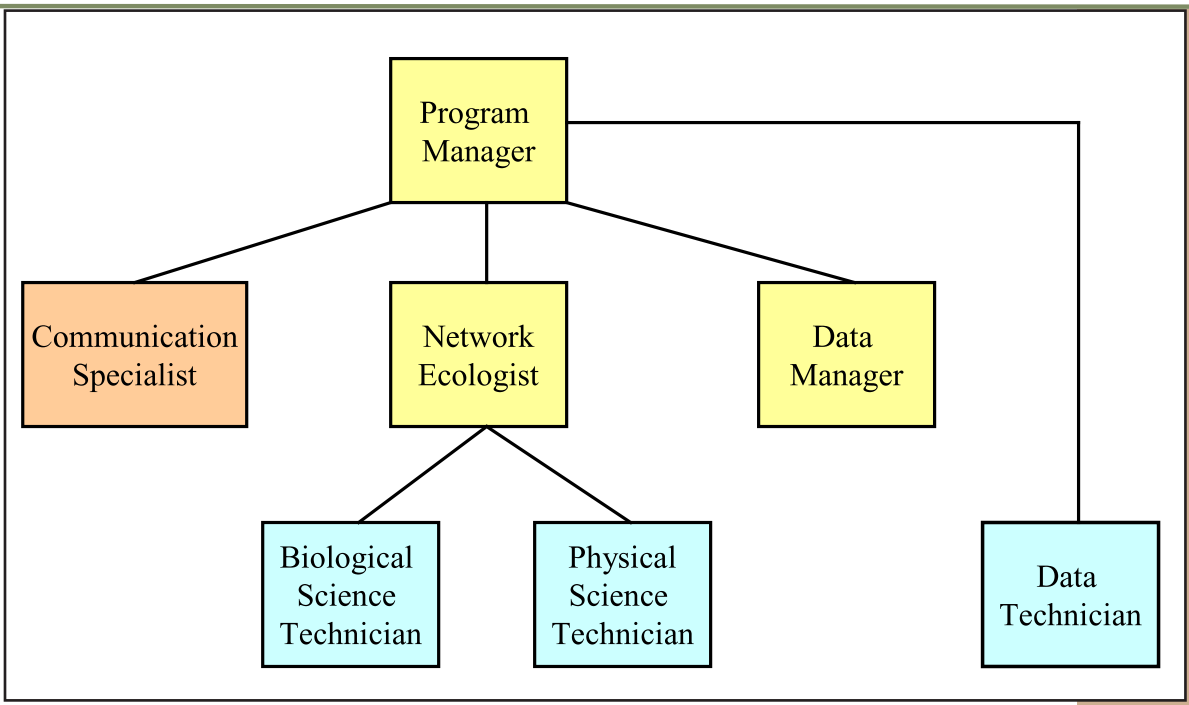


FIGURE 8.1. Organization chart for SODN as of September 2005.

YELLOW= Current permanent staff
BLUE= Under consideration
ORANGE= To be hired if funding becomes available

8.2.2. Options and Strategies for Addressing SODN Staffing Needs

Committing program funds to permanent positions requires careful consideration of staffing needs and available funds. For the past several years, increases to NPS base funds have not kept pace with congressionally-mandated increases to salary and benefits, resulting in significant fiscal pressure on NPS units. This situation is not anticipated to improve over the foreseeable future. However, there are some significant advantages to having key network tasks handled by a permanent science staff, including program consistency and professional representation of the network, as well as other inherently government tasks such as supervision and fund management. In addition, scientists hired by the network have a direct connection and responsibility to the NPS management structure not afforded by contractors and cooperators, or even scientists in other agencies. These considerations suggest that the "core staff" described in 8.2.1 is an important foundation for the SODN program. Beyond that foundation, there are a number of options for developing and operating the SODN program that will be explored as protocol development identifies specific tasks and needs (Table 8.4). Section 8.2.3 describes one approach that has been very successful during Phase planning and protocol development.

Identification of staff training needs, equipment requirements, and safety issues will be addressed during development of individual protocols, and aggregated into program documents (training plan, operations, safety plan) as protocols are completed. These additional documents will added to the Monitoring Plan as they are developed during the initial implementation of operational monitoring and will be reviewed and updated (as necessary) annually.

Table 8.4. Approaches for completing SODN tasks beyond the core staff responsibilities.

Approach	Program Element Addressed	Advantages	Disadvantages
1. Permanent technician positions	Data collection, data entry	Consistency, direct supervision by core staff	Long term commitment of funds; NPS administrative costs
2. Seasonal technician positions	Data collection, data entry	Direct supervision by core staff, flexibility	Turnover will increase training needs and decrease consistency; NPS administrative costs
3. Multi-year graduate and undergraduate interns	Data collection, data entry, analysis and interpretation	Low cost, flexibility, integration with agency and research partners, technical knowledge	Lack of consistency
4. Contractors/ Cooperators	Data collection, data entry, analysis and interpretation	Flexibility, technical knowledge	Lack of consistency; cost, accountability
5. Permanent professional positions	Data analysis and interpretation	Consistency, technical knowledge, accountability	Long term commitment of funds; NPS administrative costs

Based on the network's experience to date, it is anticipated that a combination of two or more of the staffing approaches described in Table 8.4 will be employed during operational monitoring. Final staffing decisions will be made by the SODN Board of Directors.

8.2.3 SODN/Sonoran Institute Joint Internship Program

An internship program was initiated in January 2004 with two undergraduate students and two graduate students who are supervised by the Sonoran Institute. Additional interns were added for a total of ten working in summer 2004 through the 2004-2005 school year. The interships provide students with varied and valuable experiences working with a non-profit organization (the Sonoran Institute) and a federal agency (the National Park Service Sonoran Desert Network), in an interdisciplinary setting. Interns work on protocol development through activities such as consultation with scientific experts, literature reviews, data entry and management (including GIS), data analysis, fieldwork, and scientific writing.

