National Park Service - Southern Plains Network
Inventory and Monitoring Program

# Southern Plains Network Vital Signs Monitoring Plan: Phase I Appendices

**Dustin Perkins, Heidi Sosinski, Karie Cherwin, and Tomye Zettner.**

**With contributions from Sue Braumiller, Todd Swannack, and Dan Tinker**

**October 1, 2005**

APPENDICES TABLE OF CONTENTS

Table of Contents ..... A-2
Appendix A. Glossary of Terms Used by the Inventory and Monitoring Program..... A-3
Appendix B. Summary of federal legislation and policy related to Inventory and Monitoring ..... A-5
Appendix C. Summary of GPRA goals from each SOPN park that may pertain to activities planned or in progress by SOPN..... A-10
Appendix D. Definitions of National Park Service Designations. ..... A-11
Appendix E. Individual Park Natural Resource Summaries ..... A-13
Appendix F. Network and Park Maps ..... A-78
Appendix G. State and federally listed species and endemic species that are found (X) or potentially found (P) in Southern Plains Network Parks..... A-92
Appendix H. Exotic plants found in Southern Plains Network Parks with their applicable noxious weed designations ..... A-94
Appendix I. Exotic animals found in Southern Plains Network Parks ..... A-102
Appendix J. Southern Plains Network Charter ..... A-104
Appendix K. Southern Plains Network Water Resources Report..... A-124
Appendix L. Southern Plains Network Air Quality ..... A-162
Appendix M Scoping Summaries Interviews with Each SOPN Park..... A-235
Appendix N. SOPN GIS Datasets ..... A-278
Appendix O Natural resources and stressors derived from scoping sessions and ranked by park staff ..... A-288
Appendix P. Ecosystem Workshop Reports..... A-293
Appendix Q. Monitoring projects occurring within or in the vicinity of SOPN parks ..... A-361
Appendix R. Park Conceptual Diagrams ..... A-369
Appendix S. SOPN Grassland Conceptual Models..... A-380
Appendix T. SOPN Landscape Level Issues Facing the SOPN - Conceptual Models ..... A-398
Appendix U. Piñon-juniper forest ecosystems in the southern plains network: a description and conceptual model ..... A-414
Appendix V. SOPN Palustrine Wetlands Conceptual Models..... A-420
Appendix W. SOPN Riverine and Lacustrine Conceptual Models ..... A-433

## APPENDIX A. GLOSSARY OF TERMS USED BY THE INVENTORY AND MONITORING PROGRAM

TERMS

**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 2003). 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 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

**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).

## REFERENCES CITED


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

Likens, G. 1992. An ecosystem approach: its use and abuse. Excellence in ecology, book 3. Ecology Institute, Oldendorf/Luhe, Germany.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. In D.E. Busch and J.C. Trexler, editors. Monitoring Ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives. Island Press, Washington, D.C., USA.

## APPENDIX B. SUMMARY OF FEDERAL LEGISLATION AND POLICY RELATED TO INVENTORY AND MONITORING

| 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…" |
| **National Parks Omnibus Management Act, 1998 (P.L. 105-391)** | Requires Secretary of Interior to continually improve NPS' ability to provide stateof- the-art management, protection, and research on NPS resources. Section 5939 states that the purpose of legislation is to:<br>(1) 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;<br>(2) Ensure appropriate documentation of resource conditions in the National Park System;<br>(3) Encourage others to use the National Park System for study to the benefit of park management as well as broader scientific value; and<br>(4) Encourage the publication and dissemination of information derived from studies in the NPS. |
| **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. |
| **National Historic Preservation Act of 1966, as amended (16 USC 470 et seq.)** | Congress 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 established the National Register of Historic Places composed of places and objects 'significant in American history, architecture, archeology, engineering, and culture.' NHPA requires federal agencies to account for effects of actions on historic (state and federal) properties |
| **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 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 (some 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. 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 effects of any agency action that may affect endangered, threatened, or proposed species must be evaluated in consultation with either the USFWS (non-marine species) or the National Marine Fisheries Service (all marine species) as appropriate. |
| **Wilderness Act of 1964 (16 USC 1131 et seq.)** | Establishes the National Wilderness Preservation System. Wilderness Areas designated by Congress are made 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. |
| **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. |
| **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 all focused on measurable outcomes. |
| **American Indian Religious Freedom Act of 1978** | This Act ensures the freedom of Native Americans to practice the religion of their choosing, including the use of scared lands. "It shall be the policy of the United States to protect and preserve for American Indians their inherent right of freedom to believe, express, and exercise the traditional religions of the American Indian, Eskimo, Aleut, and Native Hawaiians, including but not limited to access to sites, use and possession of sacred objects, and the freedom to worship through ceremonials and traditional rites." |
| **Archaeological Resources Protection Act of 1979** | This Act protects archaeological resources found on public and Indian lands and ensures cooperation between government agencies with respect to these resources. "The purpose of this chapter is to secure, for the present and future benefit of the American people, the protection of archaeological |

| | |
|---|---|
| | resources and sites which are on public lands and Indian lands, and to foster increased cooperation and exchange of information between government authorities, the professional archaeological community, and private individuals having collections of archaeological resources and data..." |
| **Federal Water Pollution Control Act (Clean Water Act) of 1972** | This Act protects the biological, chemical, and physical nature of the Nation's waters through the elimination of pollutants and the creation of wastewater treatment plants. "It is the policy of the Congress to recognize, preserve, and protect the primary responsibilities and rights of States to prevent, reduce, and eliminate pollution, to plan the development and use (including restoration, preservation, and enhancement) of land and water resources..." |
| **Fish and Wildlife Coordination Act of 1958 and 1980** | "The FWCA, as amended, proposes to assure that fish and wildlife resources receive equal consideration with other values during the planning of water resources development projects. The Act was passed because the goals of water-related projects (e.g., flood control, irrigation, navigation, hydroelectric power) may conflict with the goal of conserving fish and wildlife resources. Conversely, developers can design water development projects to enhance the quality and enjoyment of fish and wildlife resources if such goals are incorporated into project plans." |
| **Migratory Bird Treaty Act of 1974** | This Act prohibits the hunting or collection of migratory bird species and is an agreement between the U.S. and the following countries: Canada, Mexico, Japan and Russia. "Establishment of a Federal prohibition, unless permitted by regulations, to "pursue, hunt, take, capture, kill, attempt to take, capture or kill, possess, offer for sale, sell, offer to purchase, purchase, deliver for shipment, ship, cause to be shipped, deliver for transportation, transport, cause to be transported, carry, or cause to be carried by any means whatever, receive for shipment, transportation or carriage, or export, at any time, or in any manner, any migratory bird, included in the terms of this Convention . . . for the protection of migratory birds . . . or any part, nest, or egg of any such bird." |
| **Mining in the Parks Act of 1976** | This Act regulates the operation of mining claims within the National Park System in order to protect landmarks and resources. "Congress finds: that continued application of U.S. mining laws to National Park System lands conflicts with the purposes for which they were established; all mining operations on National Park System lands should be conducted to prevent or minimize damage to the environment and other resource values; surface disturbance from mineral development should be halted temporarily in certain National Park System areas while Congress determines whether to acquire valid mineral rights in these areas." |
| **Taylor Grazing Act of 1934** | This Act manages grazing on public lands through the use of districts and permitting schedules. "The Secretary must: provide for the protection, administration, regulation and improvement of the grazing districts; adopt regulations and enter into cooperative agreements necessary to accomplish the purposes of the Act; regulate occupancy and use; preserve the land and resources from destruction or unnecessary injury; provide for orderly improvement and development of the range. The Secretary may continue the study of erosion and flood control and perform work to protect and rehabilitate areas subject to the Act." |
| **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. |
| **Surface Mining Control and** | The Surface Mining Control and Reclamation Act was enacted in 1977. It establishes a nationwide program to protect the environment from adverse |

| | |
|---|---|
| **Reclamation Act** | 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. |
| **Other Related Public Laws & Executive Orders** | Protection of Migratory Birds (Executive Order 13186);. and Invasive Species (Executive Orders 11987) |
| **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). |
| **Invasive** | This executive order was signed into law on February 3, 1999, to prevent the |

| | |
|---|---|
| **Species (Executive Order 13112)** | introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause. Among other things, 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. |
| **Protection of Migratory Birds (Executive Order 13186)** | This Order provides additional protection for migratory birds, such that Federal agencies should "design migratory bird habitat and population conservation principles, measures, and practices, into agency plans and planning processes (natural resource, land management, and environmental quality planning, including, but not limited to, forest and rangeland planning, coastal management planning, watershed planning, etc.) as practicable, and coordinate with other agencies and nonfederal partners in planning efforts." |
| **NPS POLICIES AND GUIDANCE** | **SIGNIFICANCE TO INVENTORY AND MONITORING** |
| **Management Policies – 2001 (NPS Directives System)** | This is the basic NPS service wide policy document. The Directives System is designed to provide NPS management and staffs 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 Directors Orders** | Directors Orders serve a vehicle to clarify or supplement *Management Policies* to meet the needs of NPS managers. Relevant Directors Orders:<br>DO-2.1 Resource Management Planning<br>DO-12 Environmental Impact Assessment<br>DO-14 Resource Damage Assessment & Restoration<br>DO-24 Museum Collections Management<br>DO-41 Wilderness Preservation & Management<br>DO-47 Sound Preservation & Noise Management<br>DO-77 Natural Resource Protection |
| **NPS Handbooks and Reference Manuals** | These documents are issued by Associate Directors and 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 service-wide requirements, unless the Director has specifically authorized them to do so. Relevant Handbooks and Reference Manuals:<br>NPS-75 Natural Resources Inventory & Monitoring<br>NPS-77 Natural Resources Management Guidelines<br>NPS Guide to Fed. Advisory Committee Act<br>Website: Monitoring Natural Resources in our National Parks, http://www.nature.nps.gov/im/monitor |

## APPENDIX C. SUMMARY OF GPRA GOALS FROM EACH SOPN PARK THAT MAY PERTAIN TO ACTIVITIES PLANNED OR IN PROGRESS BY SOPN

| GPRA Goal | Park Specific Activities | Parks with this Goal |
|---|---|---|
| Ia01A - Disturbed Lands Restored | Restore land disturbed by agriculture, floods, fire, and tamarisk removal | BEOL |
| | Restore lands disturbed by development or agriculture | CAVO, CHIC, LYJO |
| | Restore land disturbed by oil and gas activities | LAMR |
| | Restore lands disturbed by development and implement monitoring for plant regeneration and exotics | PECO |
| Ia01B – Disturbed Lands – Other | Restore area invaded by eastern red cedar and ashe juniper | CHIC |
| Ia01C - Wetlands | Inventory park wetlands and conditions identified | BEOL, CHIC, LYJO, PECO, SAND |
| Ia01D - Riparian | Inventory riparian areas and conditions identified | BEOL, CHIC, FOLS, LAMR, LYJO, SAND |
| Ia01E - Uplands | Assess condition of uplands and desired conditions identified | ALFL, BEOL, CHIC, FOLS, FOUN, LAMR, LYJO, PECO, SAND, WABA |
| | Maintain short-grass prairie | CAVO |
| Ia01G - Mined Lands | Restore disturbed lands | LAMR |
| Ia02B - Species of Concern | Bison herd in good condition | CHIC |
| | Native plant and animal species that are damaging resources are controlled | FOUN |
| Ia1B - Exotic Vegetation Contained | Control exotic plants | ALFL, BEOL, CAVO, CHIC, FOUN, LAMR, SAND, WABA |
| | Scotch thistle and other alien plants are controlled | PECO |
| Ia2A - T&E Listed Species | Stable population status | LAMR, LYJO, PECO |
| Ia2C - Invasive Animals | Remove fire ants, feral pigs, and feral cats | CHIC |
| | Animal and insect populations controlled | LYJO, WABA |
| | Feral dog population controlled | PECO |
| Ia3 - Air Quality | Improve or maintain air quality | CAVO |
| Ia4a - Surface Water Quality, Rivers and Streams | Meet water quality standards | BEOL, LYJO, PECO, SAND, WABA |
| | Monitor perennial streams for bacteria | CHIC |
| Ia4b – Water Quality, Reservoirs | Meet water quality standards | CHIC, LAMR, LYJO |
| Ia4c – Water Quantity | Protect water quantity conditions | CHIC |
| IVb1A - Park Partnerships | Work with Bureau of Reclamation on inventory project | BEOL |
| | Manage park resources | ALFL, CAVO, CHIC, FOLS, FOUN, LAMR, PECO |

## APPENDIX D. DEFINITIONS OF NATIONAL PARK SERVICE DESIGNATIONS.

SOPN PARK DESIGNATIONS

**National Monument**: The Antiquities Act of 1906 authorized the President to declare by public proclamation landmarks, structures, and other objects of historic or scientific interest situated on lands owned or controlled by the government to be national monuments. SOPN Monuments: Alibates Flint Quarries, Capulin Volcano and Fort Union.

**National Historic Site**: Usually, a national historic site contains a single historical feature that was directly associated with its subject. Derived from the Historic Sites Act of 1935, a number of historic sites were established by secretaries of the Interior, but most have been authorized by acts of Congress. SOPN Historic Sites: Bent's Old Fort, Fort Larned, Sand Creek Massacre, and Washita Battlefield.

**National Historical Park**: This designation generally applies to historic parks that extend beyond single properties or buildings. SOPN Historical Parks: Lyndon B. Johnson and Pecos.

**National Recreation Area**: Twelve NRAs in the system are centered on large reservoirs and emphasize water-based recreation. Five other NRAs are located near major population centers. Such urban parks combine scarce open spaces with the preservation of significant historic resources and important natural areas in location that can provide outdoor recreation for large numbers of people. SOPN Recreation Areas: Chickasaw and Lake Meredith.

OTHER PARK DESIGNATIONS

**National Park**: These are generally large natural places having a wide variety of attributes, at times including significant historic assets. Hunting, mining and consumptive activities are not authorized.

**National Preserve**: National preserves are areas having characteristics associated with national parks, but in which Congress has permitted continued public hunting, trapping, oil/gas exploration and extraction. Many existing national preserves, without sport hunting, would qualify for national park designation.

**National Memorial**: A national memorial is commemorative of a historic person or episode; it need not occupy a site historically connected with its subject.

**National Battlefield**: This general title includes national battlefield, national battlefield park, national battlefield site, and national military park. In 1958, an NPS committee recommended national battlefield as the single title for all such park lands.

**National Cemetery**: There are presently 14 national cemeteries in the National Park System, all of which are administered in conjunction with an associated unit and are not accounted for separately.

**National Seashore**: Ten national seashores have been established on the Atlantic, Gulf and Pacific coasts; some are developed and some relatively primitive. Hunting is allowed at many of these sites.

**National Lakeshore**: National lakeshores, all on the GreatLakes, closely parallel the seashores in character and use.

**National River**: There are several variations to this category: national river and recreation area, national scenic river, wild river, etc. The first was authorized in 1964 and others were established following passage of the Wild and Scenic Rivers Act of 1968.

**National Parkway**: The title parkway refers to a roadway and the parkland paralleling the roadway. All were intended for scenic motoring along a protected corridor and often connect cultural sites.

**National Trail**: National scenic trails and national historic trails are the titles given to these linear parklands (over 3,600 miles) authorized under the National Trails System Act of 1968.

**Affiliated Areas**: In an Act of August 18, 1970, the National Park System was defined in law as, "any area of land and water now or hereafter administered by the Secretary of the Interior through the National Park Service for park, monument, historic, parkway, recreational or other purposes." The Affiliated Areas comprise a variety of locations in the United States and Canada that preserve significant properties outside the National Park System. Some of these have been recognized by Acts of Congress, others have been designated national historic sites by the Secretary of the Interior under authority of the Historic Sites Act of 1935. All draw on technical or financial aid from the National Park Service.

**Other Designations**: Some units of the National Park System bear unique titles or combinations of titles, like the White House and Prince William Forest Park.

## APPENDIX E. INDIVIDUAL PARK NATURAL RESOURCE SUMMARIES

Tomye Zettner, Dusty Perkins, and Karie Cherwin

TABLE OF CONTENTS

E.1. Alibates Flint Quarries National Monument ..... A-14
E.2. Bent's Old Fort National Historic Site ..... A-19
E.3. Capulin Volcano National Monument ..... A-24
E.4. Chickasaw National Recreation Area ..... A-30
E.5. Fort Larned National Historic Site ..... A-37
E.6. Fort Union National Monument ..... A-43
E.7. Lake Meredith National Recreation Area ..... A-48
E.8. Lyndon B. Johnson National Historical Park ..... A-56
E.9. Pecos National Historical Park ..... A-62
E.10. Sand Creek Massacre National Historic Site ..... A-69
E.11. Washita Battlefield National Historic Site ..... A-73

## E. 1. ALIBATES FLINT QUARRIES NATIONAL MONUMENT (ALFL)

Alibates Flint Quarries National Monument (ALFL) is 1,371 acres (555 ha) in size, and is located adjacent to the boundaries of Lake Meredith National Recreation Area (LAMR), approximately 21 miles (34 km) North of Amarillo in the Panhandle of Texas. For thousands of years, people have come to these red bluffs above the Canadian River for Alibates Flint, distributing it through the Great Plains and beyond. The occurrence of extensive quarry pits at the Alibates Flint Quarries and caches of large, thin bifaces at the Alibates Ruin document the intensive prehistoric mining and manufacturing occurring during the Antelope Creek phase (A.D. 1200 – 1500). Numerous Panhandle Aspect village ruins and a series of petroglyphs are found within the national monument in association with the concentration of 734 flint quarry pits. ALFL was established in 1965 and is currently managed by the staff at Lake Meredith National Recreation Area. Public access at ALFL is only available by ranger-guided tours. There were 1,794 visitors in 2004.

### *E. 1.1. Resource Overview*

The land surface at ALFL is nearly flat and slopes to the southeast at approximately 8 to 10 feet (2.4 – 3 m) per mile. In the vicinity of Lake Meredith, this flat surface has been downcut by the Canadian River and its tributaries, causing canyons or "breaks", some of which are now filled by Lake Meredith. The Alibates Dolomite is Permian in age and contains an abundance of flint, which was used by some of the earliest humans to make tools and points. The flint can often be found in alternating beds of gray and red.

The Canadian River Basin climate is characterized as semi-arid with an average annual rainfall of 20 inches (51 cm) per year. Seventy percent of the precipitation falls between April and September, which is the primary growing season. This area has hot summers and cold winters with strong winds that work to increase evaporation rates, which have been estimated to average 60-65% of the total precipitation. Elevation is approximately 3,200 feet (975 m).

### *E.1.2 Enabling Legislation / Management Documents*

On August 21, 1965, by Public Law 89-154, Congress recognized the national significance of a unique segment of Lake Meredith Recreation Area by creating the Alibates Flint Quarries and Texas Panhandle Pueblo Culture National Monument, “to provide for the preservation and public use of a concentration of unique flint quarries, used as a source of raw materials for weapons and tools by High Plains prehistoric cultures spanning 12,000 years.” The mission is defined as “to preserve and present to the public in an acceptable manner the extensive flint quarries associated with prehistoric man and the ruins of several village sites of the Panhandle Aspect culture of the Plains Village Indians.” Congress amended the park’s enabling act on November 10, 1978, by Public Law 95-625, to redesignate the monument as the Alibates Flint Quarries National Monument. The original 91-acre (37 ha) monument area is listed in the National Register of Historic Places. There is no other archeological area in the National Park System has been used as long and as continuously by humans. Thus, the monument contributes significantly toward understanding Indian occupation in the Region that spanned over 12,000 years. The monument is important for providing an understanding of the techniques involved in making chipped-stone artifacts which is fundamental to the study of archeology and to understanding prehistoric cultures.

There has been no General Management Plan created for LAMR. The most recent Resource Management Plan was completed in 1996 (Lake Meredith National Recreation Area 1996). An oil and gas management plan was developed in 2002 (Lake Meredith National Recreation Area 2002).

*E.1.3. Natural Resources*

E.1.3.1. Valuable Resources / Species of Interest

The Texas horned lizard (*Phrynosoma cornutum*) and ferruginous hawk (*Buteo regalis*), listed by the States of Texas, have been documented as occurring at ALFL. Bald eagles (*Haliaeetus leucocephalus*) over winter at adjacent LAMR and likely uses ALFL for foraging. Bird surveys conducted at LAMR/ALFL detected scaled quail (*Callipepla squamata*), scissor-tailed flycatcher (*Tyrnanus forficatus*) and Cassin's sparrow *Amiophila cassinii*) (Patrikeev and Gallyoun 2004), all on the Partners In Flight watch list for the Pecos and Staked Plains region.

E.1.3.2. Geology / Soils

The Quartermaster Formation is the principal formation at ALFL and is divided into three members – the Cloud Chief Gypsum, Whitehorse Sandstone and the locally mapped Alibates Dolomite. The ledges and cliffs that dominate the area are capped by the resistant Alibates Dolomite. The Alibates Dolomite is comprised of two dolomite layers 12-15 feet thick separated by a shale layer. Locally, the lower dolomite is replaced by silica that has formed chert lenses called the Alibates Chert. The chert has been used for the last 12,000 years by Native Americans. Soil series include Burson-Quinlan-Aspermont, Mobeetie-Tascosa, and Acuff-Palo Duro-Olton. In areas with steeper slopes, the soils tend to be shallow (10 to 20 inches [25 to 50 cm]), well drained, calcareous, loamy to gravelly soils with variable amounts of rock fragments. These soils are also associated with rock outcrops in the park. Soils on steep slopes are highly susceptible to water erosion and moderately susceptible to wind erosion. On the flat areas there are areas of dunes and other sandy deposits.

E.1.3.3. Land Use

Alibates Flint Quarries National Monument is located within the Panhandle Field which covers about 1,475,000 acres (596,911 ha), of which approximately 1,000,000 acres (404,685 ha) produces sweet gas and about 400,000 acres (161,874 ha) produces sour gas with hydrogen sulfide. This field also produces around 250,000 acres (101,171 ha) of crude oil (Thompson 1939). In the vicinity of the parks, the oil and gas producing area is called the Panhandle West Field. The adjacent LAMR is popular for water recreation, hunting, fishing, horseback riding, using motorcycles and dune buggies in the off-road vehicle areas, and camping. Ranching, extractive activities and vacation development are the current primary land uses in the area surrounding LAMR.

E.1.3.4. Hydrology

ALFL is located in the Canadian River Basin, within the Lake Meredith watershed. Water from Lake Meredith may fill the breaks in the ALFL terrain during seasons experiencing heavy rainfall. Beyond these ephemeral water bodies, no surface waters fall within the ALFL boundaries. Soil erosion and groundwater conditions are among the largest hydrological concerns for ALFL park managers. Another water resource concern is irrigation, which supports local agriculture, in turn lowering the water table contributing to soil desiccation. Furthermore, agricultural practices, in addition to oil and gas operations, are introducing contaminants to the groundwater. ALFL was included in the study area of the basic water quality assessment for LAMR conducted by the Water Resource Division (WRD) of the NPS in 2000.

E.1.3.5. Air Quality

An air emissions inventory was completed in 2003 (National Park Service 2003). ALFL is designated as a Class II area under the Clean Air Act. Ambient (i.e., ground level) concentrations of sulfur dioxide, nitrogen oxides, ozone, and particulate matter are not routinely monitored but are presumed to be in compliance with the National Ambient Air Quality Standards. The only nearby ambient monitoring was conducted until 1996 in Amarillo, Texas for PM-10 (particles with an aerometric diameter of 10 microns or less). All monitored values indicated compliance with the PM-10 NAAQS standard (highest 24-hour measurement of 60 micrograms per cubic meter compared to the 150 ug/m3 standard). Ozone levels in the project area are unknown at this time. The potential addition of nitrates and volatile organic compounds, the primary precursors for

ozone formation, to those already present in the area from existing oil and gas-related activities and energy production, may justify monitoring ozone levels to track the cumulative impact of these activities on ambient ozone levels (Lake Meredith National Recreation Area 2002). There is currently only a low risk of foliar ozone damage. Exposure to 80 ppb ozone is infrequent, and exposure to 100 ppb rare (National Park Service 2005).

Although neither LAMR nor ALFL is subject to the visibility protection provisions that apply to Prevention of Significant Deterioration Class I areas, they do experience the widespread visible haze affecting this region of the country and would benefit from any future regional strategies to reduce visibility impairing pollution. Some of those pollutants are emitted in the vicinity of the parks by existing sources. For instance, about a dozen major sources in the three county area of Hutchinson, Moore, and Potter Counties contribute over 64,000 tons per year of $SO_2$, a pollutant that is transformed in the atmosphere to fine sulfate particles which have a dramatic effect on visibility impairment caused by scattering and absorption of light. It is likely that additional industrial activity associated with oil and gas production will contribute to fine particle formation. Based on extrapolation of visibility data collected over the period from 1988-1997 by the IMPROVE (Interagency Monitoring of Protected Visual Environments) visibility monitoring network, the visual range experienced on average in this area is from 30 to 60 miles (48 to 96 km) or probably about half the distance that would be visible under natural visibility conditions in the area (Lake Meredith National Recreation Area 2002).

E.1.3.6. Wildlife

There have been several inventory related research projects for vertebrates at LAMR and ALFL (Killebrew 1977, Phillips, 1989, Yancey et al. 1998, Patrikeev and Gallyoun 2004). Most of these inventories did not specifically state which park the species was recorded in. All species detected at LAMR with the exception of those associated with riparian areas are very likely to occur at ALFL.

- **Mammals:** There have been 60 species of mammals detected at ALFL and LAMR. Bats are probably the most under recorded group of mammals at LAMR. Patrikeev and Gallyoun (2004) detected only one species of bat and Yancey et al. (1998) did not find any. Surveys are difficult to conduct at the park due to consistent high winds that make captures with mist nets problematic. Future surveys with bat detectors or a harp trap may yield additional species. Two potentially occurring rare mammals animals the Townsend's big-eared bat (*Coryhorhinus townsendii*) and swift fox (*Vulpes velox*). Black-tailed prairie dog towns have been recorded from LAMR as recently as 2001, but there are no known towns documented from ALFL.
- **Birds:** In addition to 72 species of breeding birds detected by Patrikeev and Gallyoun (2004), an anonymous park bird lists 23 additional species as nesting or likely nesting in the park, but there is no evidence, or even an author, to substantiate the list. It has been speculated that the park may be a large-overwintering site for grassland birds.
- **Reptiles and Amphibians:** There have been 32 reptile and 11 amphibian species recorded from LAMR and ALFL. The Texas horned lizard is a state listed species, but is relatively common at LAMR and ALFL (Patrikeev and Gallyoun 2004).
- **Invertebrates:** Phillips (1990) states that there may be over 600 species of insects from LAMR. Identification of specimens has varied from getting to genus or species level. The giant mole cricket (*Gryllotalpa major*) was collected in McBride Canyon and is a rare species typical of high quality mixed-grass prairie.

E.1.3.7. Vegetation

A total of 486 species have been documented and supported by vouchers from ALFL and LAMR (Wright and Meador 1981, Nesom et al. 2005). Vegetation at ALFL is dominated by yucca grassland (36%), vegetated cliffs (34%), mixed-grassland (18%), mesquite grassland (8%), and mixed forest (3%) (Lake Meredith National Recreation Area 2002). Bell et al. (2000) also provides a list of plant species from ALFL but it is un-vouchered. Bell and Coffman (2000) identified Russian olive (*Elaeangnus angustifolia*), field bindweed (*Convolvulvus arvensis*), Russian thistle (*Salsola iberica*), Belvedere summer cypress (*Kochia scoparia*), Johnson grass

(*Sorghum halpense*), King Ranch bluestem (*Borthriochloa ishaemum*) and yellow sweetclover (*Melilotus officionalis*) as the major introduced plant species at ALFL. They also identified the native honey mesquite (*Prospis glandulosa*) as an invasive species on the monument. There are no known endangered or threatened plants within the boundaries of the parks. Potentially occurring rare plants at ALFL include Correll's Wild-Buckwheat (*Eriogonum correllii*), Tall Plains Spurge (*Euphorbia strictior*), Mexican Mud-Plantain (*Heteranthera mexicana*) and High Plains Goldenrod (*Solidago altiplanities*).

*E.1.4. Management Issues*

The grassland community, prairie restoration, the Texas horned lizard, night sky and soundscape, and water quality and quantity are the most important natural resource issues at ALFL. Woody species invasion, erosion, viewshed preservation and visitor carrying capacity are the biggest threats to natural resources at the park. Restoration and maintenance of the mixed-grass prairie enhances the habitat for both species of interest and native populations, while controlling the influx of woody and exotic plant species. Prairie restoration can lead to improved groundwater recharge and stewardship of upland wetlands and springs.

The quality and quantity of groundwater in the future is of major concern in this region. Continued pumping of the aquifer for agricultural purposes has the potential to lower the water table. The greatest potential for flood hazard to park visitors at ALFL is from isolated flash floods along side drainages. This also can cause erosion, negatively impacting the cultural resources in the area.

Human activity threatens both the natural and cultural resources of ALFL. Limiting public access to the site has limited the public impact. Continued development outside the park threatens the night sky while the soundscape is impacted by the engine sounds of personal watercraft, boats, motorcycles, off-road vehicles and well drilling and production. Off-road vehicle use, unauthorized in this area, has caused severe damage to soil, vegetation and cultural resources. Maintenance of boundary fence remains an essential means of controlling unauthorized use of parklands.

Oil and gas exploration and development has been actively pursued in the vicinity of LAMR and ALFL since the late 1920s, well before establishment of the parks. The earliest well on record within what later became LAMR was completed on October 3, 1927. Many others followed. In the parks today, there are 170 active well sites, evidence of 15 abandoned (unreclaimed) operation sites, 64 km of active oil field access roads, 167 km of abandoned roads, and 6 km of existing oil and gas pipelines (Lake Meredith National Recreation Area 2002).

*E.1.5. Partnering / Neighboring Agencies*

E.1.5.1 Current Partners
Texas Parks and Wildlife, Bureau of Reclamation, National Wild Turkey Federation

E.1.5.2. Potential Partners
Quail Unlimited, US Forest Service, West Texas A+M, Texas Tech University, Amarillo College

E.1.5.3. Neighboring Land Management Agencies
Lake Meredith National Recreation Area, Palo Duro Canyon State Park, Playa Lakes Wildlife Management Area, Gene Howe Wildlife Management Area, Cross Bar (Bureau of Land Management), Buffalo Lake NWR, Muleshoe NWR, Optima NWR, McClellan Creek National Grasslands, Caprock Canyon State Park, Black Kettle National Grasslands, Four Canyon Preserve (The Nature Conservancy)

*E.1.6. Literature Cited*

Bell, J.R., M. Budd, and C. Coffman. 2000. Alibates National Monument threatened and endangered plant species survey. Report to U.S. Dept. of the Interior – National Park Service. Natural Resources Conservation Service, Amarillo, Texas.

Bell, J.R. and C. Coffman. 2000. Alibates National Monument invasive plant species survey. Natural Resources Conservation Service. 11pp.

Killebrew, F.C. 1977. A survey and population analysis of mammals by habitat at Lake Meredith Recreation Area and Alibates National Monument. A Report of the Activities of a Grant Project for the United States Department of the Interior: National Park Service. 107 pages.

Lake Meredith National Recreation Area. 1996. Resources management plan, Lake Meredith National Recreation Area, Alibates Flint Quarries National Monument. National Park Service. 64pp.

Lake Meredith National Recreation Area. 2002. Oil and gas management plan. Alibates Flint Quarries National Monument and Lake Meredith National Recreation Area.

National Park Service 2003. 2001 Air emissions inventory. Lake Meredith National Recreation Area. 88pp.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Nesom, G., R. J. O'Kennon, and M. Gallyoun. 2005. Vascular plants of Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, Potter, Moore, and Hutchinson Counties, Texas. Results of a 2002 floristic inventory and related research reviews. The Nature Conservancy, The Botanical Research Institute of Texas, and the National Park Service 124pp.

Patrikeev, M. and M. Gallyoun. 2004. Vertebrate animals of Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, Potter, Moore, and Hutchinson Couties, Texas. Results of a 2001-2003 zoological inventory and related research and reviews. The Nature Conservancy and the National Park Service. 63pp.

Philips, J.W. 1989. Checklist of Vertebrates of Lake Meredith Recreation Area. Unpublished Report. 9 pages.

Phillips, J. W. 1990. Insects of Lake Meredith Recreation Area. National Park Service. 107pp.

Thompson, Col. E.O. 1939. Summary of the Development of the Panhandle Field under Conservation Regulation, Panhandle Plains Historical Review, Volume XII, Canyon, Texas.

Wright, R.A., and K. Meador. 1981. The vegetation of the Lake Meredith Recreation Area, Texas. Unpublished report to U.S. Dept. of the Interior – National Park Service. Dept. of Biology, West Texas State University, Canyon, Texas.

Yancey, F.D., R.W. Manning, J.R. Goetze, and C. Jones. 1998. The Mammals of Lake Meredith National Recreation Area and adjacent areas, Hutchinson, Moore and Potter counties, Texas. Museum of Texas Tech Univ., Occasional Papers, No. 174. 20 pages.

## E.2. BENT'S OLD FORT NATIONAL HISTORIC SITE (BEOL)

For much of its 16-year history, this fort was the only major permanent white settlement on the Santa Fe Trail between Missouri and the Mexican settlements. William and Charles Bent, along with Ceran St. Vrain, built the original adobe fort in 1833 to trade for buffalo robes with the Southern Cheyenne and Arapaho Indians. The fort became the center of a trade empire that included Fort St. Vrain to the north and Fort Adobe to the south, along with stores at Taos and Santa Fe. The fort provided explorers, adventurers, and the U.S. Army a place to get needed supplies, wagon repairs, livestock, good food, water and company, rest and protection in this vast "Great American Desert." During the war with Mexico in 1846, the fort became a staging area for Colonel Stephen Watts Kearny's "Army of the West". Disasters and disease caused the fort's abandonment in 1849. At 799 acres (323 ha), Bent's Old Fort National Historic Site received 30,889 visitors in 2004.

### *E.2.1. Resource Overview*

Bent's Old Fort National Historic Site is located in southeastern Colorado, in Otero County, northeast of La Junta. BEOL is situated on a series of low terraces along three miles of the Arkansas River, within the Great Plains-Palouse Steppe ecological province and the short-grass prairie ecoregion Ladyman (2003). This part of the Central Short-grass physiographic region is dominated by Buffalo grass (*Buchloe dactyloides*) and blue grama grass (*Bouteloua gracilis*). In addition to the Arkansas River, a total of seven wetlands/ponds are found on the site – four on the north side of the river and three on the south side.

Temperature and rainfall reflect seasonal patterns at BEOL. The average maximum temperature from June to August is 91°F (32°C), while the average minimum temperature from December to February is 15°F (-9.5°C). Annual precipitation averages between 11 and 15 inches (28 to 38 cm). Approximately 70 percent of the precipitation falls in April through August and only about 10 percent falls in November through February.

### *E.2.2. Enabling Legislation / Management Documents*

Bent's Old Fort was established as a National Historic Site on June 3, 1960. The act stated the BEOL "shall be set aside as a public national memorial to commemorate the historic role played by such fort in the opening of the West." On March 20, 1963, the federal register described and delineated the boundary of the park as 178 acres (72 ha). An act on November 10, 1978, revised the boundary to include approximately 622 additional acres (252 ha) for developing public access to the site from U.S. Highway 50 and for maintaining the historic setting.

Several management documents are in place to guide decision-making at BEOL. A general Management Plan and a Resource Management Plan were implemented in the early 1990s. The Resource Management Plan supports the objective to ensure that natural resources are in place that minimize impacts from twentieth-century influence. Native vegetation will be restored and exotic plants controlled. (Bent's Old Fort 1994). A Wildland Fire Management Plan was first developed in 1990 and updated in 2003. A Tamarisk Control Plan was developed in 1995, while a Vegetation Restoration Management Plan was completed prior to 2003, which prescribes restoration procedures, seed mixes, planting times, and a desired condition for degraded areas (Ladyman 2003).

### *E.2.3 Natural Resources*

#### E.2.3.1. Valuable Resources / Species of Interest

The maintenance and enhancement of biotic integrity is of utmost importance to natural resource management at Bent's Old Fort National Historic Site. The habitat along the Arkansas River is part of the globally rare cottonwood/willow riparian ecosystem. Both the river and seasonal wetlands found at BEOL provide a stopover site for migratory birds. The buffalo and blue grama

grass of the short-grass prairie support a vital small mammal community that is the basis of the food chain. A small colony of black-tailed prairie dogs (*Cynomys ludovicianus*) is located in the southeastern corner of BEOL (Ladyman 2003). Several avian species of interest have been documented at the site: Ferruginous hawk (*Buteo regalis*) is listed in Colorado and Swainson's hawk *(Buteo swainsoni*) is listed in neighboring Oklahoma. Texas horned lizard (*Phrynosoma cornutum*), listed in Colorado, has been observed at BEOL. Two fish species of interest may be present in the Arkansas River at Bent's Old Fort. The Arkansas river shiner (*Notropis girardi*) is classified as threatened and is listed in all other states in the Southern Plains Network, while the Arkansas darter (*Etheostoma cragini*) is listed in Colorado, Kansas and Okalahoma, and is a candidate for federal listing.

E.2.3.2. Geology & Soils

According to a report by Koch & Santucci (2003), the Cretaceous bedrock at Bent's Old Fort is the Bridge Creek Member of the Greenhorn Limestone Formation. Mammoth remains have been discovered in the Quaternary deposits at BEOL. Tusk fragments were found in a gravel bed by Jackson Moore, a NPS archeologist, between 1963 and 1966 (Moore 1973). Near the park boundaries (approximately 8 km northeast of La Junta), a collection of 28 fossil rudists (extinct bivalve) was made, and this fossil-bearing bed extends into the park (Cobban et al. 1985). River bottom soils at Bent's Old Fort are predominately silty clay sand, with deep well-drained loam on the level upper terraces (Ladyman 2003).

E.2.3.3. Land Use

The majority of the land surrounding Bent's Old Fort is classified as agricultural, with some portions rowcropped and others grazed (Stubbendieck and Willson 1986). The eastern boundary of BEOL is shared with a 400 acre (162 ha) state wildlife area with seasonal hunts and low intensity rowcropping. County Road 194 forms a northern boundary to Bent's Old Fort, while CO 50 and a rail line form the southern boundary.

E.2.3.4. Hydrology

BEOL, containing 2.28 miles (3.67 km) of the Arkansas River, lies in the Upper Arkansas-John Martin Watershed. Seven small man-made ponds and a number of wetlands, one of which is the 55-acre (22 ha) Arch Wetland, are also present at BEOL. These ponds and wetlands help remediate heavy rainfall events and therefore protect BEOL from major flooding events. Another significant ecosystem at BEOL is the cottonwood/willow riparian area. BEOL Park managers are concerned about protecting these communities, particularly from invasion of exotic plants and erosion of the riparian substrate. The biggest potential threat facing the water resources at BEOL is point-source contaminants from nearby land practices such as agriculture and oil and gravel extractions. The State of Colorado has designated portions of the Arkansas River, including that which runs through BEOL, as impaired on its 2002 303(d) list, due to high levels of selenium. Groundwater and streamflow monitoring is currently occurring at BEOL. A basic water quality report by the WRD of the NPS was prepared in 1998.

E.2.3.5. Air Quality

BEOL is a Class II air quality area with a low risk for foliar ozone injury. There are only a few hours of exposure to ozone concentrations greater than 80 ppb occur each year, while exposures to 100 ppb are rare. One ozone-sensitive plant, Green Ash (*Fraxinus pennsylvanica*), is found at the site, but there are no known bioindicator species (National Park Service 2005).

E.2.3.6. Wildlife

- ***Mammals:*** There are no federally threatened or endangered animals documented at Bent's Old Fort. A twelve-day survey was conducted in August of 2001 by the Colorado Natural Heritage Program, with a supplemental survey over six days the following spring. A total of 21 species (38%) were documented out of 55 expected species. Although no bats were documented, they surely forage and drink at BEOL and might possibly roost there as well (Gionfriddo et al. 2002; Gionfriddo and Stevens 2003). The use of mist nets

for bat sampling at Bent's Old Fort were problematic and other survey methods are recommended in the future.

- ***Birds:*** A twelve-day breeding bird survey was conducted in August 2001 by the Colorado Natural Heritage Program, followed by a six-day supplemental survey the following spring. Seventy-two species of birds (67%) were documented out of the 108 anticipated species (Gionfriddo et al. 2002; Gionfriddo and Stevens 2003). Four species of birds detected during this survey are on the Partners In Flight High Priority list for the Central Short-grass physiographic region: ferruginous hawk (*Buteo regalis*), northern harrier (*Circus cyaneus*), grasshopper sparrow (*Ammodramus savanarrum*), and Lewis's woodpecker (*Melanerpes lewis).* The riparian habitat of the Arkansas River and surrounding wetlands provide a stopover for migratory birds.
- ***Reptiles & Amphibians:*** A twelve-day survey was conducted in August 2001 under very dry conditions by the Colorado Natural Heritage Program, followed by a six-day supplemental survey the following spring. Each survey resulted in similar findings. Three species of amphibians (27%) were documented out of the 11 anticipated species. Seven species of reptiles (28%) were detected out of the 25 expected species, including the Texas horned lizard (Gionfriddo et al. 2002; Gionfriddo and Stevens 2003). The introduced bullfrog was detected and its colonization may have a negative impact on native anurans (Gionfriddo et al. 2002).
- ***Fish:*** A twelve-day survey was conducted in August of 2001 by the Colorado Natural Heritage Program. Four species were documented at BEOL: common carp (*Cyprinus carpio*), plains killifish (*Fundulus zebrinus*), mosquitofish (*Gambusia affinis*) and green sunfish (*Lepomis cyanellus).* A better sampling technique might yield better results (Gionfriddo et al. 2002). A two-year fish-specific survey of the Arkansas River and the Arch Wetland was initiated in 2005 with the Bureau of Reclamation.

E.2.3.7. Vegetation

In a 1986 assessment of prairie, James Stubbendieck estimated that approximately 638 acres of Bent's Old Fort National Historic Site was in various successional stages leading to short-grass prairie. The dominant riparian species at the time were cottonwood (*Populus sargentii*), willow (*Salix interior*), and tamarisk *(Tamarix pentandra*) (Stubbendieck and Willson 1986). Seventeen years later, some conditions had been altered. A 2003 restoration management plan determined that approximately 124 acres (50 ha) were upland prairie, 271 acres (110 ha) were riparian grassland, 300 acres (121 ha) were riparian shrub- and grasslands recovering from tamarisk invasion, 39 acres (16 ha) were river and bars, and 61 (25 ha) acres were wetlands. A wildfire had burned most of the grassland south of the river and a portion of the north side in 2002. Tamarisk has been eradicated from the park but will require continued monitoring to ensure that it does not re-establish. The Arch wetland has expanded considerably due to the tamarisk removal. Grazing by livestock used in cultural interpretation still occurs (Ladyman 2003). Prairie restoration efforts continue at BEOL. The use of irrigation in recently reseeded sites has improved forb regeneration and the establishment of the desired buffalo grass and blue grama grass of the short-grass prairie.

A separate inventory of wetland vascular plants was taken over a 3 day period in August 2001 by the Colorado Natural Heritage Program. Two types of habitat seemed to dominate these wetlands. Those closest to the Arkansas River were dominated by cottonwood (*Populus deltoides ssp. monilifera*), with peach leaf willow (*Salix amygdaloides*) and coyote willow (*Salix exigua*) intermixed. The other wetlands contained stands of cattails (*Typha latifolia*) and bulrushes (*Schoenoplectus lacustris ssp. acutus)* (Gionfriddo et al. 2002). A follow-up inventory of the Arch Wetland vegetation was initiated by Bureau of Reclamation in 2005.

Ladyman's (2003) restoration plan states that all grasslands had varying amounts of the exotic plants, kochia (*Kochia scoparia*) and field bindweed (*Convolvulus arvensis*). Six species of exotic plants at BEOL are listed on Colorado's noxious plant list: Canada thistle (*Cirsium arvense*), hoary cress (*Cardaria draba*), perennial pepperweed (*Lepidium latifolium*), Russian knapweed

*(Acroptilon repens*), field bindweed *(Convolvulus arvense),* and jointed goat grass *(Aegilops repens)* (Ladyman 2003).

*E.2.4. Management Issues*

Natural resource issues regarding the biotic integrity of Bent's Old Fort receive the highest priority. A wildland fire in 2002 burned most of the grassland south of the Arkansas River, then jumped the river before being contained. A large section of the globally rare cottonwood-willow riparian habitat was severely burned, resulting in the death or disfiguration of scores of cottonwoods. The effects of the fire are still being measured in both the riparian areas and the grasslands. The park's fire management plan provides guidance for the use of prescribed burns to manage grasslands and assist with restoration efforts. The development of quality short-grass prairie and the elimination of invasive exotic plants will benefit the grassland community and provide suitable habitat for species of interest. Grassland birds and the small mammal community, black-tailed prairie dogs in particular, anchor this ecosystem.

The existence of a small prairie dog colony at the edge of the park brings its own set of management dilemmas. In addition to being a keystone species, black-tailed prairie dog is a candidate for federal listing and is listed by the state of Colorado. Prairie dogs are carriers of disease that threaten humans, specifically sylvatic plague. While the risk of transmission to humans is remote, there remains a concern in maintaining colonies near humans (Ladyman 2003).

Water resources have their own management issues. BEOL is fortunate to have seven wetlands in addition to three miles of Arkansas River. Consistent efforts at tamarisk removal have resulted in the expansion of Arch wetland, an important stopover for migrating birds. Many of the wetlands recharge their waters during flooding events along the river and would be negatively impacted by upstream dams. The disturbance regime of flooding can enrich the ecosystem, but also provides for invasion by exotic plants and animals. Finally, the issue of water use rights both within and outside of the park can have a profound effect on the ecosystems at Bent's Old Fort through impacts to both surface and groundwater levels.

Various human uses will continue to shape the natural resources at BEOL. The historic viewshed will continue to be threatened by surrounding land uses. While currently agricultural in nature, rowcropping and overgrazing can change the biotic community and encourage exotics. Feedlots in the vicinity would affect not only the view, but air and water quality as well. Gravel pits already exist in the area, as well as various levels of mineral, oil and gas extraction. There is a concern regarding hazardous spills associated with the highway and railway along the southern boundary of Bent's Old Fort. It must also be noted that the National Park Service does not own the mineral rights on the land south of the Arkansas River.

*E.2.5. Partnering / Neighboring Agencies & Individuals:*

<u>E.2.5.1. Current Partners</u>
CO Natural Heritage Program, CO Division of Wildlife, CO Department of Corrections, CO State Forest Service, CO Boys Ranch, La Junta City Golf Course, Fort Lyon Canal; Otero Junior College, NRCS, Adjacent landowners

<u>E.2.5.2. Neighboring Land Management Agencies</u>
Cimarron National Grassland, Comanche National Grassland, Fresh Tracks (Southern Plains Land Trust), CO Div of Wildlife Oxbow Unit, Ryan's Ponds in Rocky Ford

*E.2.6. Literature Cited*

Bent's Old Fort. 1994. Final Environmental Impact Statement, General Management Plan and Development Concept Plan for Bent's Old Fort National Historic Site: Otero county, CO. Record of Decision.

Cobban, W. A. P., W. Skelton, and W.J. Kennedy. 1985. Occurrence of the rudist *Durania cornupastoris* (Des Moulins, 1826) in the upper cretaceous Greenhorn limestone in Colorado. Geological Survey Bulletin B, D1-D8.

Gionfriddo, J.P., D.R. Culver and J. Stevens. 2002. Biological survey of Bent's old fort national historic site, Otero county, Colorado. Colorado Natural Heritage Program. Fort Collins, CO.

Gionfriddo, J.P. and J. Stevens. 2003. Survey of Bent's Old Fort National Historic Site for breeding birds and anurans. Colorado National Heritage Program. Fort Collins, CO.

Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. NPS TIC #D-107. National Park Service.

Ladyman, J.R. 2003. Bent's Old Fort National Historic Site vegetation restoration management plan. Centennial, CO. Contract number Q131002C012.

Moore, J. W., Jr., 1973. Bent's Old Fort: an archeological study. State Historical Society of Colorado, Pruett Publishing Company: 144.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E.3. CAPULIN VOLCANO NATIONAL MONUMENT (CAVO)

Capulin Volcano National Monument (CAVO) was established in 1916 to preserve a nearly perfectly shaped extinct volcanic cinder cone that stands more than 1200 feet (366 m) above the surrounding High Plains of northeastern New Mexico. A 2-mile (3.2 km) paved road spiraling to the volcano rim makes Capulin Volcano one of the most accessible volcanoes in the world. Trails leading around the rim and to the bottom of the crater allow a rare opportunity to easily explore a volcano. This 793-acre (321 ha) monument is located in Union County, New Mexico, approximately 20 miles (32 km) east of Raton and received 58,705 visitors in 2004.

### *E.3.1. Resource Overview*

Reaching an elevation up to 8,182 feet (2,494 m), Capulin Volcano is a cinder cone primarily covered with piñon-juniper woodland and surrounded by short-grass prairie. The crater itself is approximately 400 feet (122 m) deep and the rim almost a mile in circumference, providing a panoramic view of the volcanic field, distant mountains and portions of four states.

While the cinder cone is undoubtedly the most significant natural resource of CAVO, maintenance of both the viewshed and air quality are vital to the visitor experience. Protecting the cinder cone from erosion is the major natural resource management challenge, followed closely by preventing the encroachment of woody plants into Alberta arctic butterfly habitat and invasive plants into the short-grass prairie. The recent efforts at CAVO to initiate a new GMP will help coordinate the management efforts.

CAVO receives 16–20 inches (41 - 51 cm) of rain annually. The average annual temperatures range from 35°F to 62°F (2 - 17°C). Average maximum temperatures for June to August is 78°F (25.5°C), while average minimum temperatures for December to February is 19°F (-7°C).

### *E.3.2. Enabling Legislation / Management Documents*

Protection was first provided on January 16, 1891, when Capulin Mountain was "…Withdrawn from settlement, entry or other disposition under any of the public land laws, until such time as Congress may see fit to take action touching the same or until otherwise ordered by competent authority…" That authority came in the form of President Woodrow Wilson on August 9, 1916. He set Capulin aside as a national Monument by Presidential Proclamation No. 1340, to preserve "…a striking example of recent extinct volcanoes …" which "…is of great scientific and especially geologic interest." Public Law 87-635 passed by the 87th Congress on September 5, 1962, amended the proclamation to "…preserve the scenic and scientific integrity of Capulin Mountain National Monument…" because of the significance of Capulin Volcano. Finally, on December 31, 1987, Congress changed the Monument's name from, "Capulin Mountain National Monument" to "Capulin Volcano National Monument," by Public Law 100-225 (101 Stat. 1547).

A Fire Management Plan (FMP) was recently completed that implements fire management objectives stated in the Capulin Volcano Resource Management Plan. These objectives are: 1.) Maintain the diversity of habitats in the Monument with particular attention to the remaining short-grass prairie; 2.) Reduce exotic vegetation; and 3.) Reduce fuel loading and the possibility of catastrophic fire that would damage resources and threaten visitors. The FMP proposes a long-range treatment schedule in which 70 to 400 acres (28 to 162 ha) are treated annually with combinations of fuel thinning and prescribed fire projects. This plan will be guided by weather and fuel conditions and measures to mitigate adverse effects on natural and cultural resources are proposed. Monitoring of fire effects, including the emergence of invasive plants, would occur after fire events. In addition to monitoring, the adaptive management approach taken with the fire management program would include ongoing consultation with stakeholders, and annual program reviews.

*E.3.3. Natural Resources*

E.3.3.1. Valuable Resources / Species of Interest

While no currently listed or category species of terrestrial mammals have been observed at CAVO, several species of interest have been documented. These include: Townsend's big-eared bat (*Plecotus townsendii*) (listed in New Mexico), and the Alberta arctic butterfly (*Oeneis alberta capulinensis*), endemic to a few isolated windblown grassy mesas in the Raton Mesa complex in northeastern New Mexico. This park is one of the eastern-most locations with grassland, montane and piñon/juniper habitat in close proximity.

E.3.3.2. Geology & Soils

A variety of volcanic features are enclosed by the CAVO boundaries. Capulin Volcano formed approximately 60,000 years ago, during the last active period in the Raton-Clayton volcanic field. The symmetry of the cinder cone was initially preserved because lava flowed only from vents located at the base of the volcano. The dry climate of northeastern New Mexico has contributed to its preservation. The surrounding lava flows cover the remainder of the monument. Capulin Volcano has been inactive for a period long enough that it is unlikely it will erupt again.

Harfert (n.d.) states that the southeast and north slopes of Capulin are covered with a cinder/soil mix almost a foot deep, but it may be the presence of caliche that allows the unusual growth of vegetation on the cinder cone. There are at least three zones of caliche layered concentrically around the cinder cone about two feet apart, extending throughout the cone except for the western breach area. Analysis of caliche samples displayed a composition of scoria, quartz or cristobalite, and a glassy black substance cemented together with calcium carbonate and containing a minor amount of clay minerals.

E.3.3.3. Land Use

Surrounding land use at CAVO has a major impact on the aesthetic quality of visitor satisfaction. The view from the rim of the volcano is quite comprehensive and would be diminished by incompatible development near the park. Most of the state-owned lands to the north, east and west of the monument are leased for grazing. There is private ranch land from the east to the south of Capulin. Surface mining is taking place to the east.

E.3.3.4. Hydrology

The only surface waters at CAVO are three sewage lagoons. The groundwater is at risk from surrounding anthropogenic sources of contamination such as municipal wastewater discharges, ranching operations, and mining and quarrying activities, as well as atmospheric deposition. A basic water quality assessment was completed in 1993 by the WRD of the NPS.

E.3.3.5. Air Quality

CAVO has been designated a Class II air quality area. According to the report, "Air Quality in the National Parks," which monitored selected parks from 1990 - 1999, the sulfate ion concentration and wet deposition is average for the National Park Service, with wet deposition showing an improving trend and concentration trend significantly improving. Nitrate concentration, however, was below average for national parks and continuing to degrade, while nitrogen wet deposition, average for national parks, showed a significant degradation. There is currently only a low risk of foliar ozone damage. Exposure to 80 ppb ozone is infrequent, and exposure to 100 ppb rare. Soil moisture serves to constrain the uptake of ozone at higher exposure levels, reducing the likelihood of foliar injury development (National Park Service 2005). Monitoring for acid deposition, as part of a national program, continues at Capulin. Twenty years of precipitation and pH records have been collected to aid in this effort.

E.3.3.6. Wildlife

- ***Mammals:*** Biological surveys completed in 2002 by Natural Heritage New Mexico detected 28 mammal species (39%) of the 57 animals expected at CAVO. During this survey, a black bear (*Ursus americanus*) spent several nights on the monument. Rangers

have reported seeing pronghorn and elk just outside of park boundaries (Johnson et al. 2003). While no listed or category species were observed, Parmenter et al. (2000) note that the swift fox (New Mexico state listed species) may wander through the monument property.

- ***Birds:*** surveys conducted by Natural Heritage New Mexico in 2002, combined with observations by park staff, accounted for 56 (88.9%) of the 59 targeted species for CAVO. Twenty-seven species (45.8%) were found in grassland habitats, 46 species (78%) in piñon-juniper habitats, and 15 species (25.4%) in human-impacted areas (Johnson et al. 2003). Five species currently on the Partners in Flight high priority list for the Mesa and Plains Physiographic Region were detected: canyon towhee (*Piplio fuscus*), Cassin's kingbird (*Tyrannus vociferans*), juniper titmouse (*Baeolophus griseus*), Cordilleran flycatcher (*Empidomax occidentalis*), and Virginia's warbler (*Vermivora virginiae*). A listed and category species inventory conducted in 2000 observed no qualifying birds, however loggerhead shrike has been previously recorded as a rare transient at the monument and adjacent prairie habitats may harbor Baird's sparrow during winter months (Parmenter et al. 2000). Natural Heritage New Mexico suggests that "the absence of livestock grazing on CAVO has apparently encouraged an increased diversity of grassland birds, especially ground- and shrub-nesting birds such as vesper sparrows (*Pooecetes gramineus*) and lark sparrows (*Chondestes grammacus*). At the same time, conifers appear to be invading several areas of grassland and potentially decreasing the area of habitat favored by grassland birds. Efforts to clear these areas, either mechanically or by prescribed fire, will help maintain grassland habitats should forest encroachment become severe" (Johnson et al. 2003). It should also be noted that playas located on adjacent land provide a major stopover for migratory birds.
- ***Reptile/Amphibians:*** Drought affected the 2002 survey period for reptiles. Only 10 species (29%) of the anticipated 34 species were found at Capulin. Due to the unique presence of grassland, montane and piñon/juniper habitat in close proximity, other valuable resources of note are found in and adjacent to CAVO, including the eastern fence lizard, western prairie rattlesnake and Texas horned lizard.
- ***Bats:*** Two species of bats (*Myotis thysanodes* and *Myotis ciliolabrum)* found at Capulin had been listed as Category 2 species in 1994. When the USF&WS dropped the category designation and created candidate species, the two bats were no longer classified (Parmenter et al. 2000). A third species, Townsend's big-eared bat (*Plecotus townsendii*), has been recently documented at CAVO (Johnson et al. 2003), and is listed by New Mexico.
- ***Butterfly:*** A subspecies of the Alberta Arctic butterfly (*Oeneis alberta capulinensis)* was first discovered at CAVO (Brown 1970) and has been found to be endemic to a few wind-swept elevations in the area. Parmenter et al. (2000) consider this to be a genetically significant population with a wider geographic distribution and suggest it should be protected as a species of special concern. Its larvae may feed on grasses of the genus *Festuca*, which are currently being impacted by woody encroachment, resulting in only a few hectares of sparse coverage. Fire or adverse weather can easily decimate such limited and small populations. Specific surveys for the Alberta arctic butterfly in 2002 and 2003 have failed to document this butterfly on Capulin volcano (Johnson et al. 2004)
- ***Invertebrates:*** A list of beetle, grasshopper and cricket species found at CAVO has been compiled. Although no listed or category invertebrates were found, Parmenter et al. (2000) noted a number of rarely recorded species, resulting in range extensions. They suggest that "the probability is high that undescribed new species of arthropods may be found at Capulin Volcano, possibly representing endemic species [*Belotus abdominalis* (Soldier beetle), *Hyperaspis quadrivittata* (Ladybird beetle), *Sericoderus lateralis* (Minute fungus beetle), *Trox foveicollis* (Skin beetle)]." (Parmenter et al. 2000).

E.3.3.6. Vegetation

CAVO is located in the Arkansas Tablelands section of the Great Plains-Palouse Dry Steppe ecoregion. Three major habitat types are found within park boundaries: grasslands upon the lava flows, montane woodlands of ponderosa pine, and piñon/juniper forest on the cone itself. Six

communities are identified by Natural Heritage New Mexico's (NHNM) Vegetation Community Classification system are crater grassland, disturbed grassland, piñon-juniper, lowland grassland, gamble oak and ponderosa (Johnson et al. 2003). Three major ecological processes identified as affecting the monument are fire, grazing and woody plant encroachment.

No threatened or endangered plants were located during the field survey conducted by NHNM in 2002. Two hundred and forty-three species (92%) of the 255 potential species were documented (Johnson et al. 2003). Existing pockets of native short-grass prairie vegetation do remain within CAVO (Parmenter et al. 2000) even though the cinder cone has become dominated by piñon/juniper forest. Harfert (n.d.) proposes that, unlike other unforested cinder cones in the area, the dense vegetation on Capulin is due to the atypical caliche soils found interspersed on the slopes. This reduction of grasslands may negatively affect the small population of endemic Alberta arctic butterfly.

Due to the unique presence of grassland, montane and piñon/juniper habitat in close proximity, other significant and valuable resources of note are found in and adjacent to CAVO, including ungrazed short-grass prairie, fringed sagewort (*Artemesia frigida*), piñon pine, gambell oak and ponderosa pine.

*E.3.4. Management Issues*

Erosion accelerated by human disturbance and control of exotic vegetation are two critical issues facing Capulin Volcano National Monument. Runoff from the Volcano Roadway continues to cause significant erosion at the drainage culverts. Unauthorized visitor trails inevitably cause erosion on slopes of the cinder cone from trampling of vegetation. An abandoned cinder pit located on the boundary of state land requires erosion control and revegetation. CAVO continues to try and acquire additional funding to address these erosion issues. An erosion mitigation plan needs to be developed for the Volcano Road at CAVO.