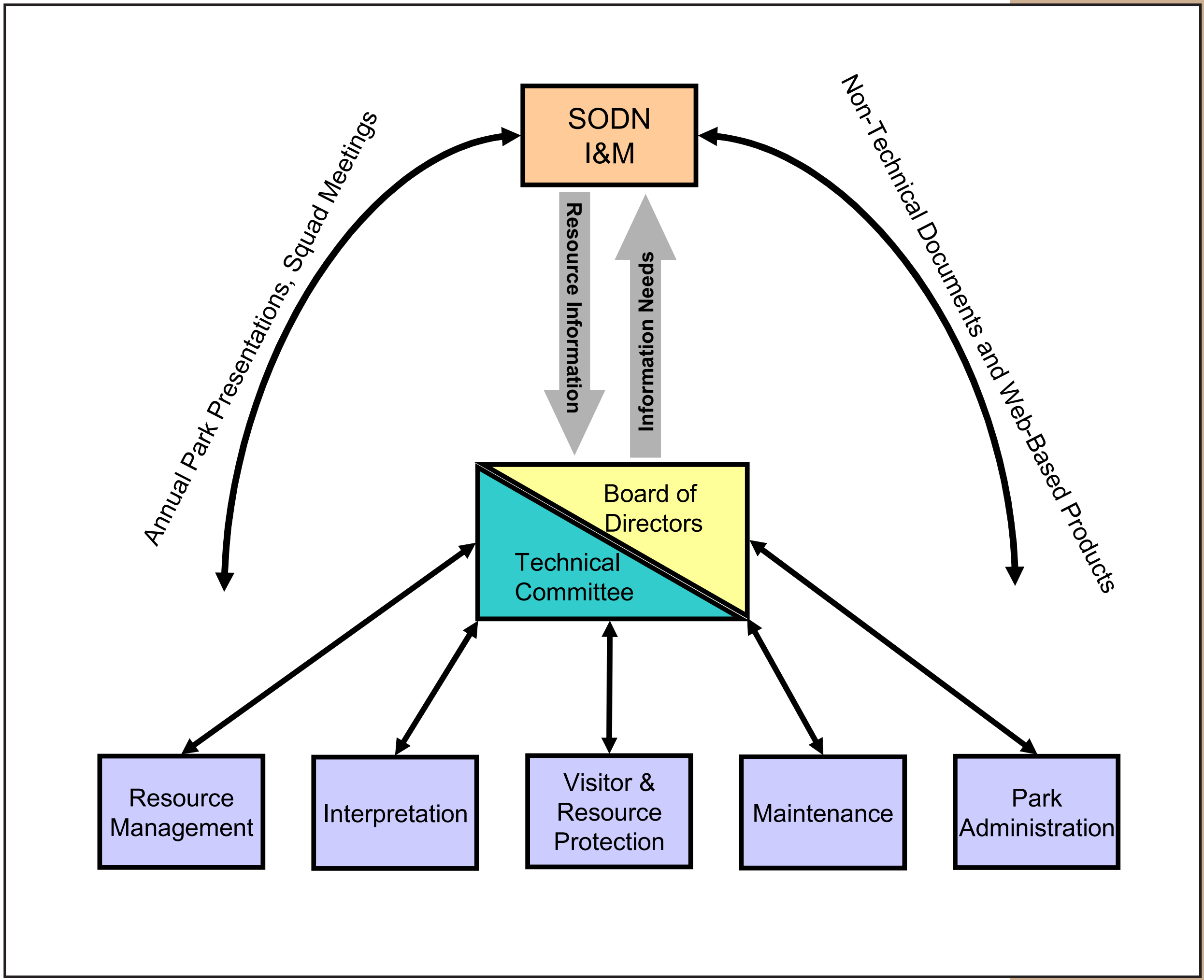
8.3. Program Integration and Partnerships

The NPS Vital Signs program is intended to augment, rather than replace, existing park management operations, including resource management and existing park-based monitoring. The SODN approach has been to build upon and complement existing programs and thereby integrate resource inventory and vital signs monitoring into overall park operations. This approach to integration has occurred at park, sub-regional, and ecoregional scales. An overview of each level follows.

8.3.1. SODN Integration into Park Operations

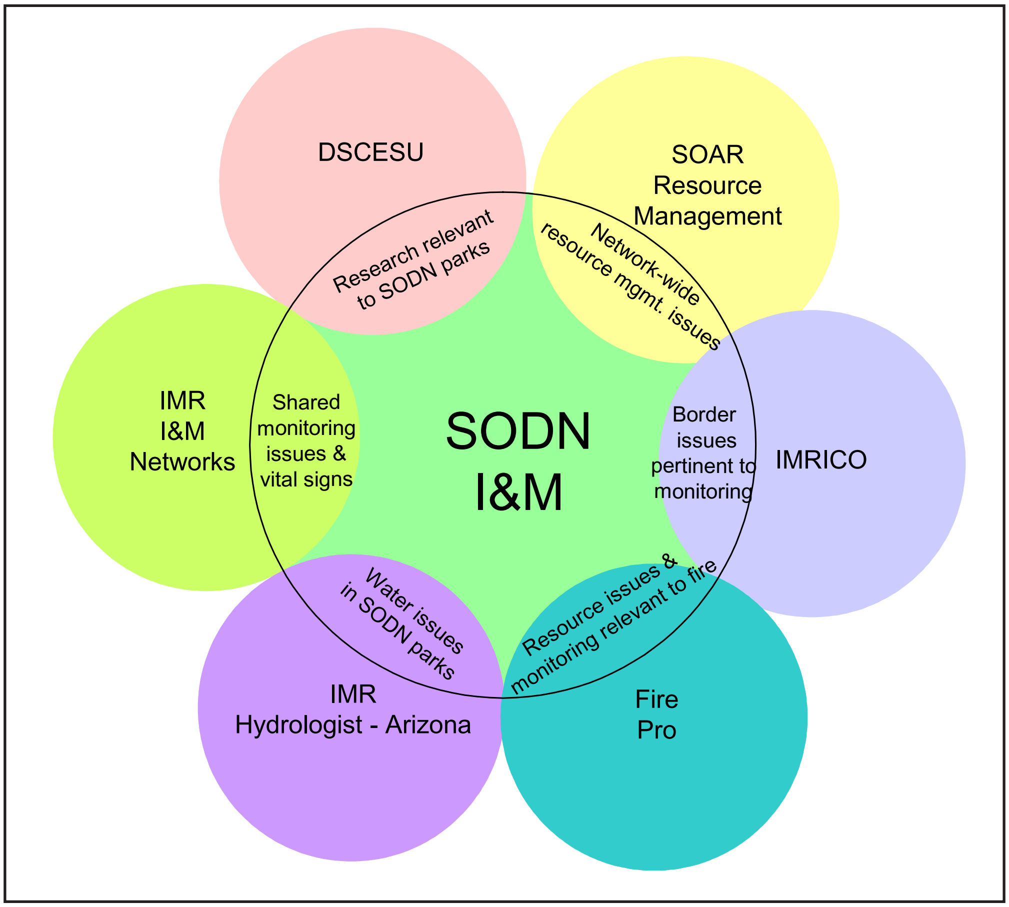
For monitoring results to support effective management of SODN parks, the vital signs program must be integrated into all relevant aspects of park operations. Figure 8.2 illustrates the interactions and pathways for park-level integration of the SODN program. Section 8.1 describes the roles of the SODN Technical Committee and SODN Board of Directors in integrating vital signs monitoring into park operations. The draft SODN Communications Plan (Appendix N) describes communication pathways for directly integrating vital signs monitoring results into park operations, and obtaining direct feedback on monitoring and programmatic issues from park divisions.

Figure 8.2. Integration of the SODN vital signs programs into park operations for 11 units in southern Arizona and New Mexico.