Control of exotic invasive plants is the second critical issue for CAVO. No federally listed noxious weeds have been found, although field bindweed (*Convolvulus arvensis*) is listed by the State of New Mexico as a Class C noxious weed (Johnson et al. 2003). These invasives cross park boundaries from adjacent lands and are introduced along roadsides by vehicles and the use of hay for erosion control. It is suspected that the effects of periodic drought combined with eighty years of fire suppression have exacerbated this situation. While exotics can be found at various construction and disturbance sites throughout the park, drastic control measures will be required along the fire road skirting the base of the cinder cone, and at selected sites below the Volcano Road. Past control efforts have targeted common mullein (*Verbascum thapsus*) and prickly Russian thistle (*Salsola tragus*) for removal.

An inventory of all vascular plants, including those introduced to the monument, was completed by Natural Heritage New Mexico in 2002. They noted that twenty-two introduced plant species had been previously detected at CAVO. Slim amaranth (*Amaranthus hybridus*) and prickly Russian thistle (*Salsola tragus*) were identified as the two most widespread introduced species within park boundaries. Eight species on the final plant list (*Bromus tectorum, Cichorium intybus, Chenopodium album, Cynoglossum officinale, Descurainia sophia, Kochia scoparia, Salsola tragus*, and *Verbascum thapsus*) are listed as noxious by other states (Johnson et al. 2003). Inventory and mapping of noxious weeds has been completed by the Great Plains Cooperative Ecosystems Studies Unit. Japanese brome (*Bromus japonicus*) and downy brome (*Bromus tectorum*) were identified as the most serious threats due to their difficulty to control. It is determined that these annual bromes inhabit 45 acres (18.1 ha). A medium urgency designation has been given to common horehound (*Marrubium vulgare*) due to its invasive potential, although it currently has low occurrence and small populations at CAVO (Natumilani et al. 2004). Eradication measures will continue as funding requests are met. Local hay sources are being screened for the presence of noxious weeds in an effort to limit further introduction. Due to the suppression of wild fire, piñon pine and juniper are now invading grassland on the slopes of

Capulin where the Alberta arctic butterfly was discovered. Recent surveys have failed to document the butterfly's presence, raising concern about the impact of this woody encroachment. Historic photos of the cinder cone readily show the increase in piñion-juniper vegetation over the past several decades.

An assessment of the condition of the prairie and recommendations given for management were completed by Stubbendieck (1986). Parmenter et al. (2000) stated that the grass habitats at CAVO "appear to be well preserved and protected." Maintaining these grassland habitats will be vital for the Alberta arctic butterfly and other dependant plant and animal species. At present, an estimated 100 acres (40 ha) are in need of restoration for a number of reasons – utility disturbance, roads, non-native invasives, woody encroachment, and exclusion of wild fire. The exclusion of grazing for several decades may also be impacting the health of these grasslands. A native plant propagation project has been approved for funding in FY05 and FY06 and includes a partnership with the NRCS Plant Materials Center in Las Lunas, New Mexico. There are pockets of native vegetation within CAVO for use as seed source.

Eighty years of fire suppression at CAVO has led to degradation of the short-grass prairie though encroachment of woody and exotic invasive species. Concerns have been raised regarding the catastrophic effect an uncontrolled wild fire and resultant conditions might have on the monument. A newly instituted Fire Management Plan has identified three objectives to restore balance: maintain habitat diversity, particularly the short-grass prairie; reduce exotic vegetation; and reduce fuel load that threatens resources and visitors. It is anticipated that these objectives can be reached through implementation of a multi-year fuel thinning/prescribed fire rotation, monitoring of fire effects after the event and an adaptive management approach involving stakeholders. Fire weather data is currently being collected and fire effects are being observed.

Unmanaged diseases and pests both to plants and wildlife are an ongoing threat in any protected area. Current monitoring continues at CAVO for the gypsy moth (*Lymantria dispar*).

There are several issues pertaining to human use that need to be addressed at CAVO. Park visitors can have a negative impact on the natural resources of the monument. As discussed earlier, unauthorized trails expose the cinder cone to accelerated erosion. The Volcano Road, used by visitors to access the volcano crater, also causes erosion and allows for the introduction of invasive plants to the slopes of the cinder cone.

Changes associated with the land surrounding the park can affect air, water, scenic quality and can affect biological communities through fragmentation and isolation. The views from Capulin Volcano are one of the most important features and resources, yet regional haze slowly increases as air quality diminishes. The potential development of two new coal fired power plants in the area would likely bolster this negative trend. Development in the form of subdivision of neighboring ranches will not only affect the viewshed but further diminish the night sky resource through the addition of all-night illumination. Attempts in 2003 to monitor this important resource were unsuccessful.

Concerns regarding water quality issues and access continue to grow. CAVO has no water features other than a water treatment lagoon, but resolution of these matters will have an impact on the monument. The Raton Basin aquifer is undeclared, resulting in questions regarding water rights. The community of Folsom, north of CAVO, has contaminated ground water.

*E.3.5. Partnering / Neighboring Agencies & Individuals*

<u>E.3.5.1. Current Partners</u>
Natural Heritage New Mexico, Natural Resource Conservation Service Plant Materials Center, New Mexico Department of Game and Fish, New Mexico Extension Service, neighboring NPS sites, USFS, Vermejo Park Ranch, Philmont Scout Ranch, 4H and FFA clubs at Des Moines School, Wildflower seed club, and local volunteers

E.3.5.2. Potential partners
Boy Scouts, YCC, Raton Youth Organization

E.3.5.3. Neighboring Land Management Agencies:
Maxwell NWR, Kiowa National Grassland, Rita Blanca National Grassland, Sugarite Canyon State Park

*E.3.6. Literature Cited*


Brown, F. M. 1970. *Oeneia Alberta* in New Mexico, a new subspecies (Lepidoptera: Satyridae). *Journal of the New York Entomological Society* **78**:134-138.

Harfert, R.C. No Date. A study of the vegetation on volcanic cinder cones and their relationship to the caliche layers of Capulin mountain.

Johnson, K., S.J. Carey and L. Pierce. 2004. Alberta arctic butterfly surveys in the Cpulin Volcano National Monument area. Final Report

Johnson, K., G. Sadoti, G. Racz, J. Butler and Y. Chauvin. 2003. National Park Service Southern Plains Network: final inventory report for New Mexico parks. Natural Heritage New Mexico. Albuquerque, NM.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Natumalani, S., S. Tunnell, G. Wilson, J. Burkholder and D. Mishra. 2004. Noxious weeds inventory and mapping at Capulin Volcano National Monument, Fort Union National Monument, and Lake Meredith National Recreation Area. Great Plains Cooperative Ecosystem Studies Unit. Cooperative Agreement Modification H60000A0100R

Parmenter, R.R., D.C. Lightfoot and W.L. Gannon. 2000. Capulin Volcano National Monument: listed and category species inventory. University of New Mexico.

Stubbendieck, J. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E.4. CHICKASAW NATIONAL RECREATION AREA (CHIC)

Chickasaw National Recreation Area (CHIC) was the first national park established in the state of Oklahoma and the seventh in the National Park System. The park preserves cultural resources, lakes, streams, and springs on the edge of the Arbuckle Mountains, providing opportunity for aquatic activities. Originally part of the Choctaw Reservation, this land was first ceded to the Chickasaw Tribe, then sold to the federal government for a promise to protect the springs from private development. In the years following Oklahoma's statehood, Platt National Park was created and provided visitor access to the "healing" waters. In 1962, Arbuckle Reservoir was authorized to provide flood control and recreation opportunities, eventually inundating 2,340 acres (947 ha) south of Platt National Park. The two facilities and connecting riparian lands were joined in 1976 to form the 9,889-acre (4,002 ha) Chickasaw National Recreation Area, which received 1,277,753 visitors in 2004.

### *E.4.1. Resource Overview*

The juncture of the southern Osage Plains and the Arbuckle Mountains in south-central Oklahoma is a transitional ecotone of Eastern deciduous forest and the Western prairies. Although much of Chickasaw National Recreation Area is in the Arbuckle Mountains physiographic province, the northwestern portion of CHIC is a transitional area to the low rolling hills of the redbed plains (Hoagland and Johnson 1999). CHIC lies within the Arbuckle Mountains geographic region, within the Arbuckle Mountain Uplift geological province, and within the Red River drainage basin. The topography of the park is moderately rolling with several steep bluffs in the northern portion and level terrain on the upland areas in the southern portion. Arbuckle Reservoir is surrounded by steep valley walls with bluffs along lengthy sections, especially on the sides of the Rock Creek arm. Elevations range from 872 feet (266 m) of Lake Arbuckle to 1,082 feet (330 m) at Mount Airy (Chickasaw National Recreation Area 1999).

Chickasaw National Recreation Area is located in Murray County, approximately 90 miles (145 km) south of Oklahoma City. North-south U.S. Highway 177 bisects the Platt District (nee Platt National Park), while State Highway 7 runs along the northern park boundary with the adjoining town of Sulphur, Oklahoma. CHIC is divided into three management units. The 934-acre (378 ha) Platt District is the former Platt National Park and preserves the historical and designed cultural landscape of intact Civilian Conservation Corps park architecture, freshwater and mineral springs that have drawn people to the area for centuries, and the 67-acre (27 ha) Veteran's Lake. The Arbuckle District, at 6,656 acres (2,694 ha), is comprised of the 2,340-acre (947 ha) Arbuckle Reservoir and its surrounding recreational lands. The reservoir is fed by Rocky Creek and its tributaries – Guy Sandy Creek, Buckhorn Creek and Travertine Creek. The Rock Creek Corridor covers approximately 1,500 acres (607 ha) and connects the Platt District to the Arbuckle District (Chickasaw National Recreation Area 1999).

The park is located in the Subtropical Humid climate zone (Hoagland & Johnson 2001), resulting in a warm continental climate. Summers are hot and humid, with an average maximum temperature June–August of (91°F [33°C]) and prevailing winds from the southwest. Winters are mild with an average minimum temperature December–February of (28°F [-2°C]). Snowfall is light and lasts only a few days, resulting in a relatively dry season. Average annual precipitation is 38 inches (97 cm), with 70% falling during the warm months predominately from thunderstorms. Damaging hail is common and tornados not unusual (Chickasaw National Recreation Area 1997).

### *E.4.2. Enabling Legislation / Management Documents*

Chickasaw National Recreation Area is the oldest park in the Southern Plains Network. The Sulphur Springs Reservation was created on July 1, 1902. This legislation provided for the federal government to purchase 640 acres (259 ha) from the Chickasaw and Choctaw Indian Nation, Indian Territory, at their request "… for the proper utilization and control of said springs and waters of said creeks." 1904 legislation added 217 acres (88 ha) to the reservation and the name

was changed on June 29, 1906, to Platt National Park. Under the auspices of the Bureau of Reclamation, the Arbuckle Federal Reclamation Project received authorization on August 23, 1962, for flood control, water supply and "…for the conservation and development of fish and wildlife, and the enhancement of recreation opportunities." March 17, 1976 legislation combined Platt National Park and Arbuckle Recreation Area with additional lands to form Chickasaw National Recreation Area "… to provide for public outdoor recreation use and enjoyment of Arbuckle Reservoir and land adjacent thereto, and to provide for more efficient administration of other adjacent area containing scenic, scientific, natural and historic values contributing to public enjoyment of the area and to designate the area in such a manner as will constitute a fitting memorialization of the Chickasaw Indian Nation …" (Chickasaw National Recreation Area 1999).

According to the 1996 Strategic Plan, the stated Mission is "… to provide for the protection of Chickasaw National Recreation Area's unique resources, springs, streams, lakes, and other natural features, and its cultural history and structures, as well as it recreational resources and built facilities; and to provide for public education, appreciation and recreational use and enjoyment of these resources" (Wikle et. al. 1998). A Fire Management Plan was formulated in 1997 to provide the guidelines necessary for sound fire management practices used in prescribed burns to promote habitat health and to reduce fuel loads. In 1998, a Water Resource Management Plan to guide water resource-related planning activities at CHIC for the next decade was developed. The Resource Management Plan (Chickasaw National Recreation Area 1999) documents the natural and cultural resources at Chickasaw, describes and evaluates resource management activities, delineates resource problems and data deficiencies, and lays out a logical course for addressing them. The major objectives of the resource program are to protect the natural and physical resources within the park and to restore most of the park to approximate its resemblance when the first Chickasaw people arrived circa 1820 (Chickasaw National Recreation Area 1999).

*E.4.3. Natural Resources*

E.4.3.1. Valuable Resources / Species of Interest

While no federally threatened or endangered plants or animals have been documented at Chickasaw, several animal species documented at Chickasaw are tracked by the Oklahoma Biological Inventory. Texas horned lizard (*Phrynosoma cornutum*) and Swainson's hawk (*Buteo swainsoni*) are of special interest to the State. Marsh rice rat (*Oryzomys palustris*) is also on the Oklahoma list and its discovery at CHIC provided the first record for Murray County.

E.4.3.2. Geology / Soils

According to the CHIC Resource Management Plan (1999), beneath Murray County are late Pennsylvania and Permian shales, with abundant marine fossils. Brachiopods, echinoderms, trilobites, pelycopods, bryozoans, graptolites, and ostracodes have all been discovered within the park (Koch and Santucci 2003). The recreation area lies within the Arbuckle Uplift, which formed the Arbuckle Mountains. The mountains eroded over eons, washing successive layers of sandstone, shales and conglomerates into the lower elevation of the park. These strata include Vanoss group and Ada Formation, with soils that are deep, gently to strongly sloping, moderately well-drained, and loamy or clayey. They are in the Clarita-Durant-Burleson, Shidler-Claremore-Clarita, and Chigley-Clarita general soil map units. The largest soil type in the Platt District is Rayford Cobble loam, a moderate to well-drained prairie soil found south of the streams and covering slopes of 5 to 20 percent grade. Bedrock along stream channels, such as Rock Creek and Guy Sandy Creek, consist of alluvium and terrace Quaternary deposits. These Garvin-Elandco soils are level to gently sloping, moderate to well drained, deep clay and loam. The conglomerate rock of CHIC is a characteristic feature of the Platt District, utilized in various ways within the cultural landscape.

E.4.3.3. Land Use

Chickasaw National Recreation Area is bordered on the north by the City of Sulphur, while the remainder of the park is surrounded by ranch land and residential developments (Chickasaw

National Recreation Area 1999). Hay production is the primary agricultural enterprise (Stubbendieck and Willson 1986) on lands immediately bordering the park, but activities in Murray County have turned to poultry and dairy production, which produce concentrated wastes (Wikle et. al. 1998). Oil seeps on Rock Creek are evident but their cause is unknown – there are abandoned oil wells near the park but the seeps may be naturally occurring (Chickasaw National Recreation Area 1999). Several resorts and youth camps are also found in the area.

Land use and circulation patterns at the northern end of CHIC were established by the time the district became a reservation in 1902. The City of Sulphur and its residential and commercial infrastructure are closely entwined with the Platt District. The city maintains some main water lines and main sewer lines within the district, as well as a 4.5-acre (1.8 ha) sewage treatment plant which also serves the historic district. Commercial land uses north of CHIC on Rock Creek include cement operations, milk production and construction. Approval has been given for construction of a water pipeline from Lake Arbuckle to serve Sulphur and perhaps alleviate the depletion of spring flow within the park, but has not been implemented (Wikle et. al. 1998).

E.4.3.4. Hydrology

Water resources are the largest asset to CHIC and account for a majority of the annual visitation. The two largest water bodies at CHIC are Lake of the Arbuckles and Veteran's Lake, both man-made reservoirs. These lakes serve a variety of functions including recreation, flood control, and a potential municipal water source. Lake of the Arbuckles is supported by five streams, Rock, Guy Sandy, Buckhorn, Wilson, and Travertine Creeks. Wilson Creek also supports Veteran's Lake. Aquifers at CHIC can experience large fluctuations in water levels. Agricultural and industrial practices, residential areas, recreational impacts, exotic plant invasions, lake eutrophication, and illegal disposal sites are all posing threats to aquatic resources at CHIC. A basic water quality assessment was completed in 1997 by the WRD of the NPS.

E.4.3.5. Air Quality

Chickasaw National Recreation Area is designated a Class II air quality area. Air monitoring studies have not been conducted, but because of the rural nature of the surrounding area, air quality is considered good. The natural sulphur gases produced by some water wells can result in disagreeable odors. The City of Sulphur, as well as distant metropolitan areas can potentially affect the air quality of CHIC (Chickasaw National Recreation Area 1999).

The risk of foliar ozone injury to plants at Chickasaw National Recreation Area is high. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest when ozone levels are somewhat reduced and moist soils do not constrain the uptake of ozone. Foliar ozone injury can be assessed using one or more bioindicator species: white ash (*Fraxinus americana)*, American sycamore (*Platanus occidentalis)*, and skunkbush (*Rhus trilobata)* (National Park Service 2005).

E.4.3.6. Wildlife

- ***Mammals:*** The Oklahoma Biological Inventory conducted a survey of mammals May – August, 2003. They observed 22 species, of which 16 were on the predicted list of 25. Six new species records for Murray County were documented, including marsh rice rat (*Orozymys palustris*), which is tracked by the Oklahoma Natural Heritage Inventory (Kelly et al. 2004). Since 1920, the park has maintained a small (3-7) historical herd of bison (*Bison bison*) within an 84-acre (34 ha) enclosure. Species extirpated from CHIC include the black capped vireo (*Vireo atricapillus*), elk (*Cervis elaphus*), black bears (*Ursus Americans*), gray wolf (*Canis lupus*) and river otter (*Ultra condenses*) (Chickasaw National Recreation Area 1999).
- ***Birds:*** A survey conducted by the Oklahoma Biological Inventory from May to July, 2003 documented 85 species of birds. Species tracked by the Oklahoma Natural Heritage Inventory that were observed at CHIC include: Black Vulture *(Coragyps atratus)*, Canada Goose *(Branta canadensis)*, Cooper's Hawk *(Accipiter cooperii)*, Swainson's Hawk *(Buteo Swansonii)*, Spotted Sandpiper *(Actitis macularia)*, and Yellow Warbler

(*Dendroica petechia*) (Kelly et al. 2004). No federally threatened or endangered birds were detected. Historical sightings have been made of the endangered peregrine falcon, the least tern and the black-capped vireo, but not in recent years (Chickasaw National Recreation Area 1999). Six species of interest to Partners In Flight in the Oaks and Prairies physiographic region were detected: northern bobwhite (*Colinus virginianus*), scissor-tailed flycatcher (*Tyrannus forficatus*), Bewick's wren (*Thryomanes bewickii*), painted bunting (*Passerina ciris*), dickcissel (*Spiza americana*), field sparrow (*Spizella pusilla*).

- ***Reptiles & Amphibians:*** A survey conducted by the Oklahoma Biological Inventory from May to August, 2003, documented 36 species of reptiles (17 snakes, 11 lizards, 8 turtles). A search for amphibians resulted in observation of 9 species (Kelly et al. 2004). No state or federal listed threatened or endangered species were detected during the survey.
- ***Fish:*** A 1993 stream survey conducted by Tulane University's Museum of Natural History collected 21 species from 10 locations. No state or federally threatened or endangered species were found. Sites closer to the reservoir were found to have greater species diversity due to stream size and habitat overlap (the edge effect). Western mosquitofish (*Gambusia affinis*) were the most abundant fish documented, but only found in the Vendome Well run. Green sunfish (*Lepomis cyanellus*), orangethroat darter (*Etheostoma spectabile)* and central stoneroller (*Campostoma anomalum*) were the next most abundant and were found throughout the study areas (Taylor 1993). In 1995, fish population studies reported that approximately 22% of the gizzard shad (*Dorosoma cepedianum*) found in Arbuckle Reservoir had tumors near their dorsal fins. Subsequent investigations revealed that the appearance of these tumors dated back to the mid-70s and appeared on shad in other lakes within the same drainage as Arbuckle. Stocking of shad had occurred between these lakes in the past (Ostrander et. al. 1998). The cause of the tumors is unknown. Arbuckle Reservoir is relatively free of agents that have historically been associated with cancer in fish (Ostrander 2000).
- ***Arthropods:*** Fifty taxa of arthropods were collected in Travertine Creek during 1968-1969. No long-lived species were collected, possibly due to the sporadic nature of water flow (McKinley et. al. 1972). No state listed species of concern have been documented in the park, but surveys should be conducted for the Oklahoma cave amphipod (*Allocrangonyx pellucidus*) and prairie mole cricket (*Gryllotalpa major)* (Chickasaw National Recreation Area 1999).

E.4.3.7. Vegetation

There are no federally threatened or endangered plant species known to exist in the recreation area (Chickasaw National Recreation Area 1999). Oklahoma Biological Survey documented 582 taxa during an inventory in 2000 and noted there was a floristic affinity with the Edwards Plateau. Ten species are tracked by the Oklahoma Natural Heritage Inventory: woodland sedge (*Carex cephalophora* var. *cephalophora*), whitesheath sedge (*Carex hyalina*), pincushion cactus (*Coryphantha vivipara*, black dalea (*Dalea frutescens*), echinacea (*Echinacea paradoxa* var. *neglecta*), lace cactus (*Echinocereus reichenbachii*), Oklahoma penstemon (*Penstemon oklahomensis*), scurfpea (*Psoralea reverchonii*), shortlobe oak (*Quercus durandii* var. *breviloba*) and Ozark dropseed (*Sporobolus ozarkanus*). The *Quercus stellata–Q. marilandica* forest and woodland association was the most prevalent woody vegetation type. The most prevalent grassland vegetation is *Schizachyrium scoparium–Sorghastrum nutans*. They type specimen of *Echinacea paradoxa* var. *neglecta* was collected in 1968 at Platt National Park (Hoagland and Johnson 2001).

Chickasaw National Recreation Area lies in a transitional zone between the eastern deciduous forests and the mixed-grass prairie (Chickasaw National Recreation Area 1999) and is located in one of the more densely vegetated areas of the county (Hoagland and Johnson 2000). There is high habitat diversity in the Rocky Creek Corridor and Arbuckle District, while the original landscape in the Platt District is highly altered. The district is considered a naturalistic area rather than a natural one. The park is currently dominated by oak-hickory forest (Chickasaw National

Recreation Area 1999) and three types of grassland are present: the little bluestem (*Schizachyrium scoparium*) type occupies well drained mesic uplands; the hairy grama type occupies xeric uplands with thin, dry soils; and the reverchon muhly type occupies poorly drained, thin soils that are saturated in the spring and very dry in the late summer (Stubbendieck and Willson 1986). Grazing was allowed throughout much of the park until 1986 (Chickasaw National Recreation Area 1997) but continues today only within a fenced pasture containing reintroduced bison (Chickasaw National Recreation Area 1999).

Hoagland and Johnson (2000) conducted an analysis of historic vegetation at CHIC. According to 1871 surveys, only one residence was within park boundaries and road development was limited. The acreage of woody vegetation exceeded that of grassland and no agricultural fields were present. Tree ring data collected from Lower Rock Creek yielded post oaks 200 - 250 years old and a chinquapin oak aged 165. The oldest eastern red cedar in the area was an average estimate of 85 years old. The overall habitat was composed of trees growing in “islands” interspersed among grasslands of little bluestem and sideoats grama (*Bouteloua curtipendula*). First encountered in 1897, eastern red cedar (*Juniperus virginiana*) dominated the area in 1956 aerial photographs. This domination, currently estimated 36% of CHIC, was aided by Civilian Conservation Corps forestation efforts performed during the 1930s, when cedar was actively planted in the landscape of the Platt District (Chickasaw National Recreation Area 1999). Woody plant encroachment and the subsequent canopy cover has resulted in decreased species diversity (Hoagland and Johnson 1999). Vegetation management using prescribed fire began in 1998 in an effort to restore habitat health (Chickasaw National Recreation Area 1999).

*E.4.4. Management Issues*

The most significant natural resource at Chickasaw National Recreation Area is water – lakes, streams, creeks, springs and aquifers. Assuring that there will be continued flow of clean water from the springs will fulfill the original agreement with the Chickasaw Nation that brought the park into being. The establishment of clear water rights will assist in maintaining adequate groundwater levels and water quality. Encouraging the City of Sulphur to switch their public water supply to lake-based instead of relying on wells will also ensure more groundwater. Management of water level, flow and release at Arbuckle Reservoir falls to both the Corps of Engineers and the Bureau of Reclamation, while recreational opportunities and issues are overseen by the park service. This has recently included decisions on the appropriate use of personal water craft and monitoring levels of E. coli. The Water Resource Management Plan (1998) presents a list of long-term monitoring needs that addresses ongoing water issues at CHIC, “levels of biological hazards (fecal coliform); spring and stream flow; groundwater levels and relationship to surface flow; domestic and commercial withdrawal rates; evaluation of effects of CHIC operations; baseline inventories describing surface waters and groundwater flow; land use changes; inventory of historic ponds and evaluation of earthen dams” (Wikle et al. 1998). In-depth studies of the relationship of surface/ground water are currently underway in the park that will assist in future management decisions.

The second major issue confronting decision-makers at Chickasaw is the maintenance of its biotic integrity, specifically vegetation management and control of exotic/invasive species. Efforts continue to control the spread of eastern red cedar throughout the grasslands and woodlands of the Platt District and upper Rocky Creek Corridor. The cedar displaces native plants and alters the invaded habitats and animal populations. Fire suppression supports the establishment of cedar, which in turn limits groundwater recharge. Loss of grassland to woody encroachment, the overabundance of raccoons and the invasion of red imported fire ants have been cited by park managers as reasons for the decrease in quail and reptile populations. Feral dogs and cats from surrounding communities negatively impact native fauna while feral hogs root up native plants and cause erosion in riparian zones. The unauthorized harvesting of desirable native species, such as echinacea and cacti, and the inadvertent introduction of alien aquatic species threaten to deplete the native diversity of CHIC. Oklahoma Natural Heritage Inventory tracks numerous species of flora and fauna found in the park and the presence of several more species of concern

are suspected. It is imperative that the valuable natural resource that is biotic integrity be maintained and enhanced at Chickasaw.

Human use has been a historic factor in shaping the landscape of CHIC and continues to impact the park. The proximity of neighboring towns and communities affect water quality and supply, air quality, the soundscape and night sky. Boundary encroachment, hazardous spills on the highways and sewer spills from the system transversing the park are just a few examples of frequent management issues. The Platt District and its springs have been a long-standing cultural resource, providing a family gathering space for centuries. Construction and landscaping completed by the Civilian Conservation Corps in the 1930s resulted in classic "park architecture" in an area that currently receives up to 1.5 million visitors a year. These numbers of visitors and their recreational activities have a tremendous effect on natural resources, providing vectors for the introduction of exotic species and increasing levels of air/water/noise pollution. Fishing is a major recreational activity at Arbuckle Reservoir but the demand for sport fish has resulted in introduced genetics from outside the watershed and diminished populations of native fish.

Adjacent land use affects the park in several ways. Agricultural rowcropping and haying, chicken farms and feedlots often result in increased nitrates in the waterways and contaminants in the fishery. Oil and gas exploration and extraction impact the natural soundscape and introduce the possibility for additional pollution. Near-neighbor communities can complicate the prescribed fire process, often requiring additional education, permitting and safeguards to insure minimal disruption to their daily routine. All of these land uses increase the possibility for the introduction and harboring of invasive and exotic species.

*E.4.5. Partnering / Neighboring Agencies & Individuals*

E.4.5.1. Current Partners
Current: Oklahoma Dept. of Wildlife Conservation; USGS; East Central University; Chickasaw Nation

E.4.5.2. Potential Partners
Noble Foundation, Lifestyle Center of America, Goddard Youth Camp, NRCS – RC+D, OK Coop. Extension, Arbuckle Master Conservancy, Sulphur Schools, Murray County, City of Sulphur, Boy Scouts, Oklahoma State University

E.4.5.3. Neighboring Land Management Agencies:
Tishomingo NWR, Hagerman NWR, Wichita Mountains NWR, Caddo National Grassland, LBJ National Grassland, McGee State Park, Boggy Depot State Park, Lake Murray State Park, Blue River WMA, Texoma-Tishomingo WMA, Pontotoc Ridge Preserve (TNC), Tallgrass Prairie Preserve (TNC), Eisenhower State Park (TX).

*E4.6. Literature Cited*

Chickasaw National Recreation Area. 1997. Chickasaw national recreation area fire management plan.
Chickasaw National Recreation Area. 1999. Resource Management Plan.
Hoagland, B.W. and F.L. Johnson. 1999. Prairie restoration recommendations for the Guy Sandy area, CHIC, Murray county, Oklahoma. Oklahoma Biological Survey: Norman, OK.
Hoagland, B.W. and F.L. Johnson. 2000. Vegetation management plan for Arbuckle District, Chickasaw national recreation area, Murray county, Oklahoma. Oklahoma Biological Survey: Norman, OK.
Hoagland, B.W. and F.L. Johnson. 2001. Vascular flora of the CHIC, Murray county, OK. Castanea 66:383–400.
Kelly, J., J. Strong, J. Bahm and A.L. Cooper. 2004. Mammal, bird and herpetological inventory of CHIC NPS. Oklahoma Biological Inventory: Norman, OK.

Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. NPS TIC #D-107.

McKinley, R.E., R. Prins and L.E. Jech. 1972. Occurrence and distribution of arthropods in Travertine Creek, Platt National Park, Murray county, Oklahoma. Proceedings of Oklahoma Academy of Science 52:49-52Oklahoma Department of Wildlife Conservation. 2001. Survey report - Oklahoma fish management program: fish management survey and recommendations for Arbuckle Reservoir 2001.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Ostrander, G.K., D.R. Geter, W.E. Hawkins and J.C. Means. 1998. Further studies of fish neoplasms at the lake of the Arbuckles, CHIC. John Hopkins University: Baltimore, MD.

Ostrander, G.K. 2000. Continued expression of malignant neopl;asms in gizzard shad at Arbuckle Lake: ten years later. Final report. John Hopkins University: Baltimore, MD.

Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

Taylor, M.S. 1993. A preliminary survey of the fishes of CHIC, Sulphur, OK. Belle Chase, LA

Wikle, T., M. Nicholl. T. Brown, J. Nord, R. Parker, and D. Weeks. 1998. Water resources management plan: CHIC. Oklahoma State University; Stillwater, OK.

## E.5. FORT LARNED NATIONAL HISTORIC SITE (FOLS)

Fort Larned was built in October of 1859 to protect traffic along the Santa Fe Trail. It served as an agency for the administration of Central Plains Indians by the Bureau of Indian Affairs under the terms of the Fort Wise Treaty of 1861 and later as a key military base during the Indian War of 1868-1869. Fort Larned began its final mission in 1872 guarding the construction workers on the Santa Fe railroad. Fort Larned National Historic Site totals 718 acres (291 ha) including easements and is divided into two units. The Fort Larned unit survives as one of the best examples of Indian Wars period forts, containing nine restored buildings on 366 acres (148 ha). This unit is surrounded by an additional 308 acres (125 ha) of scenic easement leased to preserve the historic views. A second unit, the Santa Fe Trails Ruts site, comprises 44 acres (18 ha) of remnant prairie containing remnants of wagon ruts running its length. FOLS entertained 36,541 visitors in 2004.

### *E.5.1. Resource Overview*

Fort Larned National Historic Site is located in the South-central Great Plains section of the Great Plains Steppe Ecological Province at an elevation of approximately 2000 feet (610 m). The Fort itself is situated in central Pawnee County, on the banks and in the floodplain of the Pawnee River, approximately 6 miles (10 km) from its confluence with the Arkansas River in Larned, Kansas. The detached Trail Ruts unit is found on gently rolling uplands 4.5 miles (7.2 km) southwest of the Fort unit. Both units lie on the western edge of the mixed-grass prairie region of Kansas, characterized by grama grasses (*Bouteloua spp*.), buffalograss *(Buchloe dactyloides*), big bluestem (*Andorpogon geradii*), indian grass (*Sorgastum nutans*) and associated species (Choate et al. 1998). The Trail Ruts unit, while never plowed, has had its original prairie vegetation heavily impacted by grazing and prairie dogs. It is estimated that 76% of FOLS is formerly cropped grassland that has undergone continuing prairie restoration since 1964 (Delisle and Busby 2004). The riparian area of the Pawnee River is delineated by a narrow, meandering green swath through the prairie. Deforested during the occupation of the fort, this deciduous riparian woodland has regenerated and is now composed of cottonwood (*Populus deltoides*), ash (*Fraxninus spp.*), willow (*Salix spp.*), boxelder (*Acer negundo*) and other tree species (Choate et al. 1998). There are no known federally threatened or endangered plant or animal species at Fort Larned. Black-tailed prairie dog (*Cynomys ludovicianus*), a candidate for federal listing, have a long-standing colony at the Trail Ruts unit.

FOLS has a semi-arid continental climate, generally west of the flow of Gulf moisture and east of the Rocky Mountain rain shadow (Becker et al. 1986), with changeable temperatures and precipitation. The average maximum temperature of 89°F (31.5°C) June through August is made more bearable by a constant breeze and low humidity. The dry season of winter brings average minimum temperatures of 19°F (-7°C) December through February. Snowfall averages 20 inches (51 cm) annually and seldom persists longer than three days after a snow event (Becker et al. 1986). The average annual precipitation nears 23 inches (58 cm), with most of the moisture falling from intense thunder storms August through October. Winds are constant with only rare periods of calm (National Park Service 1979).

### *E.5.2. Enabling Legislation / Management Documents*

The National Park Service recommended that Fort Larned receive an historic site designation after a 1955 reconnaissance visit by Merrill Mattes. Fort Larned National Historic Site, through Public Law 88-541, was authorized by Congress on August 31, 1964 to “commemorate the significant role played by Fort Larned in the opening of the West.” Several Management Plans guide decision-making at FOLS, a 1994 General Management Plan Amendment, Developing Concept Plan and Interpretive Prospectus that updated a 1978 master plan; a 1986 Prairie Management Plan to guide prairie restoration efforts; and a 2001 Fire Management Plan that implements fire related management actions from other management documents.

*E.5.3. Natural Resources*

E.5.3.1. Valuable Resources / Species of Interest:
The black-tailed prairie dog is the most significant species at Fort Larned National Historic Site. This species has been long established at the Santa Fe Trail Ruts unit and is impacting the cultural resource of remnant wagon ruts. This keystone species of the prairie is providing a documented home for the burrowing owl (*Athene cunicularia*), a species of concern in neighboring states, and is suspected of providing residence for several species of herptiles. All of the biota at Fort Larned is highly valued because so many species have been displaced and reduced by intensive agricultural activities, hunting and trapping in the area.

E.5.3.2. Geology & Soils
The Fort Larned area is primarily underlain by cretaceous sandstone deposits of the Dakota Formation within the Central Kansas Uplift (Evans 1999). Fort Larned also lies within the Arkansas River lowlands of the Upper Arkansas drainage basin (Evans 1999), with Post-Kansan sediment deposits (younger than 0.39 million years old) (Ross 1991). The soils of the region are chiefly silt and clay loams from Pawnee River stream and flood deposits and fine wind deposits of the Tertiary and Quarternary formation. These soils are generally fertile, but poor soil moisture limits plant growth. Five soil series are present: the Bridgeport series is the most abundant soil at FOLS, consisting of deep, well drained, moderately permeable soils on low, occasionally flooded terraces. Harney, Hord and Uly series are all deep, well drained and moderately permeable soils, while the New Cambria series is slowly permeable (Stubbendieck et al. 1980). Soil at the Santa Fe Trail Ruts site is silty loam of the Harney series (Stubbendieck et al. 1980) compacted by years of intensive grazing. While erosion due to runoff is not a problem with sufficient root mass, silting from recently plowed agricultural fields is a threat to the wagon ruts (Evans 1999). Although no paleontological resources have been discovered, the potential to find fossils within the alluvium of FOLS does exist (Koch and Santucci 2003).

E.5.3.3. Land Use
The land at Fort Larned National Historic Site was heavily impacted during the fort's active period. Woodlands along the Pawnee River were decimated for firewood and the surrounding prairie was trampled and heavily grazed. The fort was decommissioned in 1978 and auctioned off in 1884 and was farmed until 1964. Row crop agriculture (wheat, alfalfa, sorghum) is still the predominate land use surrounding FOLS, with little surrounding land left uncultivated. Alternative agriculture uses such as feed lots are also found in Pawnee County, with a stock yard found to the north of the historic site. Petroleum production has gained in importance and there is activity within two miles of the fort. State highway 156 runs along the north side of the Fort. Land surrounding the Santa Fe Trail Ruts site is entirely row crop agriculture.

E.5.3.4. Hydrology
FOLS is located along the Pawnee River and most of the Park falls within the Pawnee River floodplain. The increased use of surface and ground waters for irrigation has decreased streamflow and complete drying of the streambed during the summer has become common in recent years. Furthermore, irrigation and other agricultural practices has facilitated soil erosion on the Pawnee River, which in turn has increased turbidity levels, and has eliminated much of the riparian vegetation. The overall deterioration of water quantity and quality has led to the decline of much of the resident aquatic life (Becker et al. 1986). The Kansas Geological Survey and the Kansas Water Resource Division are currently monitoring water quantity and quality at FOLS. A basic water quality assessment was completed in 2000 by the WRD of the NPS.

E.5.3.5. Air Quality
Fort Larned National Historic Site is a Class II air quality area. The rural location of the historic site places it at low risk for foliar ozone injury to plants. There are a few plant species at FOLS that are sensitive to ozone and two bioindicator species: common milkweed (*Asclepias syriaca*), and redbud (*Cercis canadensis*) (National Park Service 2005).

E.5.3.6. Wildlife

- ***Mammals:*** No federally threatened or endangered species have been documented at Fort Larned National Historic Site, nor are there listed species documented from Pawnee County (Delisle and Busby 2004). Several biological inventories have been performed for mammals. A 1989 study identified the deer mouse *(Peromyscus maniculatus)* and white footed mouse (*Permyscus leucopus*) as the most common mammals found at FOLS. A second study conducted in mid-August 1998 by Fort Hays State University documented 17 species out of the 53 species expected. In addition to the two mice listed above, the big brown bat (*Eptesicus fuscus*) was added to the most common list (Choate et al. 1998). The most recent study from April-May 2001 by the Kansas Biological Survey observed 23 species of mammals, including four species not previously documented at Fort Larned: northern raccoon (*Procyon lotor*), eastern fox squirrel (*Sciurus niger*), Virginia opossum (*Didelphis virginiana*), and plains pocket gopher (*Geomys bursarius*). It is possible that the eastern spotted skunk (*Spilogale putorius interrupta*), a listed species, could inhabit the riparian area of the Pawnee River (Delisle and Busby 2004). The black-tailed prairie dog has maintained a healthy colony on the Santa Fe Trail Ruts unit. Prairie dogs were common along the trail and this colony was already established at the time the park service took possession of the site. This FOLS colony is one of only two populations on NPS land that is not threatened with sarcoptic (bubonic) plague (Plumb and Willson 1997). A keystone species of the short-grass prairie, prairie dogs and their colonies provide food and shelter for a number of animals, including the endangered black-footed ferret (*Mustella nigripes*). The colony has been inspected annually since 1981 for ferret, but none have been observed (Becker et al. 1986). It is speculated that the colony may be too small and isolated to support black-footed ferret (National Park Service 2001). Concern that the burrowing and foraging activities of prairie dogs are threatening the trail ruts has led to strategies for relocating the colony away from the ruts themselves. Similar burrowing activities of pocket gophers (*Geomys bursarius*) within the Fort Larned building area are not so well tolerated (Evans 1999). Mule deer and white-tailed deer are the largest mammals seen at FOLS.
- ***Birds:*** .No federally threatened or endangered birds have been documented at Fort Larned National Historic Site. A breeding bird survey was conducted by Kansas Biological Survey during May-June 2001. Of the 78 predicted species, 57 (73%) were documented. The riparian woodlands provided the greatest species diversity, accounting for 48 (84%) of the documented species at FOLS, although the grassland species provided the greatest abundance of birds. Several new species for Pawnee County were identified: eastern screech owl (*Otus asio*), eastern wood-pewee (*Contopus virens*), eastern bluebird (*Sialia sialis*), gray catbird (*Dumetella carolinensis*), spotted towhee (*Pipilo maculatus*), and indigo bunting (*Passerina cyanea*). Fort Larned is located within the migratory path of several threatened or endangered species, including bald eagle (*Haliaeetus leucocephalus*), least tern (*Sterna antillarum*), piping plover (*Charadrius melodus*), snowy plover (*Charadrius alexandrinus*), and whooping crane (*Grus americana*) (Delisle and Busby 2004). Two avian species found on the Partners In Flight High Priority list for the Central Mixed-grass region have been documented at FOLS: Bell's vireo (*Vireo bellii*) and the dickcissel (*Spiza americana*).
- ***Reptiles & Amphibians:*** A survey conducted in 1997 by Fort Hays State University documented 17 species of reptiles and amphibians. The most abundant amphibians found at Fort Union were the Great Plains toad (*Bufo cognatus*) and Woodhouse's toad (*Bufo woodhousii*). The painted turtle (*Chrysemys picta*) was the most abundant turtle found. Three new records for Pawnee County were discovered during this survey: slider turtle (*Trachemys scripta*), false map turtle (*Graptemys pseudogeographica*), and the secretive Great Plains narrowmouth toad (*Gastrophyrne olivacea*) (Choate et al. 1998). A second survey completed in June 2001 by Kansas Biological Survey also observed 17 (49%) of the 35 predicted species of reptiles and amphibians (Delisle and Busby 2004).
- ***Fish:*** The 2001 biological survey conducted by Kansas Biological Survey identified 6 species of fish in the Pawnee River. As is often the case in summer, much of the streambed of deep muck was dry, resulting in shallow, isolated pools of highly turbid

water. The dominant species were those tolerant of poor water quality: black bullhead (*Ameiurus melas*), common carp (*Cyprinus carpio*), and fathead minnow (*Pimephales promelas*) (Delisle and Busby 2004).

E.5.3.7. Vegetation:

As early as 1827, historic accounts gleaned from diaries, reports and even sketches describe the historical landscape as being full of "good grass," with considerable tree cover along the riparian corridor of the Pawnee River. By 1867–1868, photographs show overgrazed and trampled prairie with hardly a tree in sight. One hundred years later, the vast majority of the prairie was turned into cropland while the perennial Pawnee River was reduced to dry streambed during the summer. Today, the story is one of "rehabilitation" of the landscape to evoke the historic period of the fort, while restoring and maintaining vital habitats and ecological function (Evans 1999).

Fort Larned is located in the mixed-grass prairie of the Great Plains, a transition zone between the tall-grass prairies to the east and the western short-grass prairies. It is estimated that at least 400 acres (162 ha) (60%) of FOLS is considered grassland habitat (Becker et al. 1986). The 44-acre (18 ha) Santa Fe Trail Ruts unit is entirely native prairie, having never been plowed. It had, however been heavily grazed for many years, resulting in a lack of tall-grass species (Stubbendieck et al. 1980). A few other small relicts of native sod have been identified on the Fort unit. Prairie restoration at Fort Larned began in 1968 with the seeding of blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*). Short-grasses were chosen for fear that tall-grasses would pose a fire hazard (Stubbendieck and Willson 1986). Roger Landers from Iowa State University, in a 1975 report, assessed the initial restoration efforts, described the vegetation found, and gave specific recommendations for mowing, seeding and burning. This was followed by additional management recommendations in a 1980 report by Stubbendieck, Wiederspan and Kjar. The management tool of mowing was augmented in 1983 by the onset of prescribed burning (Stubbendieck and Willson 1986). Donald Becker, in his 1985 vegetation survey, stated that most plots had made "a small but significant increase" in tall-grass species and established permanent survey transects. Becker also voiced concern that exotic plants, dominated by downy brome, covered large portions of the restoration prairie. Stubbendieck and Willson revisited the prairies at FOLS in their 1986 report, reporting that mid-grass cover was increasing even as the short-grasses remained static. Cool season exotic grasses still dominated several restoration units. Restoration efforts continue to this day. A combined regimen of seeding, prescribed fire and haying moves the prairie slowly closer to its climax stage. Control of smooth brome (*Bromus inermis*) and other exotics may be possible by continuing with controlled burns.

The remnant prairie found at the Santa Fe Trail Ruts site suffers from overgrazing, first from livestock (excluded since 1975), and now from prairie dogs. No tall-grass species remain. A need exists to relocate the prairie dogs to the periphery of the ruts site to prevent further destruction of the ruts features. Debate currently focuses on reintroducing tall-grass species to the ruts while managing the periphery as short-grass (Evans 1999). Prairie dogs prefer short-grass for safety reasons, so it is hoped that this strategy might succeed where other methods have failed. Smooth brome (*Bromus inermis*) is invading the Trail Ruts site from the roadside, while kochia (*Kochia scoparia*) is attacking from the neighboring fields (Evans 1999).

Restoration of the riparian woodlands has been achieved naturally. Predominant trees in this community include black willow (*Salix nigra*), boxelder, cottonwood, green ash (*Fraxinus pennsylvanica*) and slippery elm (*Ulmus rubra*). American elm (*Ulmus americana*) had been a major component of these woodlands, but by 1968 most had been killed by Dutch elm disease (Evans 1999). Small fragments of original prairie sod exist along the banks of the Pawnee River (Stubbendieck and Willson 1986), while western wheat grass (*Agropyron smithii*) or herbaceous weeds have replaced much of the original woodland groundcover (Becker et al. 1986). Although this woodland did not exist during the period of Fort Larned, it will be retained as a visual barrier to the highway traffic and as a corridor of high biotic diversity (Choate et al. 1998).

*E.5.4. Management Issues*

Prairie restoration tops the list of management issues. The restored grasslands surrounding Fort Larned represent some of the earliest attempts at re-establishing prairie. Perhaps the greatest difficulty is the control of exotic invasive plants while perennial grasses gain hold. Over 100 acres (40 ha) are still in need of active management to remove smooth brome, kochia and poison hemlock (*Conium maculatum*). In areas where grasses have successfully established, a lack of diversity in forbs has been discovered. Reintroduction of several missing species will result in a healthier ecosystem.

Of similar concern is the impact the prairie dog colony is having on the wagon rut features at the Santa Fe Trail Ruts unit. While a valued species of concern, the colony covers three-quarters of the site and is obliterating the very elements that caused that area to first be preserved. Neighboring landowners are concerned with the colonies spread into their agricultural fields. While deemed too small to support black-footed ferret, the colony is occupied at times by burrowing owl. Monitoring of burrowing effects will continue while methods of controlling and managing the population are explored.

Restoration of displaced ecological patterns has met with mixed results. The long-term suppression of wildfire at FOLS requires the implementation of prescribed burns as a management tool for prairie restoration. Begun in 1999, there is evidence that properly timed fire has affected the seed production and vigor of the problem invasive, smooth brome. Study must continue to determine how fires timing affects species selection in restoration situations.

Seasonal flooding along the Pawnee River will likely never be restored. Irrigation drawdown and impoundment has changed the river from a perennial, clear-flowing stream to an intermittent, turbid imitation of itself. Sedimentation from erosion of agricultural fields has covered the original sand bottom with 10 feet (3 m) or more of muck. Efforts continue to insure that FOLS acquire and maintain enough water rights to insure that the Pawnee River is replenished.

Preservation of the viewsheds at FOLS is vital to providing visitors a historic impression of life at the fort. This can be accomplished with continued landowner cooperation and scenic easements. While the view from south of the fort is evocative of the historic isolation, this is not the case of scenes from other directions (Evans 1999). Threat of unsuitable land use of surrounding properties will continue. Wind farms have been proposed to take advantage of the constant breeze and feedlots continue to be an ominous possibility.

*E.5.5. Partnering / Neighboring Agencies*

E.5.5.1. Current Partners
Fort Hays State University, Kansas State University, Kansas Ornithological Society. Kansas Biological Survey, NRCS

E.5.5.2. Neighboring Land Management Agencies:
Quivira NWR. Cheyenne Bottoms Waterfowl Management Area, Sand Hills State Park, Cheney State Park, Kanopolis State Park, Smokey Valley Ranch (TNC), Cheyenne Bottoms Preserve (TNC); Konza Long Term Ecological Research

*E.5.6. Literature Cited*

Becker, D.A., T.B. Bragg and D.M. Sutherland. 1986. Vegetation survey and prairie management plan for Fort Larned National Historic Site. Ecosystems Management: Elkhorn, NE.

Choate, J., M.D. VanDoren, C.J. Schmidt, and K. Chapman. 1998. Mammal and reptile inventory and monitoring program: Fort Larned National Historic Site. Fort Hays State University.

Delisle, J.M. and W.H. Busby. 2004. Biological inventory for vertebrates at Fort Larned National Historic Site of the Southern Plains Network. Kansas Biological Survey. Report No. 103.

Evans, Q. 1999. Fort Larned National Historic Site: cultural landscape report. Land and Community Associates. Contract #1443PX600095819.
Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. National Park Service. TIC #D-107.
National Park Service. 1979. Assessment of alternatives: natural resource management, Fort Larned National Historic Site. Fort Larned National Historic Site, Midwest Regional Office.
National Park Service. 2001. Fort Larned National Historic Site: fire management plan.
National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.
Plumb, G. and G. Willson. 1997. Black-tailed prairie dog inventory and monitoring in the NPS. Draft report.
Ross, J.A. 1991. Geological map of Kansas. Kansas Geological Survey. scale 1:500,000.
Stubbendieck, J., C.J. Wiederspan and K.J. Kjar. 1980. Prairie restoration: an evaluation and specific recommendations for management. Natural Resource Enterprises, Lincoln, NE.
Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E.6. FORT UNION NATIONAL MONUMENT (FOUN)

Fort Union National Monument is comprised of 721 acres (292 ha) of short-grass prairie contained within two separate units, located in northeastern New Mexico, approximately 10 miles (16 km) northwest of Watrous and Valmora in Mora County. Established in 1851, Fort Union served the region for forty years as a military supply depot, arsenal, and frontier military post protecting the Mountain Branch of the Santa Fe Trail. Three successive forts were constructed in the area, and the majority of the remains of each fort are contained within the monument boundaries, resulting in the largest grouping of adobe ruins in the United States (Johnson et al. 2003a). Wolf Creek divides the largest unit of 637 acres (258 ha), containing the remains of two forts, from the disjunct 84 acre (34 ha) second unit that contains remnants of the original fort (Muldavin et al. 2004). Of additional significance, the monument encloses the remnants of the largest accumulation of Santa Fe Trail ruts (Koch and Santucci 2003) in the US. FOUN continues to be surrounded by a 96,000-acre (38,850 ha) cattle ranch that pre-dates the 1891 closure of the fort (Johnson et al. 2003a).

### *E.6.1. Resource Overview*

The monument, at an elevation of 6,800 feet (2,073 m), is located in a wide valley of Wolf Creek, on the southwestern fringe of the Great Plains. Annual precipitation is 16-20 inches (41 - 51 cm), with the majority of rain falling from May to September, results in a semi-arid climate with notable periods of wind (Muldavin et al. 2004). Fort Union is in a region of the heaviest thunder and lightening regions in the nation (Fort Union National Monument 2000). Temperatures range from an average high of 80°F (27°C) from June to August to an average low of 14°F (-10°C) for December to February, with daily temperature fluctuations of 30°F (16.8°C) or more. Annual visitation at FOUN totaled 13,117 people in 2004.

### *E.6.2. Enabling Legislation / Management Documents*

Fort Union National Monument was congressionally authorized by Public Law 83-429 on June 28, 1954, "to preserve and protect, in the public interest, the historic Old Fort Union, situated in the county of Mora, State of New Mexico, and to provide adequate public access thereto. . . ." The monument was formally established by the National Park Service on April 5, 1956. Additionally, under Public Law 100-35, the 100$^{th}$ United States Congress authorized the Santa Fe National Historic Trail on May 8, 1987 to commemorate the over 1,100 mile-long Santa Fe Trail from Old Franklin, Missouri to Santa Fe, New Mexico.

According to the Fort Union National Monument Resource Management Plan (2000), the “Mission of FOUN is to preserve the ruins of the historic fort, to provide for public access, and to educate the public about its significant role in the American Southwest, the Santa Fe Trail, and the development of United States rules in the Southwest.” The Resource Management Plan is a strategic planning document for management and conservation of the cultural and natural resources of Fort Union. Objectives of this planning document pertaining to natural resources include the desires to: “preserve and manage the resources, and to maintain and perpetuate the integrity of the historic remains of the three forts, the archeological resources, and the historic landscapes; … increase knowledge, understanding, and appreciation of both the natural and cultural resources;” and “… instill an awareness and sensitivity toward the fragility of the resources and the need for continued preservation and protection.” These stated objectives are in keeping with those of the 1984 General Management Plan and Environmental Assessment, which

included an additional objective “to seek a continuation of compatible activities on lands adjacent to the monument to protect the fort’s historic scene.”

*E.6.3. Natural Resources*

E.6.3.1. Valuable Resources / Species of Interest:
The most significant natural resource at Fort Union National Monument is the native short-grass prairie community. After bearing the brunt of tremendous historical use reflected in current vegetation patterns (Muldavin et al. 2004), the short-grass prairie has begun to tentatively restore itself after grazing was halted in 1956. There are no threatened or endangered species of plants or animals documented within the monument. Swainson’s hawk (*Buteo swainsoni*) and Prairie falcon (*Falco mexicanus*) have both been observed at FOUN and are on neighboring Oklahoma’s list. The adobe ruins may provide habitat for breeding and migrating birds, as well as roosts for bats and shelter for reptiles (Johnson et al. 2003a).

E.6.3.2. Geology & Soils
Fort Union is located on the east side of a southward trending valley of Wolf Creek, a tributary of the Mora River. The valley is bordered to the west by a prominent sandstone mesa and on the east and northeast by the Turkey Mountains (Fort Union National Monument 2000). The primary geologic formation exposed at FOUN is the Upper Cretaceous Graneros Shale. No fossils have been discovered within the park, although they have been found elsewhere in New Mexico from this same formation (Koch and Santucci 2003). Layers encountered in drilling the monument well were: top soil and gravel (first 7 feet [2 m]), black shale (7-140 feet [2-43 m]), white limestone (140-150 ft [43-46 m]), sandstone (150-300 ft [46-91 m]) and blue sandy shale (300-325 ft [91-99 m]) (Southwest Region 1984). Soils at FOUN are classified as Aridic Argiustolls, largely comprised of silt and stony (Partri) loams formed in alluvial material from the adjacent basalt formations and other eolian material, ranging in depth from very shallow to moderate, and unstable when devegetated (Freitag 1994).

E.6.3.3. Land Use
Fort Union is located in Mora County, an area of sparse population and low growth, where ranching is the predominant land use. The land immediately outside of the monument has been owned by the Fort Union Cattle Ranch since the early 1900’s and has been grazed since that time (Fort Union National Monument 2000).

E.6.3.4. Hydrology
FOUN contains no surface water resources within its boundaries but Wolf Creek, adjacent to the Park, intermittently produces small springs and seepage areas within the Park. Drought is increasing the susceptibility of FOUN to exotic plant invasions, so insufficient water resources is a concern to Park managers. Another concern is the potential for anthropogenic sources of contaminants being introduced to the groundwater, particularly from nearby ranching operations, storm water runoff, recreational use, and atmospheric deposition. FOUN personnel collect groundwater samples twice a month for bacteriological analyses and results have consistently complied with health standards. A basic water quality assessment has been completed (National Park Service 1998).

E.6.3.5. Air Quality
FOUN is a National Park Service Class II air quality area. No qualitative air data exists for the FOUN region and there are no air quality concerns at present (Fort Union National Monument 2000). The low levels of ozone exposure make the risk of foliar damage to plants negligible. While there are a few ozone-sensitive plants at FOUN, there are no bioindicator species at the site (National Park Service 2005).

E.6.3.6. Wildlife

- ***Mammals:*** Natural Heritage New Mexico surveyed FOUN during 2001 and 2002. They documented 16 species of mammals. Bats were not surveyed but were observed and tentatively identified as Mexican free-tailed bats (*Tadarida brasiliensis*). Ord's kangaroo rat (*Dipodomys ordii)* was the most commonly caught species in the grassland. Two elk bulls (*Cervus elaphus*) and large herds of pronghorns (*Antilocapra americana*) have been observed near the park boundary (Johnson et al. 2003b).
- ***Birds:*** Natural Heritage New Mexico surveyed FOUN during 2001 and 2002 and detected 52 species during the breeding season. Of these, 32 species (55.2%) were found in grassland habitats, 25 species (43.1%) were found in piñion-juniper habitats, and riparian habitats accounted for 20 species (34.5%). Brown-headed cowbird (*Molothrus ater*) was the most commonly detected bird, with 48.5% of detections. Cliff swallow (*Petrochelidon pyrrhonota*) and western meadowlark (*Sturnella neglecta*) were the second and third commonest species, with 13.3% and 12.2% of total detections, respectively (Johnson et al. 2003a). Six species of birds listed as high priority on the Partners In Flight Watch List for the "Physio 85 Mesa and Plains" region have been documented at Fort Union: Swainson's hawk (*Buteo swainsonii*), black-chinned hummingbird (*Archilochus alexandri*), canyon towhee (*Piplio fuscus*), Cassin's sparrow (*Aimophila cassinnii*), Cassin's kingbird (*Tyrannus vociferans*), and Virginia's warbler (*Vermivora virginiae*). As the short-grass prairie continues to improve, it may be possible to encourage the residence of several nearby species of interest - burrowing owl (*Athene cunicularia)* is known to inhabit the area, mountain plover (*Charadrius montanus*) might be found near, ferruginous hawk (*Buteo regalis*) and peregrine falcon (*Falco peregrinus*). The absence of livestock grazing on FOUN has apparently encouraged diversity of grassland birds, especially ground- and shrub-nesting birds and has probably allowed the persistence of a small marshy area near the westernmost corner of the monument. The stabilization of historical structures has also allowed nesting by several species favoring cavities for nest placement. Clusters of planted and naturally-occurring deciduous trees have likely also encouraged canopy birds, while modern building structures provide nesting substrates for others (Johnson et al. 2003a).
- ***Reptiles / Amphibians:*** Natural Heritage New Mexico surveyed FOUN during 2001 and 2002 and documented only 9 reptile and amphibian species. Severe drought during the survey period likely affected these results. Lack of habitat diversity, the small size of the park and its proximity to grazed rangeland may also reduce the number of species that permanently inhabit the monument (Johnson et al. 2003b).

E.6.3.7. Vegetation

FOUN is located in the southern parks and ranges section of the Southern Rocky Mountain Steppe ecoregion. An assessment of prairie carried out by Stubbendieck and Willson (1986) classified the majority of the monument as native prairie "in excellent condition," with blue grama as the dominant grass. The Grama-Buffalograss groundcover was thought to be similar to that of 1884 (Stubbendieck and Willson 1986). A more recent survey of vegetation by Natural Heritage New Mexico in 2004 described the plant life at FOUN as relatively diverse, with the short-grass prairie still dominant yet reflecting the impacts of historic use. Drought was prevalent during the three summer seasons of this survey, resulting in the identification of 142 taxa, 16 plant associations and 11 alliances. The most abundant grass was blue grama (*Bouteloua gracilis)*, the characteristic species of the short-grass prairie, and the most common associations were the Blue Grama/Fringed Sage Grassland (*Bouteloua gracilis/Artemisia frigida*) and the Blue Grama-Purple Threeawn (*Bouteloua gracilis-Aristida purpurea*), indicative of a long disturbance history. The remnants of the Santa Fe Trail have a different vegetation pattern - hairy grama (*Bouteloua hirsuta*) is associated with more compacted soils, while

western wheatgrass (*Agropyron smithii*) and sleepygrass (*Achnatherum robustum*) reflect the concentration of water in the trails during rainfall events. The most diverse vegetation community at FOUN is found around the seeps and springs along the lower western slope of the monument (Muldavin et al. 2004).

There is little need for restoration efforts at FOUN, although management strategies need to be investigated. Lack of grazing on these prairies, while initially beneficial, may now limit range improvement. The reintroduction of fire, of interest to the surrounding landowner, and should be explored.

The vegetation survey carried out by Natural Heritage New Mexico found only twelve species they considered “non-native alien introductions,” with none posing significant threats to native species (Muldavin et al. 2004). An earlier survey points out revegetation efforts on disturbed areas had been unsuccessful, allowing an influx of invasive species (Johnson et al. 2003a). A noxious weed inventory conducted March to August, 2003, determined that field bindweed (*Convolvulus arvensis*) was the only exotic species of concern, occupying an estimated 3.3 acres along the roadside and in the residence area. Many of the other exotic species identified at FOUN were only found in the low, wet area adjacent to Wolf Creek (Natumalani et al. 2004). In all cases, vigilance against infestation of disturbed areas was recommended as the major control method for Fort Union.