Ideally, park resource management staff would be actively and formally involved in each facet of vital signs monitoring to ensure that monitoring results address park information needs. However, this level of park staff participation is unrealistic given current and projected workloads and staffing levels in SODN parks. In addition, park staff will be extensively engaged in recommending and enacting management practices based on monitoring results as part of the adaptive management process. Despite these pragmatic realities, SODN BoD and TC members and SODN staff will seek to integrate park staff into data collection, analysis, and interpretation to the greatest degree possible.

Figure 8.3.
Relationships between SODN key partners and the primary areas of overlap.



8.3.2. SODN Integration into Sub-Regional NPS Institutions

Staffing levels and emphasis on cultural resources have historically necessitated cooperative approaches to natural resource management in SODN parks. The network has focused its effort on an integrated approach that includes other NPS institutions in the Sonoran Desert (Figure 8.3), including:

- Southern Arizona Support Office (SOAR) Resource Management Program (2 natural resource and 1 cultural resource positions)
- Intermountain Region International Conservation Programs Office (IMRICO)
- NPS Fire Management Program (FIREPRO) for southern Arizona;
- Intermountain Region Aquatic Resource Specialist for Arizona (co-located with SODN)
- Desert Southwest Cooperative Ecosystem Studies Unit (DSCESU)
- Southern Arizona Parks (SAPs) Resource Group, a collective of the 17 resource managers in SODN parks.

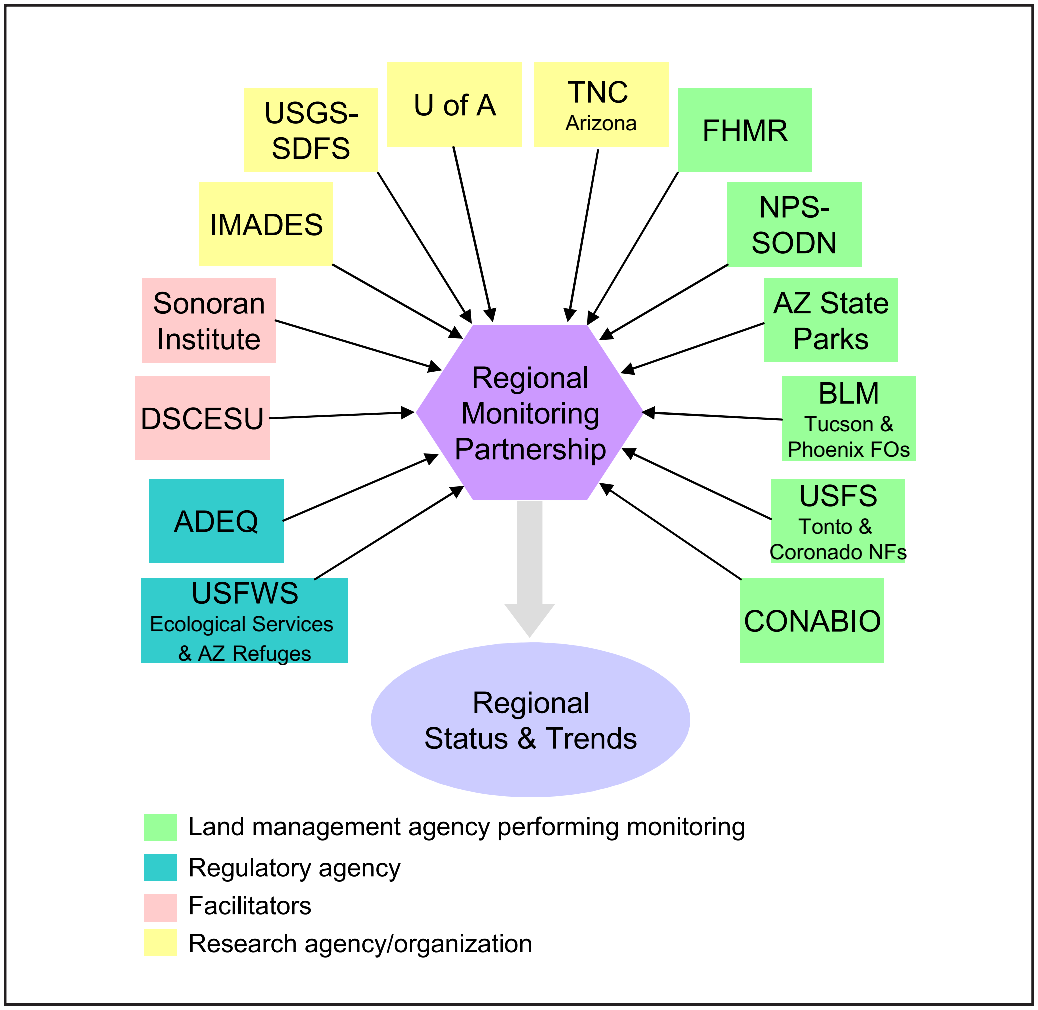


Figure 8.4. Integration of SODN into cooperative monitoring efforts through the Greater Sonoran Desert Regional Monitoring Partnership (RMP).

U of A = The University of Arizona; TNC-Arizona = The Nature Conservancy, Arizona Chapter; FHMR = Fort Huachuca Military Reservation; AZ State Parks = Arizona State Park System; BLM = Bureau of Land Management, Tucson and Phoenix Field Offices; USFS = U.S. Forest Service, Tonto and Coronado National Forests; CONABIO = Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Mexico); USFWS = U.S. Fish and Wildlife Service, Ecological Services Office (Arizona) and Refuge System in Arizona; ADEQ = Arizona Department of Environmental Quality; DSCESU = Desert Southwest Cooperative Ecosystem Studies Unit; IMADES = Instituto Nacional de Ecología (Mexico); USGS = U.S. Geological Survey, Sonoran Desert Field Station.

8.3.3. Integration with Agency, Research, and Non-Profit Partners in the Sonoran Desert Ecoregion

The Sonoran Desert and Apache Highlands ecoregions contain several land management agencies, research institutions, and non-profit groups with monitoring mandates. To maximize the application of monitoring and research information and increase the overall efficacy of monitoring and land management activities, SODN and other partners established the Greater Sonoran Desert Regional Monitoring Partnership (RMP) in 2003 (Figure 8.4) This partnership has generated collaborative approaches to conceptual modeling, protocol development, fire effects monitoring, and data management. A description of the RMP and memorandums of understanding (MOUs) defining its parameters is presented in Sonoran Institute (2004) and at www.sonoran.org/monitoring.

8.4. Program Review

Periodic reviews of the overall SODN program and individual protocols are critical for ensuring monitoring goals and objectives are being met. Protocols will receive both internal and external review every five years following acceptance of the original protocol. The SODN program will be the subject of internal and external review three years after acceptance of the monitoring plan (anticipated to be October 2005), and will recur thereafter on a five year cycle.