*E.6.4. Management Issues*

The most critical natural resource issue at Fort Union National Monument is “the need for effective means of dealing with unwanted vegetation and the problems of burrowing mammals” (Fort Union National Monument 2000). Botta's pocket gophers (*Thomomys bottae*), rabbits and other rodents are excavating large patches of monument. Many soils in and around the ruins that have been recently deposited or dug up for other purposes have become ideal habitats for these animals (Muldavin et al. 2004). This small mammal community that includes mice, voles, shrews and moles also provides a possible vector for introduction of diseases such as hanta virus and bubonic plague. Efforts at revegetation with native grasses following disturbance has met with limited success, resulting in invasive species colonizing these areas. While invasive plant species are not welcome, the establishment of native vegetation within the perimeter of the stone foundations of the ruins is desired by the park management, but as yet unattained (Johnson et al. 2003a).

The expansive landscape surrounding Fort Union is an important part of the monument’s story, and preservation of the historic scene is a goal stated in the monument’s General Management Plan. Possible intrusions on the historic scene could include a variety of incompatible land uses: both mining and timber harvesting in the Turkey Mountains have been considered in the past. Power lines, road improvements and resort/retirement residential developments are examples of other activities that could intrude on the fort’s pristine setting. The National Park Service maintains a dialog with the owners of the surrounding range land, regional utilities, and transportation agencies to encourage compatible uses of land within the Fort’s viewshed (Fort Union National Monument 2000).

The drought/monsoon cycle is well documented in northeastern New Mexico, bringing its own unique set of stressors. The deep drought experienced from 2001 – 2004 may be broken in 2005 by an expected shift in the El Nino weather pattern. Periods of drought stress the prairie ecosystem and provide beneficial conditions for hanta virus. Fortunately, the historic dust storms from the days of “Fort Windy” are no longer a problem now that vegetation has been re-established, yet dust particles are still lifted into the atmosphere, affecting air quality.

The need to introduce fire as a management tool for the short-grass prairie has been discussed. While prairie fire is thought to increase biodiversity and reinvigorate ecosystem processes, the effects of various intensities and frequencies on more arid short-grass systems must be explored. Use of this management tool is limited by the size of the monument and the need to protect the cultural resources, bur there are areas within the monument that may benefit from a prescribed burn (Muldavin et al. 2004).

The ruts of the Santa Fe Trail have either grown over with vegetation that threatens to obscure them or have eroded into active arroyos. Stabilizing erosion by revegetating affected areas runs the risk of obscuring the ruts with vegetation. It is hoped that a balance between erosion and vegetative deposition can be found to preserve these cultural relics (Muldavin et al. 2004).

*E.6.5. Partnering / Neighboring Agencies*

E.6.5.1. Current Partners
New Mexico Natural Heritage Program, Great Plains Cooperative Ecosystems Study Unit, USFWS, Soil Conservation Service.

E.6.5.2. Potential Partners
Highlands University; Weed Management organizations.

E.6.5.3. Neighboring Land Management Agencies:
Coyote Creek State Park, Colin Neblitt Wildlife Area, Las Vegas NWR, Maxwell NWR; Area in Wagon Mound.

*E.6.6. Literature Cited*

Fort Union National Monument. 2000. Resources management plan.
Freitag, A.L. 1994. Cultural landscape study of Fort Union National Monument. Thesis. University of Pennsylvania.
Johnson, K., G. Sadoti, G. Racz, J. Butler and Y. Chauvin. 2003a. National Park Service Southern Plains Network: final inventory report for New Mexico parks. Natural Heritage New Mexico. Albuquerque, NM.
Johnson, K., J. Butler and G. Racz. 2003b. Fort Union National Monument reptile, amphibian, and mammal inventory: final report. Natural Heritage New Mexico. Albuquerque, NM. Publication No. 03-GTR-254
Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. National Park Service. TIC #D-107.
Muldavin, E., Y. Chauvin, A. Browder and T. Neville. 2004. A vegetation survey and map of Fort Union National Monument Park, New Mexico. Natural Heritage New Mexico. Albuquerque, NM. Coop Agreement No. 1443CA125000008.
National Park Service Water Resources Division. 1998. Baseline water quality data inventory and analysis: FOUN. Technical Report NPS/NRWRD/NRTR-98/176.
National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.
Natumalani, S., S. Tunnell, G. Wilson, J. Burkholder and D. Mishra. 2004. Noxious weeds inventory and mapping at Capulin Volcano National Monument, Fort Union National Monument, and Lake Meredith National Recreation Area. Cooperative Agreement Modification H60000A0100R.
Southwest Region. 1984. General management plan/environmental assessment, Fort Union National Monument, Mora county, New Mexico. Draft. National Park Service. Santa Fe, NM.
Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E.7. LAKE MEREDITH NATIONAL RECREATION AREA (LAMR)

Lake Meredith National Recreation Area (LAMR) is located approximately 21 miles (34 km) North of Amarillo in the Panhandle of Texas. The park itself extends approximately 22 miles (35 km) across portions of Potter, Moore, and Hutchinson counties. Contrasting spectacularly with its surroundings, LAMR lies on the dry and windswept High Plains of the Texas Panhandle in a region known as Llano Estacado, or Staked Plain. The 46,349-acre (18,757 ha) national recreation area includes a 10,000-acre (4,047 ha) reservoir formed in the 1962 with the construction of Sanford Dam. Lake Meredith is the largest lake in the Texas and Oklahoma panhandles and was constructed primarily to supply water to the surrounding communities, with recreation as a secondary use. LAMR contains valuable cultural and natural resources. The National Park Service has administered LAMR since 1965, initially called Sanford Recreation Area. In 1972, it was renamed Lake Meredith Recreation Area, and in 1990 it was renamed Lake Meredith National Recreation Area and officially became a unit of the NPS. The park hosted 806,481 visitors in 2004.

### *E.7.1. Resource Overview*

LAMR is located on the High Plains of the Llano Estacado, specifically along the Breaks created by the Canadian River as it meanders west-east across the Texas Panhandle. Much of LAMR is in the category "Rough Broken Land" that can be divided into Mesa Top, Gravelly Slope, Steep Slope, and Bottomland. This area of Texas is comprised of gently rolling to moderately rough topography. Narrow, intermittent stream valleys flowing east to southeast dissect it. The Canadian River rises in the Sangre de Cristo Mountains of New Mexico and flows eastward across the semiarid Texas Panhandle and into Oklahoma, with a total watershed is approximately 13,000 square miles (33,670 km). The river has carved a narrow, steep-walled canyon from 197-295 feet (60-90 m) deep and up to 2 m (3.3 km) wide. Between this canyon and the surrounding caprock, many tributary streams have created a rough and broken topography, known as the Canadian River Breaks.

The Canadian River Basin climate is characterized as semi-arid with an average annual rainfall of 20 inches (51 cm) per year. Seventy percent of the precipitation falls between April and September, which is the primary growing season. This area has hot summers and cold winters with strong winds that work to increase evaporation rates, which have been estimated to average 60-65% of the total precipitation. The elevation ranges from 2800 to 3320 feet (853-1,012 m).

Sanford Dam is on the Canadian River about 38 miles (61 km) northeast of Amarillo. It is an earthfill structure 198 feet (60 m) high with a crest length of 6,380 feet (1,945 m) and a total volume of about 15,000 cubic yards. The dam impounds a reservoir with a capacity of 1,408,000 acre-feet. Lake Meredith provides an average of about 103,000 acre-feet annually for municipal and industrial uses to supplement existing ground-water supplied for eleven cities. The Canadian River is dry below the Sanford dam, which has not been opened in recent years to release water. Groundwater occurs primarily in the Ogallala aquifer, which lies uncomfortably above older rock units of the Cretaceous, Triassic, Jurassic and Permian formations. Substantial amounts of useable water are found in the Cretaceous, Triassic, and Jurassic rocks; however, water within the Permian has been found to be saline and unusable.

### *E.7.2. Enabling Legislation / Management Documents*

Lake Meredith National Recreation Area became a National Park System (NPS) unit by a series of agency actions between the NPS and the Bureau of Reclamation (BOR) spanning approximately four decades. The interaction between the BOR and the NPS began when Congress passed the Canadian River Reclamation Project Act of December 29, 1950, authorizing the BOR to design and construct the Sanford Dam and Reservoir (Public Law 81-898, 64 Stat. 1124). The dam's purposes included irrigating land, delivering water for industrial and municipal

use, controlling floods, providing recreation and fish and wildlife benefits, and controlling and catching silt.

In 1953, the NPS determined that the reservoir would provide valuable recreational uses for Texas Panhandle residents. The NPS, however, found that the reservoir lacked national significance and suggested that the state or the neighboring cities administer the recreation area. Between 1953 and 1961 the Department of the Interior adopted policies requiring its agencies to evaluate federal reservoir projects for public benefits associated with recreation and wildlife. Consistent with this policy, the NPS and the BOR signed a Memorandum of Understanding and Agreement on June 26, 1961 that required the NPS to investigate, to plan, and to develop a recreation area at the Sanford Reservoir.

To insure that the reservoir would provide recreational uses for the public, Congress passed an Act in August 31, 1964 that authorized the Secretary of the Interior "[t]o provide for the establishment and [the] administration of public recreational facilities at the Sanford Reservoir area..." (78 Stat. 744). This act caused the Sanford Dam and Reservoir to be known as the Sanford Recreation Area. After Congress passed the act, the Canadian River Municipal Water Authority (CRMWA) and the BOR entered into an agreement allowing the CRMWA to administer the area or to recommend an agency to administer the area. The CRMWA suggested, and the BOR agreed, that the NPS should assume administration of the reservoir's public uses because the NPS had access to development capital and had experience at administering multipurpose reservoirs.

To transfer the administrative duties, the NPS and the BOR signed a Memorandum of Agreement on March 15, 1965. The agreement allowed the NPS to "establish policies, rules, and regulations relating to public outdoor recreational use and occupancy of lands and water available for such use." The agreement also divided Sanford Recreation Area into two segments for operation and for maintenance. The first segment, which the BOR administered, included land and water needed for the construction, the operation, and the maintenance of the dam. The NPS administered the second segment, which encompassed land and water used for recreation and for fish and wildlife enjoyment.

By Public Law 101-628 (16 U.S.C. § 460eee), on November 28, 1990, Congress renamed Lake Meredith Recreation Area as a National Recreation Area, "to provide for public outdoor recreation use and enjoyment of the lands and waters associated with Lake Meredith in the State of Texas, and to protect the scenic, scientific, cultural, and other values contributing to the public enjoyment of such lands and waters." This change "codified the long-standing administrative arrangements between the BOR and the NPS" (136 Cong. Rec. 17,473), and made Lake Meredith National Recreation Area a National Park System unit emphasizing the importance of protecting and interpreting the natural and cultural resources of the park.

There has been no General Management Plan created for LAMR. The most recent Resource Management Plan was completed in 1996 (Lake Meredith National Recreation Area 1996). Other pertinent management documents include an oil and gas management plan developed in 2002 (Lake Meredith National Recreation Area 2002), a personal watercraft use assessment in 2003 (Lake Meredith National Recreation Area 2003), and an economic analysis of personal watercraft (National Park Service 2003a).

*E.7.3. Natural Resources*

E.7.3.1. Valuable Resources / Species of Interest

Federally listed species documented at LAMR are the Bald Eagle (*Haliaeetus leucocephalus*) and Arkansas River Shiner (*Notropis girardi*). The portion of the Canadian River from the boundary of the park to the confluence with Coetas creek was formally designated by US Fish and Wildlife Service as critical habitat for the shiner. Other documented state-listed species or species of

concern include Texas Horned Lizard (*Phrynosoma cornutum*) and Ferruginous Hawk (*Buteo regalis*).

E.7.3.2. Geology / Soils

Five geologic formations outcrop in the vicinity of the parks, and from oldest to youngest include the Permian Quartermaster Formation, Triassic Dockum Group, Tertiary (Miocene-Pliocene) Ogallala Group, Pleistocene terrace deposits, and Holocene alluvium. Soil groups include Burson-Quinlan-Aspermont, Mobeetie-Tascosa, Acuff-Palo Duro-Olton, Tascosa Burson and Dumas-Dalhart.

The soils in the Lake Meredith area can be characterized as moderately deep to very deep, nearly level to strongly sloped, fine sandy loams to clay loams (USDA, SCS, Soil Surveys 1975, 1976, and 1980). In areas with steeper slopes, the soils tend to be shallow (10 to 20 inches [25-51 cm]), well drained, calcareous, loamy to gravelly soils with variable amounts of rock fragments. These soils are also associated with rock outcrops in the park. Soils on steep slopes are highly susceptible to water erosion and moderately susceptible to wind erosion. On the gentler slopes away from the reservoir, are very deep, well drained, calcareous clay loam soils. The hazard of water erosion is severe and the chance of wind erosion is moderate in these areas. On nearly level floodplain areas in the upper reaches of the reservoir, there are deep, calcareous soils that are subject to flooding about once every three to five years. Locally there may be hydric soils and wetlands in these floodplain areas. These soils are slightly susceptible to water erosion, but soil compaction may be a problem in these areas. On the flat areas above the reservoir, there are areas of dunes and other sandy deposits. These areas are highly susceptible to wind erosion. Problems associated with soils in the LAMR area are generally related to soil texture (grain size) and slope. Unprotected areas are subject to blowing soils and water erosion. In the parks, soil compaction, erosion, and slumping occurs along roads, drillpads, and flowlines, gathering lines and pipelines. Erosion tends to increase where vegetation has been removed and cut and fill activities have occurred. Accelerated erosion is more prevalent on steeper slopes and other disturbed areas in the parks.

The formation of the Canadian River Breaks was caused by several geologic processes. Recent research indicates that subsurface salt layers in Permian Formations about 2,000 feet (610 m) below the surface dissolved, collapsing the overlying deposits. Surface drainage concentrated in the lower areas and created the pathway for the present-day Canadian River. During wetter periods over the past several million years, the Canadian River eroded down through the Ogallala Formation, deepening the canyons or “breaks”. Further evidence of salt dissolution is obvious in the vicinity of the parks where subsurface salt deposits have dissolved leaving depressions on the surface. In addition, the salinity of the Canadian River (3,000 parts per million) suggests that salt dissolution is still occurring today near the Canadian River (Spearing 1991).

E.7.3.3. Land Use

Lake Meredith National Recreation Area is located within the Panhandle Field which covers about 1,475,000 acres (596,911 ha), of which approximately 1,000,000 acres (404,685 ha) produces sweet gas and about 400,000 acres (161,874 ha) produces sour gas with hydrogen sulfide. This field also produces around 250,000 acres (101,171 ha) of crude oil (Thompson 1939). In the vicinity of the parks, the oil and gas producing area is called the Panhandle West Field.

Lake Meredith is the largest lake in the Texas and Oklahoma panhandles and is consistently, one of the top NPS Intermountain destinations in terms of visitation. In addition to water recreation, people come from a four-state area to hunt, fish, ride horseback, use motorcycles and dune buggies in the off-road vehicle areas, and to camp at numerous spots both near and away from the water. Ranching, extractive activities and vacation development are the current primary land uses in the area surrounding LAMR.

E.7.3.4. Hydrology

Lake Meredith was created when the Bureau of Reclamation constructed the Sanford Dam on the Canadian River. The reservoir was created to supply water to eleven surrounding communities, with recreational use a secondary purpose. Below the dam is a perennial stream that originates from two or more springs, but seldom flows more than 100 yards (91 m), except during periods of heavy rainfall. Also below the dam are several small artificial lakes and a large wetland, all of which are a result of the Sanford Dam. The largest of these artificial water bodies is the Stilling Basin, designed to still the water when it leaves the flood gates. This area is the most popular swimming area at LAMR. The Ogallala formation underlying LAMR is the most important aquifer to this area. It contributes to the water supply for farming, ranching, commercial and domestic uses. The heavy use of water from this aquifer is lowering the water table at a rate of 2-3 feet (61- 91 cm) per year. Ninety-nine percent of Lake Meredith is designated as impaired on the federal 303(d) list because of mercury contamination. Water quality and quantity are the most important natural resource concerns for LAMR. Erosion, exotic plant and animal invasions, non-point source pollution and recreational impacts are among the most significant factors affecting water quality. Reclamation of abandoned oil and gas and prairie restoration can lead to improved groundwater recharge of upland areas. A basic water quality assessment was completed in 2001 by the WRD of the NPS.

E.7.3.5. Air Quality

An air emissions inventory was completed in 2003 (National Park Service 2003b). LAMR is designated as a Class II area under the Clean Air Act. Ambient (i.e., ground level) concentrations of sulfur dioxide, nitrogen oxides, ozone, and particulate matter are not routinely monitored but are presumed to be in compliance with the National Ambient Air Quality Standards. The only nearby ambient monitoring was conducted until 1996 in Amarillo, Texas for PM-10 (particles with an aerometric diameter of 10 microns or less). All monitored values indicated compliance with the PM-10 NAAQS standard (highest 24-hour measurement of 60 micrograms per cubic meter compared to the 150 ug/m3 standard). Ozone levels in the project area are unknown at this time. The potential addition of nitrates and volatile organic compounds, the primary precursors for ozone formation, to those already present in the area from existing oil and gas-related activities and energy production, may justify monitoring ozone levels to track the cumulative impact of these activities on ambient ozone levels (Lake Meredith National Recreation Area 2002). There is currently only a low risk of foliar ozone damage. Exposure to 80 ppb ozone is infrequent, and exposure to 100 ppb rare (National Park Service 2005).

Although neither LAMR nor ALFL is subject to the visibility protection provisions that apply to Prevention of Significant Deterioration Class I areas, they do experience the widespread visible haze affecting this region of the country and would benefit from any future regional strategies to reduce visibility impairing pollution. Some of those pollutants are emitted in the vicinity of the parks by existing sources. For instance, about a dozen major sources in the three county area of Hutchinson, Moore, and Potter Counties contribute over 64,000 tons per year of $SO_2$, a pollutant that is transformed in the atmosphere to fine sulfate particles which have a dramatic effect on visibility impairment caused by scattering and absorption of light. It is likely that additional industrial activity associated with oil and gas production will contribute to fine particle formation. Based on extrapolation of visibility data collected over the period from 1988-1997 by the IMPROVE (Interagency Monitoring of Protected Visual Environments) visibility monitoring network, the visual range experienced on average in this area is from 30-60 miles (48 to 96 km) or probably about half the distance that would be visible under natural visibility conditions in the area (Lake Meredith National Recreation Area 2002).

E.7.3.6. Wildlife

There have been several inventory related research projects for vertebrates at LAMR and ALFL (Killebrew 1977, Phillips, 1989, Yancey et al. 1998, Munger 2002, Patrikeev and Gallyoun 2004).

- **Mammals**: There have been 60 species of mammals documented at LAMR and ALFL. There was a black-tailed prairie dog (*Cynomys ludovicianus*) town as recent as the 2001

but it was wiped out by plague. It is likely that prairie dogs will re-colonize LAMR in future years. Bats are probably the most under recorded group of mammals at LAMR. Patrikeev and Gallyoun (2004) detected only one species of bat and Yancey et al. (1998) did not find any. Surveys are difficult to conduct at the park due to consistent high winds that make captures with mist nets problematic. Future surveys with bat detectors or a harp trap may yield additional species. Two potentially occurring rare mammals animals the Townsend's big-eared bat (*Coryhorhinus townsendii*) and swift fox (*Vulpes velox*).

- **Birds**: In addition to 72 species of breeding birds detected by Patrikeev and Gallyoun (2004), an anonymous park bird lists 23 additional species as nesting or likely nesting in the park, but there is no evidence, or even an author, to substantiate the list. LAMR has a high population of nesting Mississippi kites (*Ictinia mississippiensis*) along the riparian area and there is also a great blue heron (*Ardea herodias*) rookery (Lake Meredith National Recreation Are 2002). The park is located along the central flyway and has a high number of waterfowl during migration. LAMR has a large population of bald eagles (*Haliaeetus leucocephalus*) during the winter. It has been speculated that the park may be a large-overwintering site for grassland birds. Bird surveys conducted at LAMR/Alibates Flint Quarries National Monument detected scaled quail (*Callipepla squamata*), scissor-tailed flycatcher (*Tyrnanus forficatus*) and Cassin's sparrow *Amiophila cassinii*), all on the Partners In Flight watch list for the Pecos and Staked Plains region. Three potentially rare species occurring at the park are snowy plover (*Charadrius alexandrinus*), piping plover (*Charadrius melodus*), and mountain plover (*Charadrius montanus*).
- **Reptiles and Amphibians**: There have been 32 species of reptiles and 11 species of amphibians detected at LAMR and ALFL. The Texas horned lizard is a state listed species and is relatively common at LAMR (Patrikeev and Gallyoun 2004). The Colorado checkered whiptail (*Cnemidophorus neotesselatus*) may have been caught for the first time in Moore County by Patrikeev and Gallyoun (2004).
- **Fish:** There have been 11 fish species detected from LAMR. The two rare species, Arkansas river shiners and peppered chubs (*Macrhybopsis tetranema*), present at LAMR are both threatened by impoundments and construction. The former has been found in the vicinity of Chicken and Bonita Creeks, and the latter in Chicken Creek (Patrikeev and Gallyoun 2004). A potential threat to the Arkansas River shiner at LAMR is the low water level caused by prolonged drought and extensive water retention upstream in New Mexico (Durham and Wilde, in press). Patrikeev and Gallyoun (1994) recorded the first river shiner (*Notropis blennius*) in Texas, a likely introduction.
- **Invertebrates:** Phillips (1990) states that there may be over 600 species of insects from LAMR. Identification of specimens has varied in getting to genus or species level. The giant mole cricket (*Gryllotalpa major*) was collected in McBride Canyon and is a rare species typical of high quality mixed-grass prairie.

E.7.3.7. Vegetation

A total of 486 species have been documented and supported by vouchers from the park (Wright and Meador 1981, Nesom et al. 2005). Much of the terrain surrounding the parks consists of flat grasslands. The predominant vegetative cover is comprised of blue grama (*Bouteloua gracilis*), little bluestem (*Schizachyrium scoparium*), and buffalo grasses. Stands of cottonwood (*Populus deltoides*) and hackberry trees (*Celtis occidentalis*) are found in the side canyons along the lake. The varying lake levels have encouraged the encroachment of salt cedar in the floodplain areas. Nesom et al. (2005) detected 47 exotic species, from the park based on vouchered specimens. Two of the invasives, Russian olive (*Elaeagnus angustifolia*) and Siberian elm (*Ulmus pumila*) were identified by Nesom et al. (2005) as management priorities for the park. An earlier plant list by Phillips (1997) lists 516 species but there are no voucher specimens to support the list, and Nesom et al. (2005) estimated that 59 of these species were unlikely to occur at LAMR. Nesom et al. (2005) found four new state records, plains spring parsley (*Cymopterus acaulis*), slickseed fuzzybean (*Epilobium leptophyllum*), salt marsh goosegrass (*Puccinellia fasciculata*), and *Atriplex patula*, and six species with large range extensions at LAMR during their work in 2002. There are no known endangered or threatened plants within the boundaries of the parks. Off-road vehicle

use has severely impacted vegetation along Rosita Creek, Blue Creek, and the Canadian River. Possibly occurring rare plants at LAMR include *Astragalus puniceus* var. *puniceus,* Correll's Wild-Buckwheat (*Eriogonum correllii),* Tall Plains Spurge (*Euphorbia strictior),* Mexican Mud-Plantain (*Heteranthera mexicana)* and High Plains Goldenrod (*Solidago altiplanities).*

*E.7.4. Management Issues*

The grassland community, prairie restoration, the Texas horned lizard and water quality and quantity are the most important natural resource issues at LAMR. Exotic species, erosion, air quality, non-source point pollution, off-road vehicle use, and the lack of long term management plan are the biggest threats to natural resources at the park. Prairie restoration can lead to improved groundwater recharge and stewardship of upland wetlands and springs. These improvements in turn will provide enhanced habitats for many of the species of interest as well as resident communities.

Varying lake levels have encouraged the encroachment of salt cedar in floodplain areas. The tamarisk has out-competed native species and is likely contributing to the increasing salinity levels of the lake. Investigations are ongoing with the Bureau of Reclamation introducing insects to control tamarisk.

Erosion of the lake shore line is a major concern and has been studied and discussed in several documents (Lynn 1975, Etchieson and Couzzourt 1987, Bureau of Reclamation 1990). Some of these eroded areas could affect visitation by degrading boat ramps and the road to the Stilling Basin (Pranger 2000).

The quality and quantity of groundwater in the future is of major concern in this region. Continued pumping of the aquifer for agricultural purposes can potentially lower the water table. The water level of Lake Meredith fluctuates with floods and draw-downs and is subject to non-source point pollution (including erosion within park boundaries and elevated E. coli levels) that could contaminate the fishery.

Oil and gas exploration and development have been actively pursued in the vicinity of LAMR and ALFL since the late 1920s, well before establishment of the parks. The earliest well on record within what later became LAMR was completed on October 3, 1927. Many others followed. In the parks today, there are 170 active well sites, evidence of 15 abandoned (unreclaimed) operation sites, 40 miles (64 km) of active oil field access roads, 104 miles (167 km) of abandoned roads, and 3.7 miles (6 km) of existing oil and gas pipelines (Lake Meredith National Recreation Area 2002).

Human impact threatens both the natural and cultural resources of LAMR. High visitor attendance underscores the need to determine carrying capacity at various sites around the park. Off-road vehicle use in and out of permitted areas causes severe damage to soil, vegetation and cultural resources as well as use conflict among other visitors. Maintenance of boundary fence remains an essential means of controlling unauthorized use of parklands.

*E.7.5. Partnering /Neighboring Agenices*

<u>E.7.5.1. Current Partners</u>

Texas Parks and Wildlife, Bureau of Reclamation, Canadian River Water Management Authority, National Wild Turkey Federation, Bureau of Land Management

<u>E.7.5.2. Potential Partners</u>

Ducks Unlimited, Quail Unlimited, US Forest Service, West Texas A+M, Texas Tech University, Amarillo College.

E.7.5.3. Neighboring Land Management Agencies

Alibates Flint Quarries National Monument, Palo Duro Canyon State Park, Playa Lakes Wildlife Management Area, Gene Howe Wildlife Management Area, Cross Bar (Bureau of Land Management), Buffalo Lake NWR, Muleshoe NWR, Optima NWR, McClellan Creek National Grasslands, Caprock Canyon State Park, Black Kettle National Grasslands, Four Canyon Preserve (The Nature Conservancy)

*E.7.6. Literature Cited*


Bureau of Reclamation. 1990. Memo to Regional Director, Dated September 11, 2000. 14pp.

Etchieson, G. M. and J. E. Couzzourt. 1987. Shorline survey at Lake Meredith Recreation Area in the Texas panhandle. US Department of Interior, Bureau of Reclamation, Amarillo, TX.

Killebrew, F.C. 1977. A survey and population analysis of mammals by habitat at Lake Meredith Recreation Area and Alibates National Monument. A Report of the Activities of a Grant Project for the United States Department of the Interior: National Park Service. 107 pages.

Lake Meredith National Recreation Area. 1996. Resources management plan, Lake Meredith National Recreation Area, Alibates Flint Quarries National Monument. National Park Service. 64pp.

Lake Meredith National Recreation Area. 2002. Oil and gas management plan. Alibates Flint Quarries National Monument and Lake Meredith National Recreation Area.

Lake Meredith National Recreation Area. 2003. Lake Meredith National Recreation Area personal watercraft environmental assessment. 187pp.

Lynn, A. R. 1975. Slope and shoreline modification at Lake Meredith in the Texas panhandle. Thesis, West Texas State University, Canyon, TX. 51pp.

Munger. 2002. Fish species for Lake Meredith edited by Munger 15 Nov 02. A Word document obtained from Jim Rancier (US National Park Service), 3 pp.

National Park Service. 2003a. Economic analysis of management alternatives for personal watercraft in Lake Meredith National Recreation Area.

National Park Service 2003b. 2001 Air emissions inventory. Lake Meredith National Recreation Area. 88pp.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Nesom, G., R. J. O'Kennon, and M. Gallyoun. 2005. Vascular plants of Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, Potter, Moore, and Hutchinson Counties, Texas. Results of a 2002 floristic inventory and related research reviews. The Nature Conservancy, The Botanical Research Institute of Texas, and the National Park Service 124pp.

Patrikeev, M. and M. Gallyoun. 2004. Vertebrate animals of Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument, Potter, Moore, and Hutchinson Couties, Texas. Results of a 2001-2003 zoological inventory and related research and reviews. The Nature Conservancy and the National Park Service. 63pp.

Philips, J.W. 1989. Checklist of Vertebrates of Lake Meredith Recreation Area. Unpublished Report. 9 pages.

Phillips, J. W. 1990. Insects of Lake Meredith Recreation Area. National Park Service. 107pp.

Phillips, J.W. 1997. An annotated checklist of the plants of Lake Meredith National Recreation Area. Panhandle Archeological Society Publ. No. 7. Amarillo, Texas.

Pranger, H. 2000. Memo to Lake Meredith Superintendent, dated February 9, 2000. 13pp.

Spearing, D. 1991. Roadside Geology of Texas. Mountain Press Publishing, Missoula, Montana. pp 359-377.

Thompson, Col. E.O. 1939. Summary of the Development of the Panhandle Field under Conservation Regulation, Panhandle Plains Historical Review, Volume XII, Canyon, Texas.

USDA, Soil Conservation Service. 1975. Soil Survey of Moore County, Texas.

USDA, Soil Conservation Service. 1976. Soil Survey of Hutchinson County, Texas.

USDA, Soil Conservation Service. 1980. Soil Survey of Potter County, Texas.

Wright, R.A., and K. Meador. 1981. The vegetation of the Lake Meredith Recreation Area, Texas. Unpublished report to U.S. Dept. of the Interior – National Park Service. Dept. of Biology, West Texas State University, Canyon, Texas.

Yancey, F.D., R.W. Manning, J.R. Goetze, and C. Jones. 1998. The Mammals of Lake Meredith National Recreation Area and adjacent areas, Hutchinson, Moore and Potter counties, Texas. Museum of Texas Tech Univ., Occasional Papers, No. 174. 20 pages.

## E.8. LYNDON B. JOHNSON NATIONAL HISTORICAL PARK (LYJO)

Lyndon B. Johnson National Historical Park (LYJO) preserves the settings and tells the story of our 36th President, from his ancestral heritage and boyhood home through his LBJ Ranch and final resting place, resulting in the most complete picture of any American president. The park consists of two units (Johnson City and LBJ Ranch districts) situated on the Llano uplift, in the Pedernales River Valley of the central Texas Hill Country, in Blanco and Gillespie counties, respectively. LYJO was originally established in 1969. The combined area of the two districts, which lie about 15 miles (24 km) from one another, is about 674 acres (270 ha). The park hosted 94,963 visitors in 2004.

### *E.8.1. Resource Overview*

When this area of the Edwards Plateau was first settled in the mid-1800s, it contained oak savannah bisected by riparian woodland corridors and hillside slopes of Ashe juniper (*Juniperus asheii*). Presently, only tiny patches of semi-natural vegetation remain at LYJO: mostly at the prairie restoration site and along Town Creek in the Johnson Settlement, and along the Pedernales River at the LBJ Ranch District. The park is classified as southwest plateau and plains dry steppe and shrub according to Bailey (1994). Elevations range from 1190 to 1565 feet (363-477 m).

The Johnson City District is located in the southwest portion of Johnson City (Blanco County), and consists of the park headquarters and visitor center, the LBJ Boyhood Home, some adjacent homes, historic Johnson Settlement buildings and exhibits, a nature trail, semi-natural creek and prairie habitats, a demonstration herd of longhorn cattle and horses and associated pastures, volunteer camping sites, and maintenance sheds. The LBJ Ranch District stretches along the Pedernales River in eastern Gillespie County. It includes several historic buildings and cultural sites, ranch pastures, cultivated fields and pecan orchard. Adjacent to the LBJ Ranch District is the Lyndon B. Johnson State Park and Historic Site, from which the National Park Service operates its bus tours. Lyndon B. Johnson National Historical Park is located approximately 47 miles (76 km) west of Austin and 63 miles (101 km) north of San Antonio. State Highway 290 runs along the north edge of the Johnson City District and Ranch Road 1 and the Pedernales River run along the southern edge of the Ranch District.

The subtropical, subhumid character of the Edwards Plateau results in a sunny, mild climate, except for summer's high humidity and 100ºF (38ºC) temperatures. Winter temperatures are usually in the 50sºF (10ºC); snow and ice are rare. Annual precipitation averages about 32 inches (81 cm), with May and September the wetter months and November, December and January the driest months.

### *E.8.2. Enabling Legislation / Management Documents*

Lyndon B. Johnson National historical park was originally established by Public Law 91-14 on December 2, 1969, as a national historic site. The designation was changed to a national historical park on December 28, 1980. The enabling legislation states that the purpose of the park is "to preserve in public ownership historically significant properties associated with the life of Lyndon B. Johnson." According to the General Management Plan (Lyndon B. Johnson National Historical Park 1999) the purpose is further defined "To research, preserve, and interpret significant resources and influences associated with the life and heritage of Lyndon B. Johnson", and "To provide a variety of opportunities to experience the local and regional context that shaped the last frontier president, informed his policies and programs, and defined his legacy." One of the mission goals for the park states, "the natural environment and cultural heritage of the Texas Hill Country are protected and maintained through a regional network of private and public stewardship."

A resource management plan was completed in 1996 (Lyndon B. Johnson NHP 1996). This plan states that the plan must "give direction that will compliment, preserve, and/or restore the park's natural resources as they appeared in the historic periods as defined in the area's management objectives." The plan focuses on live oak management, Hereford cattle, pasture management, pecan management, ball moss control, water resources management, rodent pest control, native grass restoration erosion control to stabilize Pedernales River bank, and insect pest management.

A fire management plan was completed in 2005 (Lyndon B. Johnson National Historical Park 2005) and an integrated pest management plan in 1999 (Baumann 1999).

*E.8.3. Natural Resources*

E.8.3.1. Valuable Resources / Species of Interest

Several species of concern have been documented at LYJO. Texas map turtle (*Graptemys versa*), Texas cooter (*Pseudemys texana*) and Guadalupe bass (*Micropterus treculii*) are all endemic to the Edwards Plateau. The American bald eagle (*Haliaeetus leucocephalus*) is federally listed as threatened and winters in the area. The most valuable species for cultural reasons, is the Hereford cow, a distinct strain is currently raised at the park that are descendents of the President's herd.

E.8.3.2. Geology / Soils

Soils in the Johnson City District are shallow and underlain by limestone and marl, they are characterized as loamy, clayey, stony soils of the Brackett-Purves-Doss association (Lyndon B. Johnson National Historical Park 1999). Shallow rooting depth, rapid runoff, available water capacity, small stones, and steep slopes are limitations (SCS, USDA 1979). The soils of the LBJ Ranch Distict are sandy to loamy, gently sloping soils of the Lukenbach-Pedernales-Heatly Association. These soils are moderately-well drained, permeability is moderately-slow, and runoff is moderate (Lyndon B. Johnson National Historical Park 1999). Soils of the Pedernales Riverbed contain recently deposited silty and sandy alluvium derived from upstream granites and sandstones, while bottomland terraces are covered with silty and sandy alluviums. Upslope outcrops of sandstone and marly limestone have weathered to pastures of sandy loams and deep redland clay loams. The river valley is surrounded by limestone hills. Sandy alluvial soils along the streams can be easily eroded during flash flood events.

E.8.3.3. Land Use

The Pedernales River valley has been and continues to be an area dominated by ranching activities and small orchards. The Johnson City District is surrounded by the Town of Johnson City and private ranch land. The LBJ Ranch District is bordered on the south by Lyndon B. Johnson State Park and Historic Site and the remainder by private ranch land, including some owned by the Johnson family.

E.8.3.4. Hydrology

The primary water bodies at LYJO are the Pedernales River and Town Creek. A few small streams and stock ponds are also present at LYJO. One of the most important aquatic resource concerns is the riparian ecosystems. The flood/drought cycle affects plant and animal presence and fecundity, in addition to water quality and quantity. The suppression of fire, which has allowed the encroachment of woody species into the riparian areas, has changed the groundwater recharge/discharge patterns. This may be contributing to the favorable conditions for the introduction and spread of plant and animal pathogens. LYJO is participating in the Lower Colorado River Authority (LCRA) River Watch Program, collecting data to be assessed by the LCRA and EPA. A basic water quality assessment was completed in 2000 by the WRD of the NPS.

E.8.3.5. Air Quality

The preservation of the night sky and the soundscape at LYJO directly impacts visitor satisfaction levels. Both districts are affected by light from San Antonio, Austin and smaller communities. The Pedernales River valley continues to succumb to a gradual change from agriculture to development and the onset of light and sound pollution. Erosion of the riverbank is also a concern, potentially occurring from the dams in the area. The Johnson City District is most affected by light as the surrounding town continues to grow, but the LBJ Ranch District is also affected by the growth and development of its neighboring community, Stonewall. US Highway 290 is near both units and as the traffic count grows, so does the ambient noise associated with high-speed roadways.

The risk of foliar ozone injury to plants at Lyndon B. Johnson National Historical Park is moderate. Concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation. While the levels of ozone exposure consistently create the potential for injury, periods of low soil moisture may reduce the likelihood of injury developing in particular years. Since LYJO is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. A program to assess the incidence of foliar ozone injury on plants at the site could use redbud (*Cercis canadensis*) (National Park Service 2005).

E.8.3.6. Wildlife

- ***Mammals:*** Patrikeev and Gallyoun detected 17 species of mammals in 2002 and 2003. Patrikeev and Gallyoun (2004) recorded the first pygmy mouse (*Baiomys taylori*) for Blanco County. Nutria (*Myocastor coypus*) are an exotic species that are controlled on a semi-monthly basis.
- ***Birds:*** Archer (1975) and Archer (1980) conducted bird surveys at Lyndon B. Johnson State Historical Park and documented 147 species. Patrikeev and Gallyoun (2004) did not specifically survey for birds due to the existing bird list, but documented 43 species during their work. There are 6 species that are documented at LYJO that are on Partners in Flight's watch list for the Edward's Plateau Region: black-chinned hummingbird (*Archilochus alexandri*), scissor-tailed flycatcher (*Tyrnanus forficatus*), northern bobwhite (*Colinus virginianus*), orchard oriole (*Icterus spurious*), Bell's vireo (*Vireo bellii*), and painted bunting (*Passerina ciris*).
- ***Reptiles and Amphibians:*** Only 9 species of reptiles and 4 species of amphibians were documented during the 2002-03 inventory. There are as many as 58 species of reptiles and 17 species of amphibians known from Blanco and Gillespie counties (Dixon 2000). The low number of species may be due to a variety of factors. Patrikkev and Gallyoun (2004) speculated that it was due to the introduction of fire ants and the large percentage of exotic grasses at the park. In addition, the survey was completed towards the end of a drought when some of these species may have been at naturally low population levels. The Texas horned lizard (*Phrynosoma conutum*) is a state-listed species that is historically known to occur at LYJO. Patrikeev and Gallyoun (2004) did not detect the species and speculated that it may be due to the invasion by non-native fire ants.
- ***Fish:*** Patrikeev and Gallyoun (2004) focused their efforts on shallow water areas with seining and detected 18 species. A supplemental survey was conducted in 2005 using electroshocking by the Lower Colorado River Authority that documented 4 additional species. Both fish surveys detected the brook silverside (*Labidesthes sicculus*) that was a new record for the Colorado River watershed. The presence of this population is puzzling since they do not survive in bait buckets and the species is generally restricted to the Sabine and Red River watersheds (Hubbs et al. 1991).

E.8.3.7. Vegetation

The majority of the Ranch District is managed as improved range with exotic plant species. The Johnson City District has approximately 39 acres that can be classified as prairie or semi-natural

prairie (Stubbendieck and Willson 1986), however these areas also contain a large number of exotic species. Portions of the Johnson City District in the immediate vicinity of the Johnson homestead are managed as overgrazed to depict the scene at the time of 1890's. The Johnson City District was probably historically planted in small grains or cotton prior to the 1920's, after this date it was converted to a pecan (*Carya illinoinensis*) grove.

Two floristic inventories have documented 609 native and cultivated species (including distinct varieties, cultivars, and hybrids) present in the park, of these 471 are naturally occurring (Sanders and Gallyoun 2004, Sanders 2005). The first inventory was conducted in 2002 and was very intensive, but was completed at the end of a drought. The 2005 inventory was recommended by Dr. Sanders and was done in a year with normal or slightly above normal precipitation and documented 51 additional species. Sanders (2005) documented two new introduced naturalized species that had not been reported from Texas. There are also two specimens of Eve's necklace (*Sophora affinis*) that may be close to champion tree status.

*E.8.4. Management Issues*

The issues of highest priority at LYJO deal with the restoration and maintenance of the grassland prairie and riverine ecological communities. LYJO currently has a cooperative agreement with the Ladybird Johnson Wildflower Center to study methods to control King Ranch bluestem (*Bothriochloa ischaemum*). Prairie restoration efforts are underway at the Johnson City District unit. Gabbard et al. (1997) and Smeins (2003) made several recommendations to restore the prairie in Johnson City, many of which are being implemented. Successful restoration and invasive control efforts should positively impact both the terrestrial vertebrate and the grassland bird diversity and populations.

The inventory results of Patrikeev and Gallyoun (2004) were lower then expected for terrestrial vertebrate fauna at LYJO. Presently, there are very few natural terrestrial habitats remaining in the park, a direct result of past ranch management objectives focused on cattle ranching. In addition, exotic fire ants (*Solenopsis invicta*) invaded around 1978 and may have caused irreversible damage to amphibian, reptile, and small mammal populations in the area, effectively driving some of those species to local extirpation.

Control and/or eradication of invasive and exotic species, both plants (Johnson grass [*Sorghum halapense*], woody succession) and animals (blackbuck antelope, nutria) are of major importance. The Gulf Coast Exotic Plant Management Team started work in 2005 to control exotic plants. A cooperative agreement with Texas A+M University was established to look at the native white-tailed deer and exotic blackbuck antelope populations. The suppression of fire has encouraged the encroachment of woody species, changing the nature of the habitat, affecting groundwater recharge and possibly allowing favorable conditions for the introduction and spread of plant and insect disease. A fire management plan has recently been completed and should help in restoring fire to the ecosystem.

Naturally occurring patterns and processes shape the ecosystem at LYJO. The flood/drought cycle of the Edwards Plateau affects the plant and animal species abundance as well as water quality and quantity - a major issue confronting the state of Texas. The park has recently started a sedimentation and erosion study of the river and the Jordan and Johnson dam with Intermountain Regional NPS staff.

Issues of additional concern that will need to be addressed include monitoring air quality, the compatibility of adjacent land use, the local tradition of hunting and wildlife management, and the ever present need for funding to be used for staff, maintenance and long-term planning.

*E.8.5. Partnering /Neighboring Agencies*

E.8.5.1. Current Partners
Lyndon B. Johnson State Park and Historic Site, Lower Colorado River Authority, Texas Forest Service, Balcones Canyonlands NWR, Ladybird Johnson Wildflower Center, Texas A+M University, Texas State University, Texas Master Naturalists

E.8.5.2. Potential
Selah Ranch, Texas Master Gardeners, Natural Resources Conservation Service, Highland Lakes Audubon Society

E.8.5.3. Neighboring Land Management Agencies
Lyndon B. Johnson State Park and Historic Site, Pedernales Falls State Park, Enchanted Rock State Park, Blanco River State Park, Barton Creek Habitat Preserve (The Nature Conservancy), Camp Bullis (Department of Defense), Balcones Canyonlands NWR, Westcave Preserve (Lower Colorado River Authority)

*E.8.6. Literature Cited*


Archer, A. 1975. The birds of Lyndon B. Johnson State Park. Bulletin of the Texas Ornithological Society, Volume VIII pp 6-7.

Archer, A. 1980. Bird life of Lyndon B. Johnson State Park. Unpublished report. 7pp.

Bailey, R.G. 1994. Ecological classification for the United States. Washington, DC: USDA Forest Service.

Baumann, P. A. 1999. A biological study of weeds and formulation of an integrated pest management plan for Lyndon B. Johnson National Historical Park. Texas Agicultural Extension Service, Texas A+M University. 84pp.

Dixon, J.R. 2000. Amphibians and reptiles of Texas. Second edition. Texas A&M University Press, College Station. 421 pages.

Gabbard, B., J. M. Noel, and Fowler, N. L. 1997. The Johnson settlement vegetation restoration project. University of Texas. 35pp.

Hubbs, C., R.J. Edwards, and G.P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. The Texas Journal of Sciences. Volume 43 (4) - Supplement: pages 1-56.

Lyndon B. Johnson National Historical Park. 1996. Resources management plan, Lyndon B. Johnson National Historical Park. National Park Service. 63pp.

Lyndon B. Johnson National Historical Park. 1999. Final general management plan, environmental impact statement, Lyndon B. Johnson National Historical Park. National Park Service.153 pp.

Lyndon B. Johnson National Historical Park. 2005. Lyndon B. Johnson National Historical Park fire management plan. 130pp.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Patrikeev, M. and M. Gallyoun. 2004. Fishes, amphibians, reptiles, and mammals of Lyndon B, Johnson National Historical Park, Gillespie and Blanco Counties, Texas. Results of a 2002-2003 zoological inventory and related research and reviews. The Nature Conservancy and the National Park Service. 63pp.

Sanders, R. W. and M. Gallyoun. 2004. Vascular plants of Lyndon B. Johnson National Historical Park Blanco and Gillespie Counties, Texas. Results of a 2002 floristic inventory and related research and reviews. The Nature Conservancy, Botanical Research Institute of Texas and National Park Service. 51pp.

Sanders, R. W. 2005. Update to: Vascular plants of Lyndon B. Johnson National Historical Park Blanco and Gillespie Counties, Texas. Results of a 2005 supplemental floristic inventory. Botanical Research Institute of Texas and the National Park Service. 36pp.

Smeins, F. E. 2003. Native prairie restoration and monitoring on the Lyndon B. Johnson National Historical Park, Johnson City, Texas. Unpublished report 15pp.

Soil Conservation Service. 1979. Soil survey of Blanco County, Texas. U.S. Department of agriculture, Temple, TX.
Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E.9. PECOS NATIONAL HISTORICAL PARK (PECO)

Pecos National Historical Park (PECO) was established in 1965 and preserves 12,000 years of human history within its two units. The ancient Pecos Pueblo and other indigenous American structures, two Spanish colonial missions, a section of the Santa Fe Trail, the 20th century history of Forked Lightning Ranch, three miles of Glorieta Creek battlefield and almost four miles of the Pecos River are all preserved in the 5,989 acre (2,424 ha) Pecos Unit. The 682 acre (276 ha) Glorieta unit, comprised of the two subunits of Pigeon's Ranch and Cañoncito, contains Mexican era homesteads and sites related to the Civil War Battle of Glorieta Pass. PECO received 33,691 visitors in 2004.

### *E.9.1. Resource Overview*

Located in San Miguel County, 28 miles (45 km) southeast of Santa Fe, New Mexico, most of PECO lies in the upper Pecos River valley. This narrow valley is bordered by the 13,000-foot (3,962 m) Sangre de Cristo Mountains to the north, the rugged hills of the Tecolote Range to the east, and the steep Glorieta Mesa to the west. The 8,200-foot (2,499 m) Glorieta Mesa escarpment is the most prominent geologic feature in the area, rising abruptly above the 7,000-foot (2,134 m) valley floor. Glorieta Pass connects the Apache Canyon area and the northern Rio Grande Valley to the High Plains and short-grass prairie of New Mexico (Reed et al. 1999).

The southern Rocky Mountain Steppe geographic province, southern parks and ranges ecoregion gives way to the Mexican Highlands in this area, producing a climate and vegetation unique for this elevation. Major habitats found within PECO include riparian corridors, grasslands of old pastures, and predominant piñon/juniper (*Pinus edulis* / *Juniperus monosperma*) woodland (Parmenter and Lightfoot 1996). Annual precipitation varies from 16 to 20 inches (41-51 cm) per year, with the majority falling during the summer season. Temperatures range from an average high of 80°F (27°C) June to August to an average low of 15°F (-9°C) December through February. The spring season tends to be windy.

There are no threatened or endangered plants of animals documented at PECO. Dwarf milkweed (*Asclepias uncialis*), which has a State listing, has been documented in the park. Major management challenges include declining water quality from upstream activities in the Pecos River, resulting in contaminants in the fishery, and the influx of exotic plants and animals in the park.

### *E.9.2. Enabling Legislation / Management Documents*

Pecos National Monument was created on June 28, 1965 to "… set apart and preserve for the benefit and enjoyment of the American people a site of exceptional historic and archeological importance ... including the remains and artifacts of the seventeenth century Spanish missions and ancient Indian pueblo" (PL 89-54, June 28, 1965; 79 Stat. 195). The monument was expanded on June 27, 1990 to become Pecos National Historic Park, composed of Pecos National Monument and the Forked Lightening Ranch, in order to " … recognize the multi-theme history, including the cultural interaction among diverse groups of people of the Pecos area and its 'gateway' role between the Great Plains and the Rio Grande valley … and to provide for the preservation and interpretation of the cultural and national resources of the Forked Lightening Ranch." (PL 101-313, June 27, 1990; 104 Stat. 279). On November 8, 1990, Congress once again expanded the park to include the 682-acre Glorieta unit. This unit was added to ",,, preserve and interpret the Battle of Glorieta Pass and to enhance visitor understanding of the Civil War and the Far West." (PL 101-536, November 8, 1990; 104 Stat. 2358).

The stated purpose of Pecos Unit is "to preserve and interpret an exceptional cultural and natural area that has had a long human history'" while the purpose of the Glorieta Unit is "to preserve and interpret areas where the Civil War Battle of Glorieta Pass took place" (Pecos National Historical Park 1995). Several other management documents provide guidance for the stewardship of

Pecos National Historic Park, including: the Natural and Cultural Resource Management Plan approved in 1999, which primarily addresses the Pecos Unit; The Pecos National Historic Park Land Protection Plan, approved in 1993, that describes land protection strategies for the Glorieta unit; and the Santa Fe National Historic Trail Comprehensive Management and Use Plan completed in 1990.

*E.9.3. Natural Resources*

E.9.3.1. Valuable Resources / Species of Interest

Landscape elements are among the parks valuable resources. Glorieta Pass has been a traditional link through the Sangre de Cristo Mountains between the Rio Grande valley and the Great Plains. For centuries, people have followed this common corridor. While the pass itself is not in the park, it can be seen from various vantage points within the park and provides an important historical context and connection. The Pecos River is one of only five year-round, free-flowing rivers in New Mexico and is one of the longest in the state. Along with Glorieta Creek, it flows for almost four miles through the park and sustains valuable riparian corridors that support the greatest diversity (Pecos National Historical Park 1995).

A small population of dwarf milkweed (*Asclepias uncialis*), which has a State listing, was detected in the Pecos Unit in 1995 (Sivinski 1995), however additional searches have not detected the species and it is no longer present in the original location. Scientists have caught sight of flycatchers in the park but have been unable to determine if they may be the federally endangered Southwest willow flycatcher (*Empidonax traillii extimus*) (Pecos National Historical Park 1995).

E.9.3.2. Geology & Soils

The bedrock of the Pecos River valley floor consists of Pennsylvanian and early Permian soft shales, sandstones, siltstones, limestones and conglomerates of the Sangre de Cristo formation. Most of the formation is covered by alluvial fill and a mantle of thick soil derived from weathering and decomposition. The Magdalena group, consisting primarily of limestone, underlies the formation. Outcroppings are exposed on both sides of the Pecos River by the ranch house. Outcrops along Glorieta Creek are of igneous and metamorphosed Precambrian rocks, the Magdalena group and the Sangre de Cristo, Yeso and San Andres formations. Uplifting of the land and downcutting of the Pecos River during the Pleistocene are largely responsible for the area's present topography. Subsequent uplifting and downcutting shifted the river eastward to its present location. Deep alluvial gravel deposits and a series of terraces mark the former course of the river. Based on regional seismic and exploration activities, the formations in the park are not believed to have commercially exploitable mineral deposits, and the various strata are not associated with oil and gas producing beds (Pecos National Historical Park 1995). The federal government owns all of the mineral rights for lands within the park boundary that are under jurisdiction of the Park Service (Reed et al. 1999).

Petrified wood has been found on the eastern portion of the Pecos Unit (Reed et al. 1999). Although no fossils have been discovered from within the boundaries at PECO, two geologic units are exposed at the park that have been reported with paleontological resources in other areas. The oldest formation exposed at Pecos is the Upper Pennsylvanian to Lower Permian Sangre de Cristo Formation. The other fossiliferous formation is the Upper Pennsylvanian Upper Member of the Madera Formation. Multiple reports of fossils from the Madera Formation suggest that there is a strong possibility of discovering specimens within PECO (Koch and Santucci 2003).

Soils of the Pecos Unit are identified as Vibo-Ribera and Ribera-Sombordoro-Vibo associations, and Tuluso-Sombordoro-Rock outcrop and Laporte-Rock outcrop complexes. On the Pecos River and Glorieta Creek floodplains there are frequently flooded soils. The upland soils vary from deep fine sandy loams on relatively flat slopes to very shallow stony loams on the ridges. Generally the park's soils are moderately to well drained, have moderate permeability and erosion hazards, and moderate to severe limitations for building. Soils of the Glorieta unit are identified as Cueva very

stony clay, Capillo-Rock outcrop complex, Ortiz gravely loam, Prewitt loam and Rednum loam. These soils generally have moderate to slow permeability, medium to very rapid runoff and severe to very severe erosion hazards. Soils in the Canoncito subunit were mapped as Pojoaque-Rough broken land complex, Travessilla-Rock outcrop, and Fivemile loam, potentially a prime agricultural soil. These soils have moderate permeability, medium to rapid runoff and moderate to severe erosion hazards (Pecos National Historical Park 1995).

E.9.3.3. Hydrology

Most of PECO lies in the Upper Pecos River Valley and contains four miles of the Pecos River. Additional surface waters include Glorieta Creek, a riparian restoration area, a pond, and several marshy habitats. Portions of the Pecos River, including the section that flows through PECO has been classified as impaired on the federal 303(d) list for inadequate temperatures and turbidity levels. The Pecos River is experiencing a decline in water quality and quantity because of drought conditions and from upstream activities outside of the Park. A basic water quality report was prepared by the WRD of the NPS in 1995.

E.9.3.4. Air Quality

Pecos National Historic Park is a Class II air quality area. Air quality is rated as better than required by the national ambient air quality standards. Air quality and visibility are usually excellent. However, in the winter air inversion periodically trap smoke from wood burning stoves, resulting in a haze (Pecos National Historical Park 1995; Reed et al. 1999). The Cañoncitos subunit is affected with visual and noise intrusions and air pollution from Interstate 25 (Pecos National Historical Park 1995). The low levels of ozone exposure at Pecos National Historic Park make the risk of foliar ozone injury to plants low. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury. If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine (*Pinus ponderosa*) or skunkbush (*Rhus trilobata*) as bioindicators for ozone (National Park Service 2005).

E.9.3.5. Land Use

The Pecos Unit is bounded on the east by the Santa Fe National Forest, which is generally managed consistent to NPS management standards. However, some recreational uses in the Forest are not allowed in the park, so the boundaries need to be clearly marked. Both Glorieta Creek and the Pecos River are affected by the septic systems of private development upstream of the park. Both Pigeon's Ranch and Canoncito subunits are surrounded by private land and some Santa Fe National Forest land. Residential development continues to increase outside the boundaries and there are some agricultural uses nearby, primarily grazing. New Mexico State Road 50 runs through the Pigeon's Ranch unit and has a major negative effect on its natural and cultural resources and values. Interstate 25 also affects the Cañoncito subunit with visual and noise intrusions and air pollution (Pecos National Historical Park 1995).

E.9.3.6. Wildlife

- ***Mammals:*** There are no known federally listed threatened or endangered animals in PECO. A complete faunal survey conducted by Parmenter and Lightfoot (1996) documented 25 mammal species. The list is dominated by rodents, with the deer mouse being the most common and widespread species in the park. Black bear tracks have been seen in the Pigeon's Ranch unit and the Pecos unit. Mountain lion tracks have also been seen in the Pecos unit. The riparian area was also historic habitat for river otter. There are several exotic species present in the park, including feral dogs and cats (Pecos National Historical Park 1995). Feral dogs (*Canis familiarus*) are trapped and removed from the park on a regular basis (Johnson et al. 2003).
- ***Birds:*** There are no known federally listed threatened or endangered birds in PECO. The USF&WS has identified four listed species that may occur in the area: bald eagle (*Haliaeetus leucocephalus)*, peregrine falcon (*Falco peregrinus anatum*), Mexican spotted owl (*Strix occidentalis lucida*) and Southwestern willow flycatcher (*Empidonax*

*extremus*). A peregrine was observed flying down the Pecos River valley near the park in June 1988. The Mexican spotted owl has been recorded in the Santa Fe National Forest. In 1992, a pair of flycatchers were observed nesting 3 miles north of the park (Pecos National Historical Park 1995). In a 2002 breeding bird survey (Johnson et al. 2003) carried out by the New Mexico Natural Heritage Program:

> "…one sex undetermined and two male willow flycatchers (*Empidonax traillii*) were detected on 4 and 5 June along the Pecos River. A visit by NMBBA staff on June 8 again detected willow flycatchers, but subsequent visits and nest-searches by NMNHP and NMBBA staff detected none. Because habitat conditions at present do not appear suitable for breeding willow flycatchers (Sogge et al. 1997), these birds were very likely migrants. Willow flycatcher subspecies cannot be distinguished by observation; it is therefore unclear if these birds were the northern *E. t. adastus* subspecies or the endangered southwestern *E. t. extimus* subspecies. Breeding willow flycatchers are limited by impacts to vegetation by historical livestock grazing, small patch size of potentially suitable vegetation, and limited riparian regeneration due to lowered river levels from drought and upstream diversions.

This survey detected 79 bird species. Violet-green swallow *(Tachycineta thalassina*) was the most commonly detected bird, with Brewer's blackbird (*Euphagus cyanocephalus*), western wood-pewee (*Contopus sordidulus*), and yellow warbler (*Dendroica petechia*) also among the most commonly detected species (Johnson et al. 2003). Ten species of breeding birds on the Partners In Flight high priority list for the Mesa and Plains physiographic region were documented during this survey: black-chinned hummingbird (*Archilochus alexandri*), scaled quail (*Callipepla squamata*), canyon towhee (*Piplio fuscus*), Cordilleran flycatcher (*Empidomax occidentalis*), gray flycatcher (*Empidomax wrightii*), Cassin's kingbird (*Tyrannus vociferans*), gray vireo (*Vireo vicinor*), juniper titmouse (*Baeolophus griseus*), Virginia's warbler (*Vermivora virginiae*), and Grace's warbler (*Dendroica graciae*). The Pecos River riparian area was observed to be the most important bird habitat in the ranch with the highest number of bird species and the greatest number of nest sights. The reproduction of six species were observed to be affected by brood parasitism of brown-headed cowbirds (*Molothrus ater*) (Pecos National Historical Park 1995).

- ***Reptiles & Amphibians:*** Parmenter and Lightfoot (1996) documented 7 reptile species and 3 amphibian species. Eastern fence lizard (*Sceloporus undulatus*) and woodhouse toad (*Bufo woodhousei*) were the most common species found at that time. A subsequent survey during the summer of 2002 by New Mexico Natural Heritage Program documented 10 species (28.7%) on target list: 6 reptiles and 4 amphibians, including the tiger salamander (*Ambystoma tigrinum*). The number of species detected was probably strongly influenced by low rainfall in the months preceding the inventory. Monsoon rains were sporadic as well, which likely impacted amphibian activity patterns (Johnson et al. 2003).
- ***Fish:*** The Rio Grande cutthroat trout may once have inhabited the park. According to the New Mexico Department of Game and Fish, the number and size of fish in the park in 1992 were average for the Pecos River and above average for statewide fish. There are several exotic species present in the park, including rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). In the summer of 1992, the NPS began testing the Pecos River for baseline water quality variables and contaminants. Preliminary results indicate elevated levels of heavy metals, including arsenic, chromium, lead, selenium and PCB in river fish. Levels flagged concerns for human health and fish and wildlife predators (Pecos National Historical Park 1995).
- ***Arthropods:*** Parmenter and Lightfoot (1996) conducted an intensive survey for arthropods. 514 species were documented (407 had been identified at the time of the report). The most common and widespread terrestrial invertebrates included wolf spider,

gnaphosid spider, camel cricket, grasshopper, western harvester ant and darkling beetles, among others. A comparison of grassland communities to woodland communities "… revealed that grassland sites support very different arthropod taxa and numbers of individuals when compared with piñon-juniper (sites), with species richness greatest in open grassland."