CHAPTER 9: SCHEDULE

As described in Chapter 5, all of the SODN's vital sign protocols are currently under development. A draft or final protocol is expected to be prepared for nine of the 20 SODN protocols by spring of 2006 (Table 9.1). Operational monitoring will be underway once a draft protocol has been externally reviewed and accepted, all standard operating procedures follow the Oakley et al. (2003) format, and monitoring is implemented fully in the field. The Regional Program Manager retains final approval authority for protocol acceptance.

For all 20 SODN protocols, Table 9.2 depicts the time of year sampling is expected to occur. Some data will be collected continuously (e.g., climate data), while other data will be collected during discrete events (e.g., vegetation data). Field efforts are distributed throughout the calendar year (Table 9.2).

Superintendent Alan Whalon assists with groundwater monitoring at Chiricahua NM.

Monitoring landscape-level vegetation at Coronado NM.

Collard lizard *(Crotaphytus collaris)* at Gila Cliff Dwellings NM.

Table 9.1. Tentative schedule for SODN protocol development.

	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007
Monitoring protocols										
Air Quality										
Develop data acquisition and analysis methods										
Finalize protocol										
Data collection										
Climate - Broad-scale										
Develop data acquisition and analysis methods										
Finalize protocol										
Data collection										
Climate - fine scale										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										
Channel Morphology										
Protocol development										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										
Soil Stability and Compaction										
Protocol development										
Test methods in pilot study										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										
Soil Cover and Biological Soil Crusts										
Protocol development										
Test methods in pilot study										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										

Table 9.1. continued.

	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007
Monitoring protocols										
Water Quantity										
Protocol development										
Test methods in pilot study	■	■								
Draft protocol	■	■								
Field test protocol		■								
Revise and finalize protocol		■								
Protocol peer review		■								
Begin operational monitoring		■	■	■	■	■	■	■	■	■
Water Quality										
Protocol development										
Draft protocol	■									
Field test protocol	■									
Revise and finalize protocol		■								
Protocol peer review		■								
Begin operational monitoring			■	■	■	■	■	■	■	■
Aquatic macroinvertebrates										
Protocol development										
Draft protocol	■	■								
Field test protocol			■							
Revise and finalize protocol			■							
Protocol peer review				■						
Begin operational monitoring							■			
Vegetation Community Structure										
Protocol development										
Draft protocol	■	■								
Field test protocol			■	■						
Revise and finalize protocol					■					
Protocol peer review						■				
Begin operational monitoring							■	■	■	
Vegetation Life Form Abundance										
Protocol development										
Test methods in pilot study		■	■							
Draft protocol			■	■						
Field test protocol				■	■					
Revise and finalize protocol					■					
Protocol peer review						■				
Begin operational monitoring							■	■	■	

Table 9.1. continued.

	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007
Monitoring protocols										
Phenology of Key Plant Species										
Protocol development										
Data mining, research	■									
Test methods in pilot study		■	■							
Draft protocol				■						
Field test protocol				■	■					
Revise and finalize protocol					■					
Protocol peer review					■					
Begin operational monitoring						■	■	■	■	■
Exotic Plants- Early Detection										
Protocol development										
Test methods in pilot study		■	■							
Draft protocol		■	■							
Field test protocol			■	■						
Revise and finalize protocol				■						
Protocol peer review					■					
Begin operational monitoring							■	■	■	
Fish Community Dynamics										
Protocol development										
Test methods in pilot study			■							
Draft protocol				■	■					
Field test protocol					■					
Revise and finalize protocol						■				
Protocol peer review							■			
Begin operational monitoring							■	■	■	
Bird Community Dynamics										
Protocol development										
Draft protocol	■									
Revise and finalize protocol		■								
Protocol peer review		■								
Begin operational monitoring			■	■			■	■		
Illegal Roads and Trails										
Protocol development										
Draft protocol	■	■								
Field test protocol			■		■					
Revise and finalize protocol					■					
Protocol peer review					■					
Begin operational monitoring					■					

Table 9.1. continued.

	Fall 2005	Winter 2005	Spring 2006	Summer 2006	Fall 2006	Winter 2006	Spring 2007	Summer 2007	Fall 2007	Winter 2007
Monitoring protocols										
Visitor Use										
Protocol development										
Test methods in pilot study										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										
Visitor Use Impacts										
Protocol development										
Test methods in pilot study										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										
Landscape Dynamics										
Protocol development										
Test methods in pilot study										
Draft protocol										
Field test protocol										
Revise and finalize protocol										
Protocol peer review										
Begin operational monitoring										

Table 9.2. Timing of sampling for SODN monitoring protocols.

Protocol	January	February	March	April	May	June	July	August	September	October	November	December
Air Quality	X	X	X	X	X	X	X	X	X	X	X	X
Climate	X	X	X	X	X	X	X	X	X	X	X	X
Channel Morphology			X	X	X					X	X	
Biological Soil Crusts & Soil Cover			X	X	X			X	X			
Soil Stability & Soil Compaction					X	X						
Hydrology – Groundwater		X			X			X			X	
Hydrology – Surface Water		X			X			X			X	
Water Quality		X			X			X			X	
Early Detection of Exotic Plants			X	X	X			X	X			
Phenology of Key Plant Species		X	X	X	X	X	X	X	X	X		
Vegetation Life Form Abundance			X	X	X			X	X			
Vegetation Community Structure					X	X						
Bird Community Dynamics		X	X	X	X	X	X	X				
Fish Community Dynamics			X	X								
Aquatic Macroinvertebrates			X	X								
Visitor Use	X	X	X	X	X	X	X	X	X	X	X	X
Visitor Use Impacts					X	X		X	X			
Illegal Roads and Trails									X	X		
Landscape Dynamics		X	X						X	X		

CHAPTER 10: BUDGET

This chapter presents the budget for the SODN vital signs monitoring program during the first year of operational monitoring (FY2006) and projects fixed costs five years out (FY2010). The SODN receives $670,000 from the NPS Servicewide Inventory and Monitoring Vital Signs program and $64,000 from the NPS Water Resources Division annually. The funds comprise the "base funds" for the monitoring program and form the foundation for long-term planning and commitment of funds for operational monitoring. In addition to these base funds, SODN has successfully competed for internal (NPS) and external funds to augment basic monitoring operations. These competitive funds are uncertain; therefore, they are not included in the budget projections presented in this chapter.

10.1. Annual Budget and Workplan Process

An annual budget detailing anticipated expenditures is generated at the start of each fiscal year by the SODN Program Manager, within the guidelines set forth by the Natural Resource Challenge legislation, service-wide I&M guidance, and NPS budget office. This proposed budget is linked to specific inventory and monitoring activities in the Annual Administrative Report and Workplan. The SODN staff and Technical Committee provide input on budget issues, and the SODN Board of Directors and IMR Regional Program Manager review and approve the draft budget documents. The service-wide I&M program (vital signs and water resources) retains final approval authority for the SODN budget.