E.9.3.7. Vegetation:

The Pecos River valley is in the Rocky Mountain conifer vegetation zone, within a transition zone between piñon/juniper and ponderosa pine (*Pinus ponderosa*), and some small Douglas fir (*Pseudotsuga menziesii*) stands in the eastern side of the park. The park is also close to the grasslands of the Great Plains. Naturally occurring fire has been suppressed for at least 50 years. According to the New Mexico Forestry Department, 41% of the Pecos unit is covered by piñon/juniper, interspersed with Ponderosa pine and Douglas fir. Another 26% is covered primarily with piñon/juniper, and 10% with a juniper/grassland cover. 3% is floodplain meadow, less than 1% has riparian deciduous forest dominated by cottonwoods and willows, 15% is pasture, and 5% is developed/altered/inundated. Small areas of old-growth piñon, which is an increasingly rare habitat type in New Mexico, are present. The Pecos River in the southern part of the Pecos Unit and Glorieta Creek on the northwestern portion support a rare cottonwood hybrid species, lance-leaf cottonwood (*Populus acuminata*). This species is believed to be a cross between narrow-leaf cottonwood (*P. angustifolia*) found at higher elevations and plains cottonwood (*P. deltoides*), found at lower elevations (Pecos National Historical Park 1995). Approximately 40 acres (of the original monument) is classified as Grama-Galleta Steppe prairie. Grazing generally ceased in June 1967 when the boundary fence was completed. The 64-acre core of the monument has been closed to grazing since the 1940s, while the newest acreage was protected from grazing in 1978 (Stubendieck and Willson 1986).

There are no known federally listed threatened or endangered plants within PECO. The Holy Ghost ipomopsis (*Ipomopsis sancti-spiritus)* has been proposed for federal listing as an endangered species with critical habitat and has been identified in the mountains north of the park and could occur in the park. Two other rare species, Grama grass cactus (*Pediocactus papyriacanthus)* and Santa Fe cholla (*Opuntia viridiflora)* may occur on the ranch section (Pecos National Historical Park 1995).

A vegetation survey conducted by PECO between 1992 and 1994 resulted in 354 species of vascular plants, 57 of which were exotics (Reed et al. 1999). A study was done in 1999 by the New Mexico Natural Heritage Program to assess the riparian/wetland communities along Glorieta Creek in the Pecos unit prior to removal of two small dams and reservoirs. The creek was divided into upper, middle and lower segments. The upper and middle segments were dominated by rabbitbrush shrubland with some cottonwood forested wetland. The lower segment was dominated by coyote willow shrub wetland and was found to be in the best condition, with less fragmentation and fewer past impacts. The middle segment sustained the most impact with the reservoirs and levees. Natural recovery was occurring along Glorieta Creek and with careful management some degree of restoration was deemed possible (Muldavin et al. 1997). Park personnel have recently planted large numbers of cottonwood and willow trees as part of this riparian restoration project (Johnson et al. 2003).

There are several exotic species present in the park, including Russian thistle (*Salsola spp.*), Siberian elm (*Ulmus pumila*), and salt cedar (*Tamarix spp*.). The majority of the Pecos Pueblo ruins are covered by kochia (*Kochia scoparia*), which is damaging the ruins, and an old apple orchard (*Pyrus malus*) is present near the Pecos River (Pecos National Historical Park 1995). Exotic trees are not presently abundant (Sivinski, 1995), but there is potential for invasion in wet areas (Johnson et al. 2003).

*E.9.4. Management Issues*

Maintaining the biotic integrity of Pecos National Historic Park takes the management issue with the highest priority. There are several exotic species present in the park, including rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), feral dogs and cats (*Felis domesticus*), European clovers and grasses, Russian thistle, Siberian elm, and salt cedar. Kochia is growing on the pueblo ruins, and an old apple orchard is present near the Pecos River (Pecos National Historical Park 1995). The urban interface surrounding the park is a major source of feral dogs (*Canis familiaris*), which have been identified as potential disease vectors, are a danger to park visitors, and can decimate wildlife populations.

The water resources of Glorieta Creek and the Pecos River are another major focus for park managers. These riparian areas contain the highest biodiversity found at PECO and serve as vital corridors for species migration and dispersal. They also are integral to the cultural landscape. Visitors are drawn to these riparian areas, where use leads to soil compaction, vegetation trampling and disruption of wildlife behavior (Pecos National Historical Park 1995). Water quality of the Pecos River has been impacted by sources outside of the park. Contaminant levels in fish pose health hazards for both humans and wildlife. The sewage treatment plant for the city of Pecos discharges into the river 2 miles upstream of the park. There is also a practice of dumping untreated waste by private landowners into the Pecos River and Glorieta Creek. Staging for the widening and resurfacing of NM 50 was in a particularly vulnerable area of Glorieta Creek, just north of the park boundary, which included mining for soil and gravel. Because of these actions water quality has been impacted within the park due to the heavy erosion and ensuing sedimentation (Reed et al. 1999).

PECO was set aside partially to preserve scenic resources. Scenic elements remain from the time of the ancestral Pueblo Indian and Spanish occupation, but are affected by land use changes outside the park. Residential development continues to increase outside the park boundaries. New Mexico State Road 50 runs through the Pigeon's Ranch unit and has a major negative effect on its natural and cultural resources and values. Interstate 25 also affects the Cañoncito subunit with visual and noise intrusions and air pollution (Pecos National Historical Park 1995).

The Santa Fe National Forest adjoins several units of PECO, and piñon-juniper woodland comprises the majority of park habitat, requiring an emphasis on fire and forestry management. Grasslands in PECO continue to be encroached upon by woody vegetation. The Ips beetle causes die-off in patches of piñion pine, often stressed by drought. Previous decades of fire suppression has allowed for buildup of fuels. There is a need for a well-developed and coordinated fire plan in order to adequately manage this resource.

*E.9.5. Partnering / Neighboring Agencies*

E.9.5.1. Current Partners
New Mexico Natural Heritage Program

E.9.5.2. Neighboring Management Agencies:
Las Vegas NWR, Santa Fe National Forest, Villaneuva State Park, Sevilleta LTER – Sevilleta NWR

*E.9.6. Literature Cited*

Johnson, K., G. Sadoti, G. Racz, J. Butler and Y. Chauvin. 2003. National Park Service Southern Plains Network: final inventory report for New Mexico parks. Natural Heritage New Mexico. Albuquerque, NM.

Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. National Park Service TIC #D-107.

Muldavin, E., R. Wallace and M. Bradley. 1997. Riparian/wetlands vegetation assessment for the reservoir removal and floodplain restoration project of Glorieta Creek, Pecos National Historic Park. Albuquerque, NM.

National Park Service. 2005. Assessing the risk of foliar injury from ozone on vegetation in parks in the Southern Plains Network.

Parmenter, R.R. and D.C. Lightfoot. 1996. A field study of the faunal resources of the Pecos unit, Pecos national historical park, Pecos, NM. Albuquerque, NM. Cooperative Agreement Number CA7029-1-0012.

Pecos National Historical Park. 1995. Draft general management plan, development concept plan, environmental impact statement. National Park Service, Denver Services Center. Denver, CO.

Reed, J., S. Marten, B. Simpson and L. Hudson. 1999. Natural and cultural resource management plan: Pecos National Historical Park. Pecos, New Mexico.

Sivinski, R. 1995. A botanical inventory of Pecos National Historical Park, New Mexico. Report to NPS.

Sogge, M., R.M. Marshall, S.J. Sferra, and T.J. Tibbitts. 1997. A southwestern willow flycatcher natural History summary and survey protocol. Technical Report NPS/NAUCPRS/NRTR-97/12.

Stubbendieck, J., and G. Willson. 1986. An identification of prairie in national park units on the Great Plains. NPS Occasional Paper No. 7.

## E. 10. SAND CREEK MASSACRE NATIONAL HISTORIC SITE (SAND)

On November 29, 1864, Colonel John M. Chivington led approximately 700 U.S. volunteer soldiers to attack and kill about 150 Cheyenne and Arapaho people, mainly women, children, and the elderly, peacefully encamped along Big Sandy Creek. SAND will recognize the national significance of this massacre in American history, and its ongoing significance to the Cheyenne and Arapaho people and descendents of the massacre victims. While authorized, the proposed 12,480 acre (5,051 ha) historic site will not be established or open to the public until enough land is acquired to provide for the preservation, commemoration, and interpretation of the Sand Creek Massacre. To date, 920 acres (372 ha) have been purchased and an additional 1,465 acres (593 ha) is owned by the Cheyenne and Arapahoe tribes and managed by the NPS.

### *E.10.1. Resource Overview*

SAND is located approximately 180 miles (290 km) southeast of Denver, in eastern Kiowa County, Colorado, within the High Plains section of the Great Plains-Palouse Dry Steppe Province ecoregion, at an elevation of approximately 4,000 feet (1,219 m). The site lies along a 5.5-mile (8.9 km) meandering stretch of intermittent Big Sandy Creek, through gently rolling prairie grassland with extensive viewsheds.

The climate at SAND is fairly typical of the eastern Colorado Plains – predominately clear and dry with moderate winds out of the southeast. Average annual precipitation is 13-14 inches (33-36 cm), falling fairly evenly throughout the year. Summer thunderstorms can bring heavy rains and hail, while winter snowfalls average 27 inches (69 cm) annually (Anderson et al. 1981). Temperatures range from an average of 87°F (31°C) from June through August, to an average minimum of 14°F (-10°C) December through February.

### *E.10.2. Enabling Legislation / Management Documents*

On October 6, 1998 Congress authorized the SAND Site Study Act. This legislation (Public Law 105-243) mandated that the National Park Service identify the location and extent of the massacre area and determine its suitability and feasibility as a potential National Historic Site. Two years later, the Site Location Study and Special Resource Study/Environmental Assessment provided Congress with site boundaries and enough supporting information to move forward with the endeavor. SAND was therefore authorized by Public Law 106-465 on November 7, 2000. The purposes of the Act are to recognize the national significance of the massacre in American history, and its ongoing significance to the Cheyenne and Arapaho people and descendents of the massacre victims. Establishment of the historic site will occur once an adequate amount of land has been secured from willing sellers. The park's authorizing legislation directs NPS to manage the site as close as practicable to the 1864 cultural landscape. On August 2, 2005, President Bush signed into law P.L. 109-45 which authorized the United States to take into trust 1,465 acres (565 ha) in the core area of the massacre site currently owned by the Cheyenne and Arapaho Tribes of Oklahoma.

### *E.10.3. Natural Resources*

<u>E.10.3.1. Valuable Resources / Species of Interest:</u>
The natural resources of SAND provide a fairly intact ecosystem. Work is being conducted to determine how the landscape has changed since 1864. Proper biotic inventories have yet to be completed, as most of the property within the proposed park boundaries remains in private hands. Black-tailed prairie dog (*Cynomys ludovicianus*), Arkansas darter (*Etheostoma cragini*), mountain plover (*Charadrius montanus*), and burrowing owl (*Athene cunicularia*) are state listed and/or federal candidate species that have been documented at SAND. Prairie dogs are a keystone species of the short-grass prairie that provides habitat for many other as-yet-undetected species of concern, such the, black-footed ferret (*Mustela nigripes*) and Swift fox (*Vulpes velox velox*). Of particular interest is the Lesser prairie chicken (*Tympanuchus pallidicinctus*), listed as

threatened in Colorado and a federal candidate species. This dramatically declining bird has been historically documented within the authorized boundaries of SAND. Another significant bird species that may occur at SAND is the ferruginous hawk (*Buteo regalis*). Colorado bursage (*Ambrosia linearis)*, is only found in Kiowa County and a few other areas in southeastern Colorado. The floodplain of Big Sandy Creek may provide ideal habitat for this highly endemic plant.

E.10.3.2. Geology & Soils:

Big Sandy Creek drains the eastern side of a broad southeasterly trending valley composed largely of Quaternary wind-deposited sands from the Holocene and Pleistocene periods over sands, silt and gravel. The bluffs on the western side of the creek consist of non-calcareous, excessively drained Valent and Bijou-Valent loamy sands, while the terraces and eastern slopes contain deep, well-drained Kim-Harvey- Stoneham (KHS) loams derived from coarse, calcareous materials, to loess derived Wiley loam. Floodplain soils are level and poorly drained. The dune and valley fill deposits average 20 to 50 feet (6-15 m) in depth above the chalky Smoky Hill Shale. Runoff erosion is not as problematic as wind erosion because of the high permeability of most of the soils at SAND (Sharps 1976; National Park Service 2000).

The Sand Creek Massacre National Historic Site sits along the center of the northeast-southwest trending axis of the Las Animas Arch 38. Gas was discovered in 1952 approximately 12 miles (20 km) southwest of SAND, while oil was discovered in 1964, northwest to east and closer to the historic site. Helium is being produced at a refinery northeast of Sand Creek in Cheyenne Wells. Most of the drilling for oil or gas near SAND has been unsuccessful. There are no known mineral extraction operations in the vicinity of Big Sandy Creek other than several oil/gas wells and subsurface mineral rights are held by individual landowners (National Park Service 2000).

E.10.3.3. Land Use:

All surrounding land use at Sand Creek Massacre National Historic Site is agricultural – grazing, dry land farming, and land enrolled in the Conservation Reserve program. All but 920 acres (372 ha) of the land within the proposed boundaries is privately owned, divided among thirteen families and the Cheyenne and Arapaho tribes. County Road W cuts through three miles (5 km) of the southern edge of the massacre site, with a few secondary access roads within the park. Remnants of other man-made alterations include the crumbling Chivington canal, an abandoned ranch house and various fence lines, water tanks and windmills. There are various remnants of former ranch headquarters the original 12,480 acre (5,051 ha) authorized boundary. One major underground natural gas pipeline crosses SAND from the southwest to the northeast (National Park Service 2000).

E.10.3.4. Hydrology

SAND lies along an 5.5 miles (8.85 km) stretch of the Big Sandy Creek, also referred to as the Big Sandy Creek. Precipitation provides water for Big Sandy Creek, which intermittently flows based on rainfall events. During many years the creek does not have substantial enough water to reliably be used for potable or irrigation purposes. Several strips of wetlands are present at and around SAND. Groundwater at the site has been rated as fair to poor. These conditions are likely a result of ambient levels of minerals in the area. The biggest threat facing SAND water resources is erosion along the streambanks. Additionally, a wetland on the southern edge of SAND contains the federally listed Arkansas Darter. The only hydrological monitoring currently occurring is by Eads public works.

E.10.3.5. Air Quality

The study site and the entire Kiowa County area have generally excellent air quality and meet the “attainment” status for all required air pollutants monitored in the National Ambient Air Quality Standards. The area is a Class II airshed (National Park Service 2000).

E.10.3.6. Wildlife:

- ***Mammals:*** No formal surveys have been conducted for SAND. The black-tailed prairie dog is common on portions of SAND, so it is thought that the state and federally listed endangered black-footed ferret (*Mustela nigripes*) may also be a resident on and/or near the site. Free-ranging mule deer (*Odocoileus hemionus*), white-tail deer (*Odocoileus virginianus*), and pronghorn (*Antilocapra americana*) are present, as well as coyote (*Canis latrans*), raccoon (*Procyon lotor*), and badger (*Meles meles*) (National Park Service 2000).
- ***Birds:*** A bird survey was initiated in 2005 by the Rocky Mountain Bird Observatory. The state and federally candidate species, mountain plover, as well as the state listed burrowing owl occurs at the park.
- ***Fish:*** The Arkansas darter was found at SAND in 2005. This species is listed as a candidate species for federal listing and is listed by Kansas, Colorado, and Oklahoma. A more in-depth survey will begin in 2006.
- ***Reptiles and Amphibians*****:** There have been no formal surveys for reptiles and amphibians at SAND.

E.10.3.7. Vegetation

Consultations with the Cheyenne and Arapahoe tribes have identified protection of the landscape as one of the highest natural resource priorities at SAND. There are three types of habitat identified: riparian cottonwood along sections of the creek, short-grass prairie north of Big Sandy Creek; and the sand sage (*Artemisia filifolia*) community to the south. Within these grassland communities there are pockets of grasslands with tall-grass species due to the sandy soils. Over a long period of time, the intermittent flow and periodic flooding of Big Sandy Creek selects for largely dry prairie plant species through the riparian area, although mesic and wetland species are found around surface water or shallow groundwater. Eastern cottonwood (*Populus detloides*) are the only trees at the site and are found in even-aged stands along seasonal stream traces. These trees are only successful in the presence of available water and minimal grazing pressures, so may have been historically limited by grazing bison (*Bison bison*) and firewood gathering by Indian tribes. The blue grama (*Bouteloua gracilis*) and buffalo grasses (*Buchloe dactyloides*) of the short-grass prairie dominate at SAND, accompanied by some switchgrass (*Panicum virgatum*) and side-oats gramma (*Bouteloua curtipendula*). Sand sage has gained a foothold on drier slopes and where grazing has been excessive (National Park Service 2000). The rare showy prairie gentian (*Eustoma russellianum*) has been found at the park.

Exotic plants are not currently a large problem either along Big Sandy Creek or within the proposed park boundaries. Cheat grass (*Bromus tectorum*) and sand burr (*Cenchrus echinatus*) are the most common nuisance species, but Canada thistle (*Cirsium vulgare*) to the east and leafy spurge (*Euphorbia esula*) to the northwest will require vigilance to keep them from invading the park. Restoration of areas eroded from heavy foot and livestock traffic will continue to keep SAND relatively free of exotic vegetation (National Park Service 2000).

*E.10.4. Management Issues*

It has been a challenge for managers at SAND to develop a management plan because there is a dearth of baseline information available. With most of the proposed parkland still in private ownership, these inventories will develop slowly. It is fortunate that the site is in good shape, but efforts must be made to maintain its health. No one knows how the traditionally grazed grasslands will respond once they are taken out of grazing. Fire has long been excluded from the grasslands. The presence of healthy prairie dog colonies provides a strong basis for the possibility of many rare species. The existence of any small mammal community in the West brings the concern of disease transmission to humans – sylvatic plague in prairie dogs and hanta virus in deer mice are not easily passed on to humans, but care must be taken nonetheless. A looming management concern is the range expansion of feral hogs, a destructive invasive animal that brings destruction to riparian areas.

Sand Creek National Historic Site preserves approximately 5-1/2 miles of Big Sandy Creek. Maintenance of groundwater levels will be important to insure the continued flow of springs and seeps in the area, while water quality is important to wildlife and humans alike. Water rights, while not currently of major concern, should be addressed to insure an adequate supply of water for both the park and the wildlife in it. The flood process along Big Sandy Creek must also be maintained for the health of the natural resources within the boundaries of Big Sandy Creek National Historic Site. Erosion concerns, while minimal, do exist. Several small areas of bank erosion need to be restored before exotic plants gain a foothold.

The future effects of visitors must be taken into account, as hardscaping, foot traffic and vehicular traffic will impact the historic site. Air quality will be affected in the area with the onslaught of visitors, roadways will impact the hydrology and the soundscape will be impacted. Boundary fencing must be in place to exclude activities such as hunting and off-road vehicle use. Surrounding land uses, while currently benign, could change with time, bringing their own alterations. Mineral, oil and gas extraction is carried on in Kiowa County. While no extractive activities are currently occurring along the proposed park boundary or within SAND, contingency plans should be developed for future use. The viewshed from the Sand Creek Massacre site extends for several miles to the north, east, and south, and still conveys a strong sense of its likely appearance at the time of the 1864 massacre. There is currently very little use of night lighting in a several mile radius area around the study site except for residential and agricultural operations (National Park Service 2000).

*E.10.5. Partnering / Neighboring Agencies*

E.10.5.1. Current Partners
Colorado Historical Society, the Cheyenne and Arapaho Tribes in Oklahoma, the Northern Cheyenne Tribe in Montana, the Northern Arapaho Tribe in Wyoming, NRCS, Colorado Division Of Wildlife, Kiowa County, Rocky Mountain Bird Observatory, Colorado Natural Heritage Program, The Conservation Fund, Colorado State Historical Fund, SAND property owners, Colorado Range Riders, Colorado State University.

E.10.5.2. Potential Partners
Colorado Native Plant Society, Volunteers for Outdoor Colorado.

E.10.5.3. Neighboring Land Management Agencies
Bohart Ranch (TNC); the Great Plains Reservoirs (Neenoshe, Neesopah, Neeskah, and Neegronda) and surrounding land owned by Colorado Division of Wildlife, Adobe Creek Reservioir (9,425 acres), Bureau of Land Management, and Small Chivington Reservoir.

*E.10.6. Literature Cited*

Anderson, D.L., J.G. Lesh, and D.W. Wickman. 1981. Soil survey of Kiowa county, Colorado. U.S. Department of Agriculture: Soil Conservation Service, in cooperation with Colorado Agricultural Experimental Station.

National Park Service. 2000. Sand Creek massacre project, volume two: special resource study and environmental assessment natural resources environment. Intermountain Region. Denver, CO. NPS.

Sharps, J.A. 1976. U.S. geologic map of the Lamar quadrangle, Colorado and Kansas. 1:250,000, Map I-944. U.S. Department of the Interior: U.S. Geological Survey.

## E. 11. WASHITA BATTLEFIELD NATIONAL HISTORIC SITE (WABA)

Washita Battlefield National Historic Site (WABA) protects and interprets the site of the Southern Cheyenne village of Peace Chief Black Kettle that was attacked by the 7th U.S. Cavalry under Lt. Col. George A. Custer just before dawn on November 27, 1868. Hailed at the time as a significant victory, the battle of Washita remains controversial because many Indians and whites labeled Custer's attack a massacre. The site retains important cultural and historical value for the Cheyenne and other Southern Great Plains tribes, and its protection supports their on-going struggle to maintain control of their traditional homelands (Milner 2003). Black Kettle is still honored as a prominent leader who never ceased striving for peace even though it cost him his life. This 326-acre (132 ha) historic site received 14,215 visitors in 2004.

### *E.11.1 Resource Overview*

WABA is in the Rolling Plains, near the western limit of the Redbed Plains physiographic region of the Great Plains Steppe and Shrub Province. The area was once continuous mixed and short-grass prairie amid red sandstone and gypsum outcroppings. Surrounded by parcels of the Black Kettle National Grasslands in west-central Oklahoma, WABA is less than a mile northwest of the town of Cheyenne, in Roger Mills County, Oklahoma. The Washita River winds west to northeast for 1.25 miles (2 km) across the park, dividing WABA into a floodplain bounded to the north and south by wooded “benches” at an approximate 2000 foot (610 m) elevation.

The climate at Washita Battlefield is sub-humid, temperate and continental. It is characterized by hot summers, mild winters, relatively high wind velocities and wide fluctuations in rainfall. Average maximum temperature June through August is 91°F (33°C), while average minimum temperatures December through February is 23°F (-5°C). Average annual precipitation is 25 inches (64 cm) with most of this falling between April and August. Severe thunderstorms are common and can produce tornados (National Park Service 2001).

### *E.11.2. Enabling Legislation / Management Documents*

The Washita Battlefield was first named a National Historic Landmark in 1965. On November 12, 1996, Washita Battlefield National Historic Site was established to “recognize the importance of the Battle of the Washita as a nationally significant element of frontier military history and as a symbol of the struggles of the Southern Great Plains tribes to maintain control of their traditional use areas.” (Public Law 104-333). The legislation also specifies that the park will work cooperatively with the Cheyenne-Arapaho Tribe in developing the management plan and in the preparation of educational programs for the public (Washita Battlefield National Historic Site 2001). Three purposes for WABA are identified as: 1) to recognize the attack by Lt. Col. George Armstrong Custer and the 7$^{th}$ U.S. Cavalry on the Cheyenne encampment of Chief Black Kettle as a nationally significant element of the United States government Indian policy; 2) to recognize the struggles of the Cheyenne and other Southern Great Plains tribes to maintain control of their traditional homelands; and 3) to protect, preserve and interpret the cultural and natural resources of the national historic site through the collaborative efforts of the United States government and the Cheyenne-Arapaho Tribe (National Park Service 2001).

Mission Goals have also been set for WABA. Those pertaining to natural resources include: Natural and cultural resources and associated values of WABA are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context; and WABA contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information (National Park Service 2001).

Several management documents guide staff in their efforts. A Strategic Plan was develop in 1998 to provide interim support until the General Management Plan was accepted in 2001. That same year, a specific Resource Management Plan was established and its recommendations are

currently being implemented in the park. A Wildland Fire Management Plan was adopted in 2002 to assist with the implementation of prescribed burning used as a restoration tool.

*E. 11. 3. Natural Resources*

E.11.3.1. Valuable Resources / Species of Interest:
There are two striking features of Washita Battlefield. The sweeping overlook vista of the floodplain campsite of Black Kettle and his people rises up in the distance to rose-colored gypsum outcrops, providing the visitor with a sense of space and reverence. The second thing a visitor might notice is the sound of quietness as the wind sighs across the prairie. These characteristics define WABA.

The short-grass/mixed-grass prairie ecosystem supports several species of interest at Washita. No federally threatened or endangered plant or animal species have been documented at the historic site. However, several animal species are found that are listed by the State of Oklahoma. Texas horned lizard (*Phrynosoma cornutum*) has been documented at WABA and is also listed by neighboring states of Texas and Colorado. The northern earless lizard (*Holbrookia maculata maculata*) has been observed, as well as Swainson's hawk (*Buteo swainsoni*).

E.11.3.2. Geology & Soils:
Washita Battleground National Historic Site is near the western limit of the Red Bed Plains physiographic zone, with exposure of the Cloud Chief Formation, which is composed primarily of Permian-aged red sandstones, siltstones, mudstones and impressive white gypsum (Neff 2002; Koch & Santucci 2003). Outcrops of gypsum, or alabaster, protrude from the ridge that divides the southern floodplain from the adjoining uplands. The Cloud Chief Formation has not been known to produce many fossils, although a few have been found just east of the park boundary (Brown 2001). WABA lies on the southern flank of the Anadarko Basin, a large, deep, sedimentary basin that is a major source of oil and gas. There is primarily deep gas production from Pennsylvanian age Cherokee, Atoka and Morrow Groups reservoirs near the historic site. Six wells within 1-1/2 miles of the site have tested these reservoirs and were unproductive, so perhaps future oil and gas drilling activities near WABA will be minimal. The previous landowner retained all the subsurface mineral rights at Washita (National Park Service 2001).

The Dust Bowl of the 1930s heavily impacted this part of Oklahoma, to the point that most of the original prairie topsoil is gone (Inglis 2001). The soil survey for Roger Mills County (USDA 1963) identifies 10 principal soil associations within WABA.. Soils found on uplands and slopes include: Woodward (loam and fine sandy loam), Miles-Springer Complex (somewhat sandy), Miles-Nobscot complex (fine sandy loam to sand), hilly Springer loamy fine sand, and hilly Pratt loamy fine sand. Floodplain soils include: Spur and Port (silty-loam), hummocky Springer loamy fine sand, Yahola fine sandy loam, and Lincoln (National Park Service 2001)

E.11.3.3. Land Use
For the past one hundred years, land both in and around the Washita Battlefield National Historic Site has been used for farming and grazing. Land was cleared, fields were terraced and the Washita River was impounded and straightened in sections. A now-abandoned rail line was laid across the southern section of WABA in the 1920s, involving cuts at the eastern end of the park and fill on the west end. An underground pipeline runs from the southwest corner of the park to the northeast.

E.11.3.4. Hydrology
WABA is located on the Washita River. The "Dust Bowl" of the 1930's likely resulted in considerable changes to the local hydrology (Inglis 2001) and may be the cause of the stream characteristics that are discordant with its watershed conditions. Currently, the Washita River is considered an undersized stream with a wide valley-bottom floodplain (Inglis 2001). In addition to the drought conditions of the 1930's, dams along the Washita River and irrigation of surface and ground waters have contributed to the current state of the river. Groundwater at WABA is

generally hard and may contain excessive dissolved solids. Sulfate concentrations, in particular, are often above the recommended drinking limit. The greatest threats to the water resources at WABA include the silt build-up, dams, regional waste pits, invasive plant establishment in riparian areas, residential development, cattle ranching, and oil well operations. The USGS has gauged the Washita River at a station downstream from WABA for over 60 years. Additionally, they collected water quality data bi-annually from the 1930's to the 1990's. A functional evaluation of the Washita River was performed by the WRD in 2001 but no baseline water quality report has yet been completed.

E.11.3.5. Air Quality

There are no known point sources of air pollution currently visible from Washita Battleground National Historic Site (Washita Battlefield National Historic Site 2001). Current local sources of air pollution include particulate matter from agricultural practices, prescribed burning, and emissions associated with vehicle and farm usage. WABA is designated a Class II area (National Park Service 2001).

E.11.3.6. Wildlife

- ***Mammals:*** A survey was conducted by Okalahoma Natural Heritage Inventory during 2000-2001. Twenty-one mammal species were detected, 10 of which were from the small mammal community. The most common mammal trapped was the hispid cotton rat (*Sigmodon hispidus*), only found south of the Washita River, followed by the white-footed mouse (*Peromyscus leucopus*). The most common species detected at tracking plates were raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), opossum (*Didelphis virginiana*) and southern plains woodrat (*Neotoma micropus*) (Lomolino and Smith 2001).
- ***Birds:*** No formal avian surveys have been completed at WABA, but an incidental list was compiled of observations by Oklahoma Natural Heritage during their 2000-2001 mammal survey. 45 bird species were recorded at this time (Lomolino and Smith 2001), including several on the Partners In Flight watch list for the Rolling Red Plains physiographic region: Swainson's hawk (*Buteo swainsoni*), red-headed woodpecker (*Melanerpes erythrocephalus*), Cassin's sparrow (*Aimophila cassinii*), and scissor-tailed flycatcher (*Tyrannus forficatus*). A baseline inventory of avian species is currently underway.
- ***Reptiles/Amphibians:*** A survey was conducted by Okalahoma Natural Heritage Inventory during 2000-2001, documenting 11 reptiles and 4 amphibians. By far the most common reptile on site was the prairie racerunner (*Cnemidophorus sexlineatus*). Texas horned lizards (*Phrynosoma cornutum*), listed as a Category II species of concern by the state of Oklahoma, were also seen regularly. Along the river, Blanchard's cricket frogs (*Acris crepitans*) were very common (Lomolino and Smith 2001). The northern earless lizard (*Holbrookia maculata maculata*) is another species listed by the State that has been documented at WABA.
- ***Fish:*** Oklahoma Biological Survey conducted an inventory of fish found in the Washita River at WABA. Sampling was conducted three separate times during 2002-2003 and documented 16 species of fish. Mosquitofish (*Gambusia affinis*) and red shiners (*Cyprinella litrensis*) were extremely abundant. The moderately common fish species found are tolerant of siltation and turbidity (Bergey 2003).
- ***Invertebrates:*** A survey for aquatic invertebrates in the Washita River at WABA was conducted by Oklahoma Biological Survey during 2002-2003. Three sampling resulted in 82 taxa of aquatic invertebrates and 26 taxa of aerial insects. Beetles, mayflies and dragonflies/damselflies were especially speciose. The river has a mosaic of different habitats which have characteristic associated invertebrates, resulting in a high diversity of invertebrate fauna (Bergey 2003).