10.2. SODN FY2006 Budget Summary

Table 10.1 provides a brief summary of the anticipated FY2006 SODN budget. The Servicewide I&M guidance recommends that at least 30% of the vital signs budget be allocated to data management to ensure that monitoring information persists and is accessible to the diverse audiences and end-users of vital signs products. As illustrated in Table 10.1, approximately 36% of the FY06 SODN budget is designated for data management.

10.3. Long-term SODN Budget Projections

As vital signs networks are intended to provide ongoing, long-term ecological monitoring of NPS units, it is incumbent that each network considers long-term budget commitments when designing the monitoring program. Table 10.2 projects fixed personnel, administrative, and operations costs for "bare bones" operational monitoring of the 25 high-priority SODN vital signs from FY06-FY10. Inflation, budget allocation, and personnel costs are based on current NPS fiscal planning guidelines, with the goal of keeping total fixed costs below 80% of the anticipated budget. Note that these projections are based on the most rudimentary level of operations for attaining SODN monitoring objectives.

TABLE 10.1. Anticipated FY2006 budget for the Sonoran Desert Network.

EXPENSE CATEGORY		AMOUNT	% DATA MANAGEMENT	AMOUNT FOR DATA MANAGEMENT
Income				
	Vital Signs Monitoring	$670,000		
	Water Quality Monitoring	$64,000		
Personnel (57%)				
	Program Manager (GS-13)	$101,747	20%	$20,349
	Ecologist (GS-12)	$86,411	30%	$25,923
	Data Manager (GS-11)	$79,898	100%	$79,898
	Data Technician (GS-5/6/7)	$42,232	100%	$42,232
	Physical Science Technician (GS-5/6/7)	$54,305	40%	$21,722
	Biological Science Technician (GS-5/6/7)	$54,305	40%	$21,722
	Subtotal	$418,898		$211,847
Cooperative Agreements (31%)				
	SODN/Sonoran Institute Joint Internship Program	$143,780	30%	$43,134
	Office lease (1 year extension)	$49,797		
	Landbird monitoring	$35,000	20%	$7,000
	Subtotal	$228,577		$50,134
Contracts (1%)				
	Laboratory Analysis - water chemistry	$6,700		
	Laboratory Analysis - aquatic macroinvertebrates	$4,250		
	Subtotal	$10,950		
Operations/ Equipment (7%)				
	Field Equipment and Supplies	$19,275		
	Vehicle costs	$12,547		
	Office and lab supplies	$3,000		
	Utilities, Telephones	$14,153		
	Subtotal	$48,975		
Travel (2%)				
	I&M-related travel (park and network staff)	$13,000		
	Subtotal	$13,000		
Other (2%)	Assessments and administrative support (SOAR, IMRO, WASO)	$13,600		
	Subtotal	$13,600		

Table 10.2.
Budget projection for the Sonoran Desert Network.

	Item	FY06	FY07	FY08	FY09	FY10
Personnel[1]	Program Manager	$101,747	$105,116	$108,485	$111,853	$115,221
	Ecologist	$86,411	$89,243	$92,076	$94,909	$97,742
	Data Manager	$79,898	$82,262	$84,625	$86,989	$89,353
	Data Technician	$42,232	$46,956	$49,194	$50,791	$52,388
	Physical Science Technician	$54,305	$55,903	$57,500	$59,097	$60,695
	Biological Science Technician	$54,305	$55,903	$57,500	$59,097	$60,695
"Bare Bones" Fixed Costs[2]	Lease	$49,797	$51,142	$52,523	$53,941	$55,397
	Utilities	$11,260	$11,564	$11,876	$12,197	$12,526
	Vehicles	$12,547	$12,886	$13,234	$13,591	$13,958
	Base Travel (Parks)	$5,316	$5,459	$5,607	$5,758	$5,914
	Req'd Equip. & Supplies	$18,319	$18,813	$19,321	$19,843	$20,379
	Total:	$516,136	$535,247	$551,939	$568,064	$584,268
	VS Budget[3]:	$736,936	$739,884	$742,843	$745,815	$748,798
	Proportion of Basic Fixed Costs to Budget:	70%	72%	74%	76%	78%

[1] based on: scheduled grade/step increases; 3%/yr COLA; 35% benefit rate; 3.5% benefit/yr benefit growth rate
[2] includes 2.7%/yr inflation
[3] includes 0.4% base increase/yr

CHAPTER 11: LITERATURE CITED

Aber, J.D. and J.M. Melillo. 1991. Terrestrial Ecosystems. Saunders College Publishing, Philadelphia, PA.

Arizona Department of Environmental Quality. 2001. Draft Quality Assurance Program Plan for the Surface Water Monitoring and Standards Unit. Arizona Department of Environmental Quality. Water Quality Division.

Aguiar, M. R. and O. E. Sala. 1999. Trends in Ecology and Evolution **14**:273–277.

Archer, S. 1995. Herbivore mediation of grass-woody plant interactions. Tropical Grasslands **29**: 218-235.

Archer, S. 1989. Have southern Texas savannas been converted to woodlands in recent history? The American Naturalist **134**:545-561.

Asner, G. P., S. Archer, R. F. Hughes, R. J. Ansley, and C.A. Wessman. 2003. Net changes in regional woody vegetation cover and carbon storage in Texas drylands, 1937-1999. Global Change Biology **9**:316-335.

Bahre, C. J. 1991. A legacy of change: Historic human impacts on vegetation in the Arizona borderlands. University of Arizona Press, Tucson, AZ.

Bailey, R. G. 1998. Ecoregions: The ecosystem geography of the oceans and continents. Springer-Verlag Inc., New York, NY.

Baldys, S. III. 1990. Trend analysis of selected water-quality constituents in the Verde River Basin, central Arizona. US Geological Survey, Tucson, AZ. Water Resources Investigations Report 90-4128.

Barrett, J. P. and L. Goldsmith. 1976. When is N sufficiently large? The American Statistician **30**:67-7.

Barrett, W.G., G.M. VanDyne, and E.P. Odum. 1976. Stress ecology. Bioscience **26**:192-194.

Belnap, J., R. Rosentreter, S. Leonard, J. H. Kaltenecker, J. Williams, and D. Elderidge. 2001. Biological soil crusts: Ecology and management. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Information and Communications Group, Denver, CO. Technical Reference 1730-2. U.S.

Bowden, C. 1977. Killing the hidden waters. University of Texas Press, Austin, TX.

Brown, D. E. and C. H. Lowe. 1980. Biotic communities of the southwest. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA. U.S. Forest Service General Report RM-78.

Brunt, J. W. 2000. Data management principles, implementation, and administration. Pages 25-47 *in* K. W. Michener and J.W. Brunt, editors. Ecological data: design, management and processing. Blackwell Science, Inc. Malden, MA.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Drake, D.L. Borchers, and L. Thomas. 2001. Distance sampling. Oxford University Press, Oxford, UK.

Busch, D. E. and J. C. Trexler. 2003. The importance of monitoring in regional ecosystem initiatives. Pages 1-23 *in* D.E. Busch and J.C. Trexler, editors. Monitoring ecosystems. Island Press, Washington, D.C.

Chapin, F. S. III, P. A. Matson, and H. A. Mooney. 2002. Principles of terrestrial ecosystem ecology. Springer, NY.

Chapin, F. S., III, M. S. Tom, and M. Tateno. 1996. Principles of ecosystem sustainability. The American Naturalist **148**:1016-1035.

Chappelka, A., G. Somers, and J. Renfro. 1999. Visible ozone injury on forest trees in Great Smoky Mountains National Park, USA. Water, Air, and Soil Pollution **116**: 255-260.

Crance, J. H. 1987. Guidelines for Using the Delphi Technique to Develop Habitat Suitability Index Curves. Biological Report 82(10.134). National Ecology Center, Division of Wildlife and Contaminant Research, Fish and Wildlife Service, U.S. Department of the Interior, Washington, DC.

Croze, H. 1982. Monitoring within and outside protected areas. In J.A. McNeely and K.R. Miller, eds. National Parks, Conservation and Development: The Role of Protected Areas in Sustaining Society. Proceedings of the World Congress on National Parks. Bali, Indonesia. Smithsonian Institution Press, Washington DC. 11-22 Oct, 1982: 628-633.

Dale, V. H. and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators **1**:3-10.

D'Antonio, C. M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics **23**:63-87.

Davis, G. E. 1989. Design of a long-term ecological monitoring program for Channel Islands National Park, California. Natural Areas Journal **9**:80-89.

Davis K. and W. L. Halvorson. 2000. A study plan to inventory vascular plants and vertebrates: Sonoran Desert Network, National Park Service. Final Report, National Park. Service, Cooperative Agreement.

Dimmitt, M. A. 2000. Biomes and communities of the Sonoran Desert region. Pages 3-18 *in* S. J. Phillips and P. W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

Diroll, M. and D. Marsh. DRAFT – 2004. The status of Water Quality in Arizona. Arizona's 2004 Integrated 305(b) Assessment and 303(d) Listing Report. Arizona Department of Environmental Quality, Phoenix, AZ.

Durgin, P. B. 1980. Organic matter content of soil after logging of fir and redwood forests. Pacific Southwest Forest and range Experimental Station, U.S. Forest Service, U.S. Department of Agriculture, Berkeley, CA. Research Note PSW-348.

Elzinga, C. L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Bureau of Land Management, Denver, Colorado. BLM Technical Reference 1730-1.

Emmanuel, W. R., H. H. Shugart, and M. P. Stevenson. 1985. Climate change and the broad-scale distribution of terrestrial ecosystem complexes. Climate Change **7**:29-43.

Epple, A. O. 1995. A Field Guide to the Plants of Arizona. The Globe Pequot Press, Guilford, CT.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wegner. 1995. Effect of road traffic on amphibian density. Biological Conservation **73**:177–182.

Forman, R. T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics **29**: 207–231.

General Accounting Office. National Park Service: Activities outside park borders have caused damage to resources and will likely cause more. GAO/RCED-94-59, January 1994.

Halvorson, C. H. 1984. Long-term monitoring of small vertebrates: a review with suggestions. Pages 11-25 *in* J. L. Johnson, J. F. Franklin, and R.G. Krebill, coordinators. Research Natural Areas: Baseline Monitoring and Management. Proceedings of a Symposium, Missoula, MT, March 21, 1984. USFS General Technical Report IINT 173. Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah. 84 pp.

Harris, S. L. 1990. Agents of Chaos. Mountain Press Publishing Co., Missoula, MT.

Hobbs, R. J. and H. A. Mooney. 1986. Community changes following shrub invasion of grassland. Oecologia **70**:508-513.

Holling, C. S. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, New York, NY.

Ingram, M. 2000. Desert storms. Pages 41-50 *in* S. J. Phillips and P. W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

International Panel on Climate Change. 2001. Climate Change 2001: Summary for Policymakers. A Report of Working Group I of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Jenkins, K., A. Woodward, and E. Schreiner. 2002. A framework for long-term ecological monitoring in Olympic National Park: Prototype for the coniferous forest biome. U.S. Geological Survey, Olympic Field Station. Port Angeles, WA.

Johnson, W. C. and S. P. Bratton. 1978. Biological monitoring in UNESCO biosphere reserves with special reference to the Great Smoky Mountains National Park. Biological Conservation **13**:105-115.

Jones, K. B. 1986. The inventory and monitoring process. Pages 1-9 *in* A.Y. Cooperrider, R. J. Boyd, and H. R. Steward, editors. Inventory and Monitoring of Wildlife Habitat. USDI Bureau of Land Management. Service Center, Colorado.

Jones, D., and M. Kunze. 2004. Guide to sampling soil compaction using hand-held soil penetrometers. Center for Management of Military Lands, Colorado State University, Fort Collins, CO. CEMML TPS 04-1.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yany, and I.J. Schlosser. 1986. Assessment of biological integrity in running water: a method and its rationale. Illinois Natural History Survey Special Publication 5. 28 p.

Kaufmann, P.R., P. Levine, E.G. Robinson, C. Seegliger, and D.V. Peck. 1999. Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington, D.C.

Kurtz, J., L. Jackson, and W. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators **1**:49-60.

Lambeck, R.J. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology **11**: 849-856.

Lawson, Lin. 1995. Upper Santa Cruz River intensive survey; A volunteer driven study of the water quality and biology of an effluent dominated desert grassland stream in Southeast Arizona. Arizona Department of Environmental Quality, Phoenix, AZ. OFR 95-5.

Lohr, S.L. 1999. Sampling: design and analysis. Duxbury Press, NY.

MacMahon, J. A. 1985. Deserts. Alfred A. Knopf, Inc, New York, NY.

Marshall, J. T. 1957. Birds of the Pine-Oak Woodland in Southern Arizona and Adjacent Mexico. Cooper Ornithological Society, Berkeley, CA.

Marshall, R. M., S. Anderson, M. Batcher, P. Comer, S. Cornelius, R. Cox, Gondor, D. Gori, J. Humke, R. Paredes Aguilar, I.E. Parra, and S. Schwartz. 2000. An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion. Joint publication of The Nature Conservancy-Arizona Chapter, Sonoran Institute, and el Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora. Tucson, AZ.

Martin, P.S. 1999. Deep history and a wilder West. Pages 255-290 *in* R. H. Robichaux, editor. Ecology of Sonoran Desert plants and plant communities. University of Arizona Press, Tucson, AZ.

Mau-Crimmins, T., J.A. Hubbard, and G.R. McPherson. 2004. Nonnative plant mapping and prioritization at Montezuma Castle and Tuzigoot National Monuments. Sonoran Desert Network, Tucson, AZ.

McDonald, T. 2003. Environmental trend detection: a review. Environmental Monitoring and Assessment **85**:277-292.

McDonald, T. 2004. Draft Ecological Survey Recommendations for the Buffalo National River and Ozark National Scenic Riverways Parks. West, Inc. Cheyenne, WY.

McDonald, T. and P. Geissler. 2004. Systematic and stratified sampling designs in long-term ecological monitoring studies. Online: http://science.nature.nps.gov/im/monitor/SamplingDesign.htm.

McGarigal, K., W. H. Romme, M. Crist, and E. Roworth. 2001. Cumulative effects of roads and logging on landscape structure in the San Juan Mountains, Colorado (USA). Landscape Ecology **16**:327-349.

McLaughlin, S. P., and J. L. Bowers. 1999. Diversity and affinities of the flora of the Sonoran Floristic Province. Pages 12-35 *in* R. H. Robichaux, editor. Ecology of Sonoran Desert plants and plant communities. University of Arizona Press, Tucson, AZ.

McPhee, J. 1990. Basin and Range. Noonday Press, New York, NY.

McPherson, G. R. 1993. Effects of herbivory and herb interference on oak establishment in a semi-arid temperate savanna. Journal of Vegetation Science **4**:687-692.

McPherson, G.R. 1997. Ecology and management of North American savannas. University of Arizona Press, Tucson, AZ.

McPherson, G. R. and S. DeStephano. 2003. Applied ecology and natural resource management. Cambridge University Press, Cambridge, UK.

Moore, Carl M. 1994. Group techniques for idea building. Applied social research methods series, vol. 9. Sage Publications, Thousand Oaks, CA.

Nabhan, G. P. 2000. Biodiversity: The variety of life that sustains our own. Pages 119-126 *in* S. J. Phillips and P. W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

Nabhan, G. P., and A. R. Holdsworth. 1998. State of the Sonoran Desert Biome:

Biodiversity, Threats and the Adequacy of Protection in the Sonoran Bioregion. The

Wildland Project, Tucson, AZ.

Nabhan, G. P., and M. Klett. 1994. Desert Legends: Re-Storying the Sonoran

Borderlands. Henry Holt & Co.

National Assessment Synthesis Team. 2001. Climate change impacts on the United States: The potential consequences of climate variability and change: Overview. U. S. Global Change Research Program. Cambridge University Press, Cambridge, UK.

National Park Service, Department of the Interior, September 1997. VERP: The Visitor Experience and Resource Protection (VERP) Framework, A handbook for planners and managers. Denver Service Center, Denver, CO.

National Park Service, Department of the Interior, 2001. Management Policies. Denver Service Center, Denver, CO.

National Park Service, Department of the Interior, 2003. Statistical Abstract 2003. Public Use Statistics Office, Social Science Program, Denver, CO.

Nations, D., and E. Stump. 1983. Geology of Arizona. Kendall/Hunt Publishing Co., Dubuque, IA.

Neilson, R. P. 1986. High-resolution climatic analysis and southwest biogeography. Science **232**: 27-34.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. Pages 73-100 *in* D.E. Busch and J.C. Trexler, editors. Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, D.C.

Norse, E., K. Rosenbaum, D. Wilcove, B. Wilcox, W.H. Romme, D. Johnson, and M. Stout. 1986. Conserving Biological Diversity in our National Forests. The Wilderness Society, Washington, D.C.

Oakley, K.L., L.P. Thomas, and S.G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin **31**:1000-1003.

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, J. F. Lamoreux, T. H. Ricketts, I. Itoua, W. W. Wettengel, Y. Kura, P. Hedao, and K. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience **51**:933-938.

Organ Pipe Cactus National Monument. 1999. Ecological monitoring program annual report 1996. Organ Pipe Cactus National Monument, Arizona.

Phillips, S.J. and P.W. Comus. 2000. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 1999. Environmental and Economic Costs Associated with Non-indigenous species in the United States. Available on-line: http://www.news.cornell.edu/releases/Jan99/species_costs.html (Accessed August 2004).

Quinn, J.F. and C. van Riper. 1990. Design considerations for national park inventory databases. Pp 5-14 in C. van Riper III, T. J. Stohlgren, S. D. Veirs, Jr., and S. C. Hillyer, eds. Examples of Resource Inventory and Monitoring in National Parks of California. Proceedings of the Third Biennial Conference on Research in California's National Parks, September 13-15, 1990. University of California, Davis, CA. 268 pp.

Rabalais, N. N. 2002. Nitrogen in aquatic ecosystems. Ambio **31**:102-112.

Reisner, M. 1986. Cadillac desert: The American West and its disappearing water. Penguin Books. New York, NY.

Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor **82**:309-313.

Riiters, K. H. and J. D. Wickham. 2003. How far is the nearest road? Frontiers in Ecology and the Environment **1**:125-129.

Roman, C.T. and N. E. Barrett. 1999. Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center, Cooperative National Park Studies Unit, Narragansett, RI.

Rosgen, D.L. 1994. A classification of natural rivers. Catena **22**:179.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Scarborough, Robert. 2000. Geologic Origin of the Sonoran Desert. Pages 71-85 *in* Phillips, S.J. and P.W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonoran Desert Museum. Tucson, AZ.

Schnase, J. L., J. A. Smith, T. J. Stohlgren, S. Graves, and C. Trees. 2002. Biological invasions: A challenge in ecological forecasting. IEEE International Geoscience and Remote Sensing Symposium, 24th Canadian Symposium. 122-124.

Scholes, R.J. and B.H. Walker. 1993. An African Savanna: synthesis of the Nylsvley study. Cambridge University Press, Cambridge, UK.

Sellers, W. D., R. H. Hill, and M. Sanderson-Rae. 1985. Arizona climate: The first hundred years. University of Arizona Press, Tucson, AZ.

Sheridan, T. 1995. Arizona: A history. University of Arizona Press, Tucson, AZ.

Sheridan, T. 2000. Human ecology of the Sonoran Desert. Pages 105-118 *in* S. J. Phillips and P. W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the U.S. Southwest. Climate Research **21**:219-238.

Shreve, F., and I. L. Wiggins. 1951. The Vegetation of the Sonoran Desert. Carnegie Institute, Washington, D.C.

Sonoran Institute. 2004. Creating a Regional Framework for Ecological Monitoring in the Sonoran Desert. Sonoran Institute, Tucson, AZ.

Spellerberg, I.F. 1991. Monitoring ecological change. Cambridge University Press, Cambridge, UK.

Spellerberg, I.F. 1998. Ecological effects of roads and traffic: A literature review. Global Ecology and Biogeography **7**:317-333.

Sprouse, T.W., R.M. Emanuel, and S.A. Storrer. 2004. Water Quality Monitoring Program for High-Priority Water Bodies in the Sonoran Desert Network.

Stevens, Jr., D.L. 1994. Implementation of a national monitoring program. Journal of Environmental Management **42**:1-29.

Stevens, D.L. and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association **99**:262-278.

Suter, G.W., II. 1993. A critique of ecosystem health concepts and indexes. Environmental Toxicology and Chemistry **12**:1533-1539.

Swetnam, T.W. and C. H. Baisan, 1996. Historical fire regime patterns in the Southwestern United States since AD 1700. Proceedings of the Second La Mesa Fire Symposium, Los Alamos, NM, USDA Forest Service General Tech. Rep. RM-GTR286:11-32.

Swetnam, T. W., J. L. Betancourt. 1990. Fire-Southern Oscillation relations in the southwestern United States. Science **249**:1017-1020.

Swetnam, T. W., J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate **11**:3128-3147.
Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications **9**:1189-1206.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: A search for general principles. Ecology **80**:1455-1474.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology **14**:18-30.

Van Devander, T.R. 2000. The deep history of the Sonoran Desert. Pages 61-70 *in* S. J. Phillips and P. W. Comus, editors. A natural history of the Sonoran Desert. Arizona-Sonora Desert Museum Press, Tucson, AZ.

Walters, C.J. 1986. Adaptive management of renewable natural resources. MacMillan, New York, NY.

Warshall, P. 1994. The biopolitics of the Mt. Graham Red Squirrel (*Tamiasciuris hudsonicus grahamensis*). Conservation Biology **8**:977-988.

West, R. 1949. The mining community in northern New Spain: The Parral mining district. University of California Press, Berkeley, CA.

West, N.E. 1992. Shrubs: adaptations and ecosystem functions. Pages 175-181 *in* W.A. Nierenberg, editor. Encyclopedia of earth system science, Academic Press, Orlando, FL.

White, P. S. and S. P. Bratton. 1980. After preservation: the philosophical and practical problems of change. Biological Conservation **18**:241-255.

White, P.S., and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. Pages 3-13 *in* S.T.A. Pickett and P.S. White, editors. The ecology of natural disturbance and patch dynamics. Academic Press, New York, NY.

Wicklum, D. and R.W. Davies. 1995. Ecosystem health and integrity? Canadian Journal of Botany **73**:997-1000.

Wiersma, G.B. 1984. Integrated global background monitoring network. Presented at Symposium: Research and monitoring in circumpolar biosphere reserves. Waterton Biosphere Reserve, Waterton Lakes, Alberta, Canada. August 27-31.

Williams, D.G. and Z. Baruch. 2000. African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biological Invasions **2**:123-140.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. *In* J. Kay and G. Francis, editors. Ecological integrity and the management of ecosystems, St. Lucie Press, Delray Beach, FL.

Woodward, A., K. J. Jenkins, and E.G. Schreiner. 1999. The role of ecological theory in long-term ecological monitoring: Report on a workshop. Natural Areas Journal **19**:223-233.

LIST OF ACRONYMS

AARWP – Annual Administrative Report and Work Plan
ADEQ – Arizona Department of Environmental Quality
ARS – Agricultural Research Service (United States Department of Agriculture)
ASCII - American Standard Code for Information Interchange
ASDM – Arizona – Sonora Desert Museum
ASU – Arizona State University
BLM – Bureau of Land Management
BoD – Board of Directors
CAGR – Casa Grande Ruins National Monument
CASTNet – Clean Air Status and Trends Network
CHIR – Chiricahua National Monument
CNF – Coronado National Forest
CORO – Coronado National Memorial
CSU – Colorado State University
DMP – Data Management Plan
DSCESU – Desert Southwest Cooperative Ecosystem Studies Unit
EMP – Ecological Monitoring Program
EPA – Environmental Protection Agency
ERD – Entity Relationship Diagram
FGDC – Federal Geographic Data Committee
FIREPRO – Fire Management Program
FMP – Fire Management Plan
FOBO – Fort Bowie National Historic Site
FOIA – Freedom of Information Act
GAO – Government Accounting Office
GICL – Gila Cliff Dwellings National Monument
GIS – Geographic Information System
GMP – General Management Plan
GPRA – Government Performance Results Act
GPS – Global Positioning System
IMADES – Instituto del Medio Ambiente y et Desarrollo Sustentable del estado de Sonora (State of Sonora)
IMPROVE – Interagency Monitoring of Protected Visual Environments
IMR – Intermountain Region
IMRICO – Intermountain Region International Conservation Program Office
LTER – Long Term Ecological Research Site (National Science Foundation)
MOCA – Montezuma Castle National Monument
MOU – Memorandum of Understanding
NADP/NTN – National Atmospheric Deposition Program/National Trends Network

NAST - National Assessment Synthesis Team
NBII – National Biological Information Infrastructure
NGO – Non-Governmental Organization
NIFC – National Interagency Fire Center
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
NRC - National Research Council
NRPC – Natural Resource Program Center
OALS – Office of Arid Lands Studies (University of Arizona)
ORPI – Organ Pipe Cactus National Monument
QA/QC – Quality Assurance/Quality Control
RAWS – Remote Automated Weather Station
RMP – Resource Management Plan
SAGU – Saguaro National Park
SAPs – Southern Arizona Parks
SCC – Servicewide Combined Call
SDCP – The Sonoran Desert Conservation Plan (Pima County, Arizona)
SDFS – Sonoran Desert Field Station (United States Geological Survey)
SEMARNAP – Secretaria del Medio Ambiente, Recursos Naturales y Pesca (Mexico)
SI – The Sonoran Institute
SOAR – Southern Arizona Office (National Park Service)
SODN – Sonoran Desert Network
SOPs – Standard Operating Procedures
SRNR – School of Renewable Natural Resources (University of Arizona)
STORET – STORage and RETrieval
TC – Technical Committee
TNC – The Nature Conservancy
TONT – Tonto National Monument
TUMA – Tumacacori National Historical Park
TUZI – Tuzigoot National Monument
UA – The University of Arizona
USGS – United States Geological Survey
USFS – United States Forest Service
WRRC – Water Resources Research Center (University of Arizona)

GLOSSARY OF TERMS USED BY THE NPS INVENTORY AND MONITORING PROGRAM

Adaptive Management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form-"active" adaptive management-employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Attributes are 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 2002). See Indicator.

Ecological integrity is 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.

Ecosystem is defined as, "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).

Ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large scale influences on natural systems.

Ecosystem management is 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.

Focal resources are 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.

Indicators are 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 2002). 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.

Measures are the specific feature(s) used to quantify an indicator, as specified in a sampling protocol.

Stressors are 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.

Vital Signs, as used by the National Park Service, 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. 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).

National Park Service
U.S. Department of the Interior

Intermountain Region
Sonoran Desert Network
Inventory & Monitoring Program
7660 E. Broadway Blvd., Ste. 303
Tucson, AZ 85710

www.nature.nps.gov/im/units/sodn/