E.11.3.7. Vegetation

Washita Battlefield National Historic Site is located at the juncture of several ecoregions. Moisture-loving eastern species overlap the more arid southwestern species, while tall-grass prairie gives way to short-grasses. The site itself can be divided into several clear habitats:

upland forest, grasslands, old field, wetlands and riparian areas. It is estimated that historically, riparian areas covered 19 acres (8 ha) of park, while grassland dominated 316 acres (128 ha) (Hoagland et al. 2005). Baseline vegetation data was collected under drought conditions by Stotts and DuBey (1998). Their analysis suggested that the southern riparian area was the most "pristine," the upland prairie in the southeast sector was the most ecologically healthy, and that the wooded "bench" to the north, although heavily grazed, had never been plowed (Stotts and DuBey 1998; Milner 2003). The Oklahoma Biological Survey conducted a vascular flora inventory in 2002, collecting over eight months. They documented 272 species of vascular plants, 32 of which were trees, shrubs or vines. Five species tracked by the Oklahoma Natural Heritage Inventory were found: low silverbush (*Argythamnia humilis*), plains beeblossom (*Gaura brachycarpa*), cutleaf nightshade (*Solanum triflorum*), giant dropseed (*Sporobolus giganteus*), and prairie zinnina (*Zinnia grandiflora*) (Hoagland et al. 2005).

Thirty-two exotic species were documented, representing 11.8% of the flora collected at Washita Battlefield (Hoagland et al. 2005), several of which are listed by the State of Oklahoma as noxious weeds: Johnson grass (*Sorghum halepense*), white and yellow sweet clover (*Melilotus alba* and *M. officinale*), field bindweed (*Convolvulus arvensis*), bermuda grass (*Cynodon dactylon*), and downy brome (*Bromus mollis*). Control of exotic species is on-going at Washita and several areas are in need of restoration. The floodplain, once mid-grass prairie, has been plowed for decades and is now invaded by kochia (*Kochia scoparia*) and scotch thistle (*Onopordum acanthium*). Research is being done to assess the effectiveness of RoundUp™ on eradication of thistle. Successful efforts to remove tamarisk (*Tamarix chinensis*), once estimated to comprise 80% of the riparian cover, began in 1999 (Milner 2003). Four acres of black locust (*Robinia pseudoacacia*), invading from neighboring fields, were cleared from the eastern boundary in 2000 (Washita Battlefield National Historic Site 2001).

*E.11.4. Management Issues*

The most critical management issues at Washita Battlefield National Historic Site deal with biotic integrity. A portion of the parks enabling legislation reads, "to protect and preserve….the visual scene as closely as possible as it was at the time of the battle" – a tall order for an area that has been under agricultural management for a century. The grasslands of WABA, especially those in the floodplain, have been heavily altered by the plow. Minimal regard for soil conservation practices resulted in fertile prairie topsoil being blown away during the Dust Bowl. Those grasslands not plowed were heavily grazed, permanently changing the prairie plant communities. Exotic and native invasive plants quickly colonized disturbed areas. Western red cedar and mesquite began to invade overgrazed pasture. The suppression of wildland fire has encouraged this woody succession while enabling exotic plants to gain a foothold. The decline in habitat in conjunction with fragmentation, has doubtless affected wildlife composition. The Washita River underwent failed attempts to straighten its meander. Somewhere along its course, tamarisk was planted to control the resulting erosion, only to dominate the riparian vegetation to the exclusion of other native species. Efforts aimed at controlling exotic species began shortly after the formation of WABA in 1996. The need to follow control efforts with the reintroduction of desired species is apparent. Fire, in the form of prescribed burns, must be reinstated in the management regime, both to encourage prairie health and to reduce potentially dangerous fuel loads. The role of grazing must also be evaluated as a management tool for Washita.

The protection of the viewsheds and the soundscape are among the most important issues at Washita. An effort is being made to establish a baseline sound measurement so that change can be monitored. Noise generated by park management activities will be minimized and equipment purchase and use will take decibel levels into account, all with a goal of preserving the all too rare silence. The nightsky feature, currently unpolluted by surrounding lights, contributes greatly to the visitor experience. The vistas at Washita Battlefield have been little altered and are generally evocative of the 1868 view. The skyline to the north is dominated by a series of deep red shale outcroppings. It is desired that all of these sensory experiences can be preserved through landowner cooperation and judicious easements, but adjacent land use can be difficult to control.

Development of subdivisions, industry and extractive activities can all impact the sights and sounds at Washita (National Park Service 2001).

The management of the limited water resources will be vial to assuring that there will be water available for Washita Battlefield. Upstream impoundments and agricultural drawdown have altered the renewing floods and depleted the stream flow. Contamination from industrial activities is a dire threat, as is siltation from runoff erosion of agricultural fields. Groundwater level and quality, while possibly unsuitable for human consumption, remains important for the health of the ecosystem.

Visitor use at WABA will be closely monitored to prevent additional degradation to sensitive natural resources. Barriers and erosion control measures will be used to control compaction and trampling caused by trail erosion and unauthorized trails. This is particularly critical in the riparian area, where controlled crossing and access points will be developed. Visitor education and the presence of ranger patrols will also reduce unintentional visitor impacts (National Park Service 2001).

*E. 11. 5. Partnering / Neighboring Agencies & Individuals:*

E.11.5.1. Current Partners
USFWS – Washita NWR, USFS Black Kettle Grasslands,; Oklahoma Historical Society, Southern Cheyenne–Arapahoe Tribes

E.11.5.2. Neighboring Land Management Agencies:
Washita NWR, Black Kettle National Grasslands, Foss State Park

*E.11.6. Literature Cited*


Bergey, E.A. 2003. Aquatic invertebrates and fishes of the Washita River in the Washita Battlefield National Historic Site. Oklahoma Biological Survey. Project 125-5967.

Brown, J. 2001. Washita Battlefield Geology Site Bulletin: National Park Service.

Hoagland, B.W., A. Buthod and W. Elisens. 2005. Vascular flora and historic vegetation of Washita Battlefield National Historic Site, Roger Mills county, Oklahoma: final report. Oklahoma Biological Survey.

Inglis, R.R. 2001. Trip report for travel to Washita Battlefield July 16-19, 2001. Water Resources Division.

Milner, J. Associates, Inc. 2003. Washita battlefield national historic site cultural landscape report: part 2. Task Order T7486010178. Charlottesville, VA.

Koch, A.L. and V.L. Santucci. 2003. Paleontological resource inventory and monitoring: southern plains network. NPS TIC #D-107. National Park Service.

Lomolino, M.V. and G.A. Smith. 2001. Baseline inventory of mammals, reptiles, and amphibians at Washita Battlefield National Historic Site, Oklahoma. OK Natural Heritage Inventory: Norman, OK.

National Park Service. 2001. Washita Battlefield National Historic Site: final general management plan/environmental impact statement. Denver, CO.

Neff, L.C. 2002. Archeological survey and soil testing at Washita Battleground National Historic Site, Roger Mills county, Oklahoma. Western Archeological and Conservation Center: Tucson, AZ. Publications in Anthropology 82.

Stotts, P. and R. DuBey. 1998. Washita Battlefield National Historic Site vegetation analysis. National Park Service. Santa Fe, NM.

United State Department of Agriculture. 1963. Soil survey of Roger Mills County, Oklahoma. Series 159, No. 29.

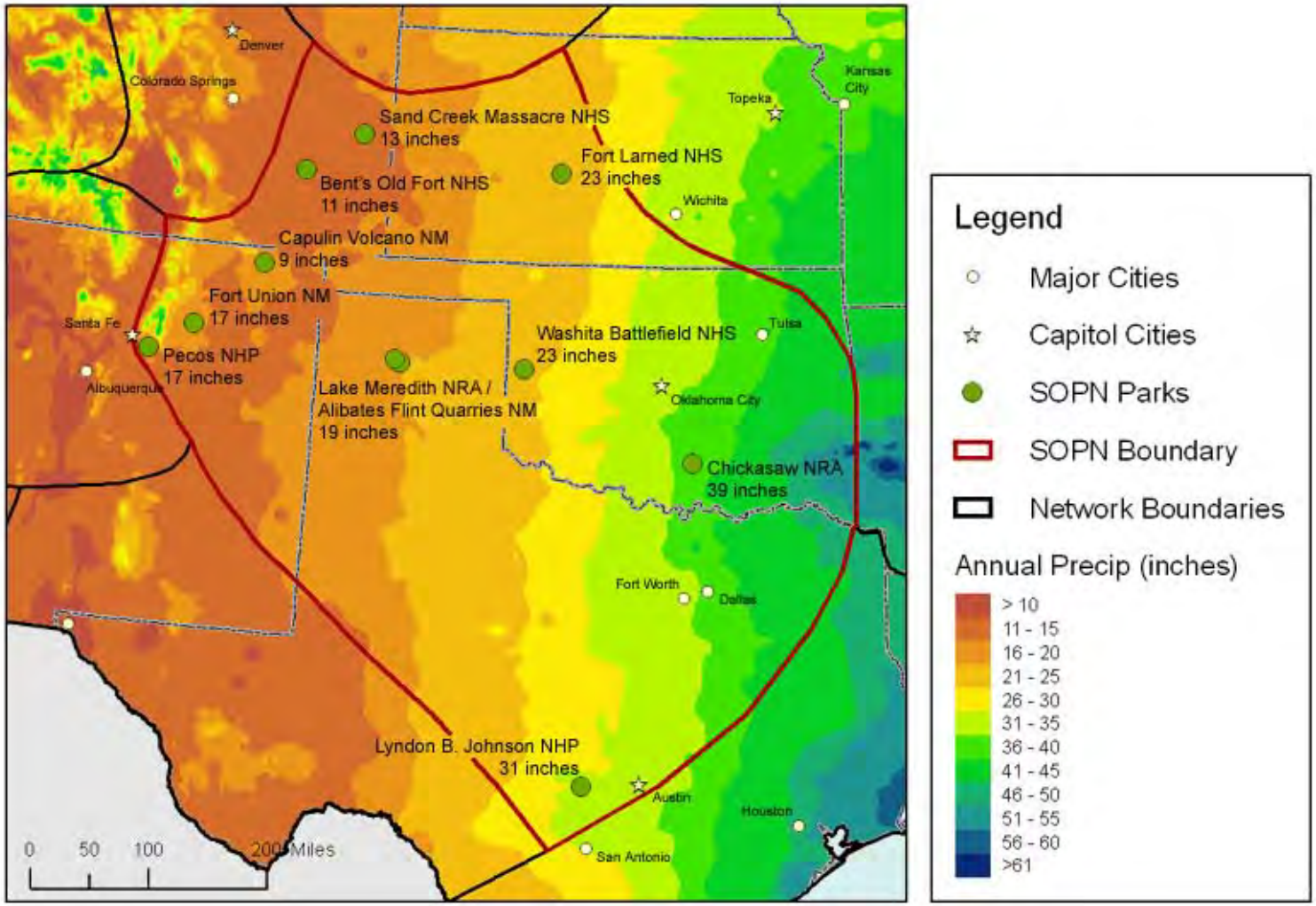
Washita Battlefield National Historic Site. 2001. Resource management plan – Washita Battlefield National Historic Site.

## APPENDIX F. NETWORK AND PARK MAPS

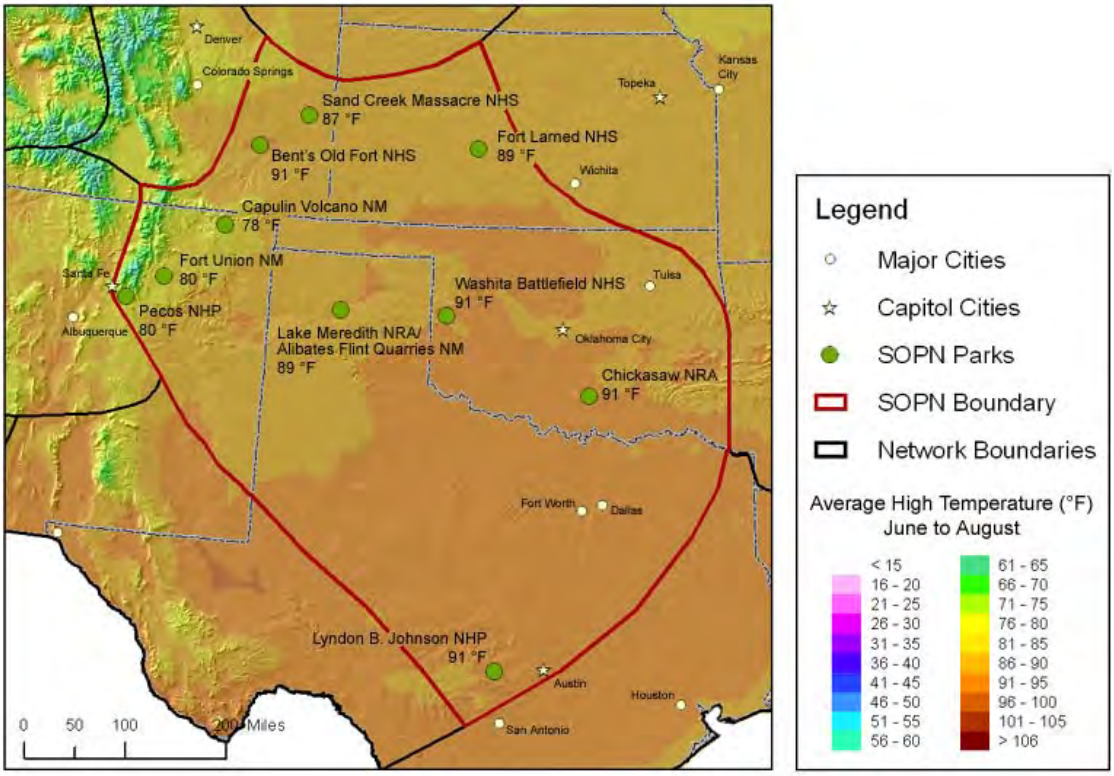
Heidi Sosinski

TABLE OF CONTENTS

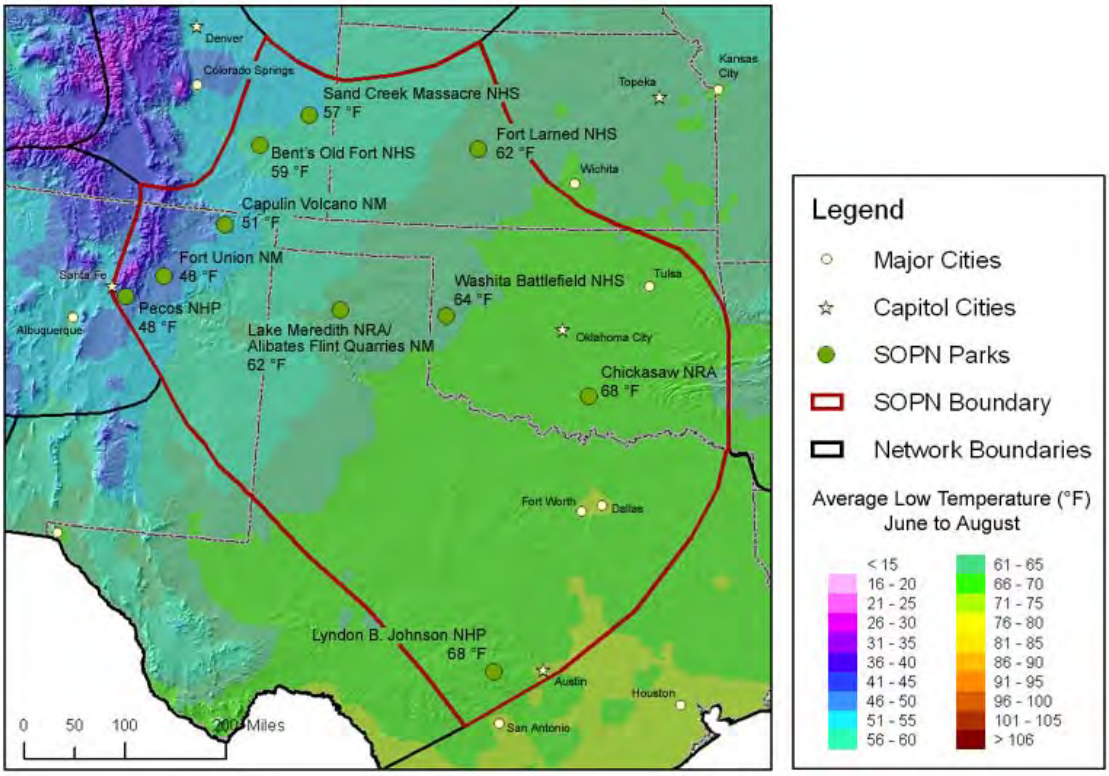
F.1. SOPN Precipitation Map ..... A-79
F.2. SOPN average maximum (a) and minimum (b) summer temperatures..... A-80
F.3. SOPN average maximum (a) and minimum (b) winter temperatures..... A-81
F.4. Bent's Old Fort National Historic Site..... A-82
F.5. Capulin Volcano National Monument..... A-83
F.6. Chickasaw National Recreation Area..... A-84
F.7. Fort Larned National Historic Site ..... A-85
F.8. Fort Union National Monument ..... A-86
F.9. Lake Meredith National Recreation Area ..... A-87
F.10. Lyndon B. Johnson National Historical Park..... A-88
F.11. Pecos National Historical Park..... A-89
F.12. Sand Creek Massacre National Historic Site ..... A-90
F.13. Washita Battlefield National Historic Site..... A-91




**Map F.1. SOPN Precipitation Map**

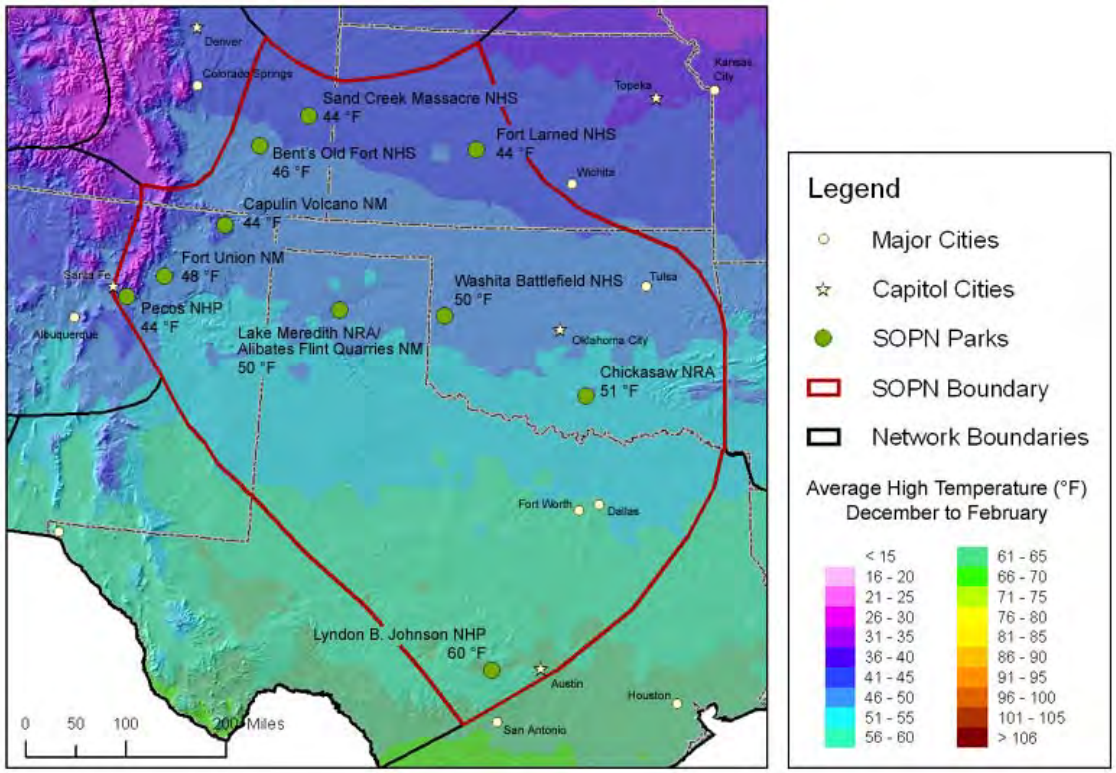



**a.**

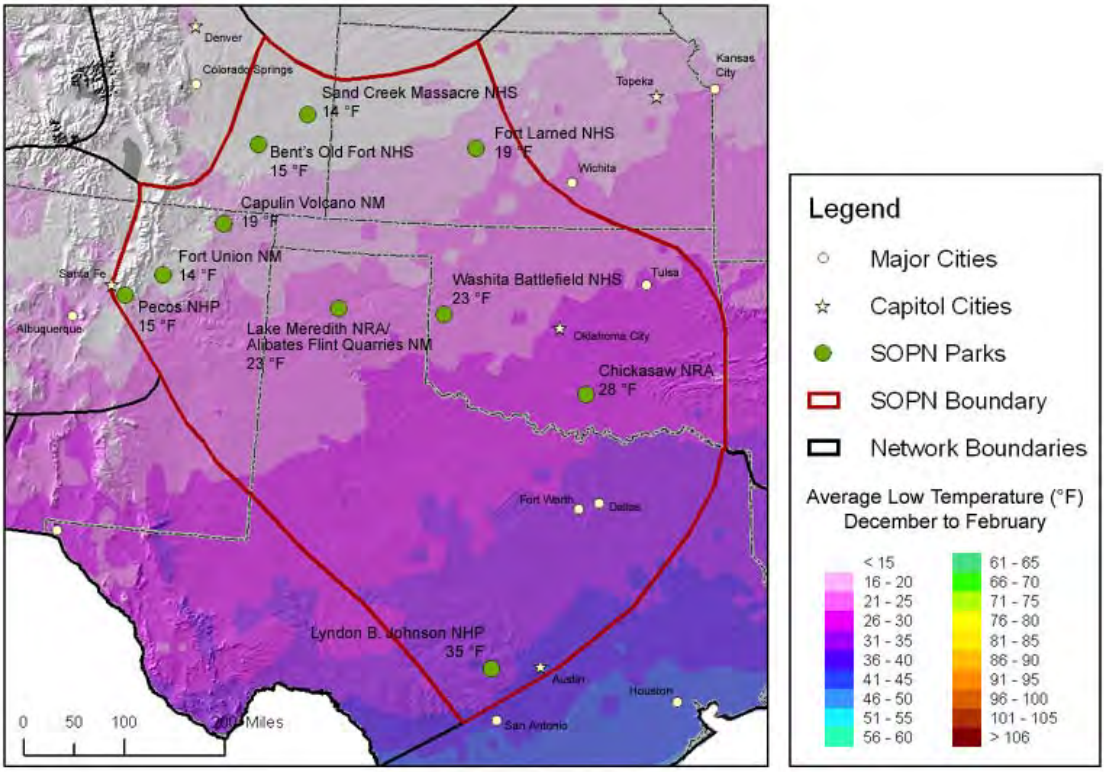



**b.**

**Map F.2. SOPN average maximum (a) and minimum (b) summer temperatures.**




**a.**




**b.**

**Map F.3. SOPN average maximum (a) and minimum (b) winter temperatures.**

# Bent's Old Fort National Historic Site

Park Information

William and Charles Bent, along with Ceran St. Vrain, built the original fort on this site in 1833 to trade with plains Indians and trappers. The adobe fort quickly became the center of the Bent, St.Vrain Company's expanding trade empire that included Fort St.Vrain to the north and Fort Adobe to the south, along with company stores in Mexico at Taos and Santa Fe. The primary trade was with the Southern Cheyenne and Arapaho Indians for buffalo robes.

For much of its 16-year history, the fort was the only major permanent white settlement on the Santa Fe Trail between Missouri and the Mexican settlements. During the war with Mexico in 1846, the fort became a staging area for Colonel Stephen Watts Kearny's "Army of the West". Disasters and disease caused the fort's abandonment in 1849. Archeological excavations and original sketches, paintings and diaries were used in the fort's reconstruction in 1976.

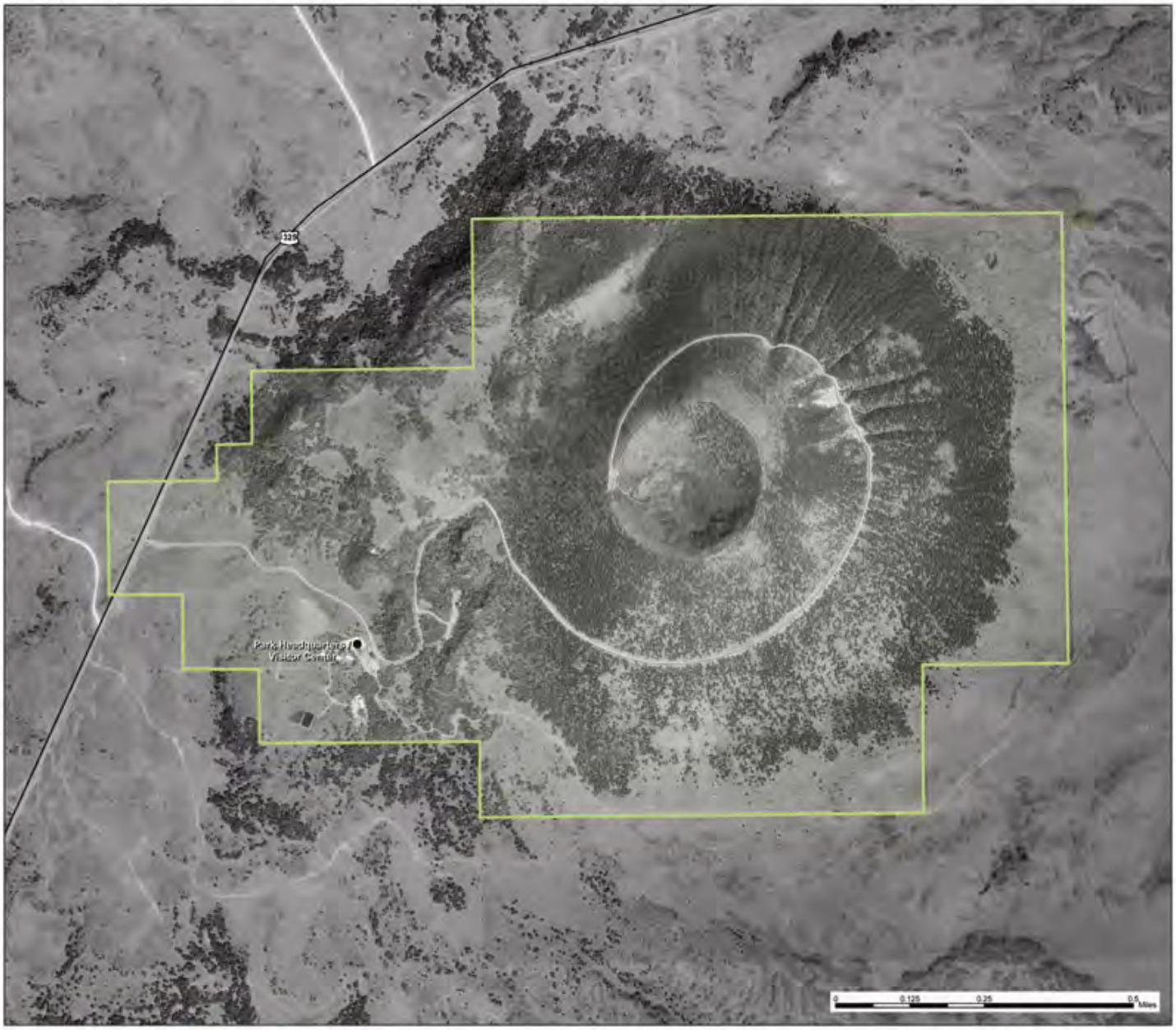
N W E S

Park Boundary
Forest Service
Bureau of Land Management
Fish and Wildlife Service
Department of Defense
Department of Transportation
Interstate
Highways
Park Roads
Santa Fe Trails
Arkansas River

Produced by Southern Plains I&M Program

November 2004

# Capulin Volcano National Monument



## Park Information

Capulin Volcano National Monument is a well-preserved, relatively young (58,000 to 62,000 years old), symmetrical cinder cone. It rises steeply from the surrounding grassland plains to an elevation of 8,182 feet above sea level. The irregular rim of the crater is about a mile in circumference and the crater about 400 feet deep.

Capulin Volcano is one of the outstanding landmarks located in the northeast corner of New Mexico, where the rolling grasslands meet the foothills of the Sangre de Cristo Mountains. Capulin Volcano's highest point provides unobstructed, panoramic views of the volcanic field, distant snow-capped mountains, and portions of four states (New Mexico, Oklahoma, Texas and Colorado). Capulin Volcano also offers visitors excellent opportunities for observing and understanding volcanic formation. The large volcanic field surrounding the monument contains at least 100 recognizable volcanoes, and aids visitors in gaining insights into 10 million years of the geological history of Northern New Mexico.

N
W E
S

- Park Boundary
- State Park
- Department of Defense
- Forest Service
- Fish and Wildlife Service
- Interstate
- State Highways
- Secondary and Park Roads
- Trails

Produced by Southern Plains I&M Program

November 2004

# Chickasaw National Recreation Area

## Park Information

The "Peaceful Valley of Rippling Waters" appropriately describes Chickasaw National Recreation Area, as it is known for its many mineral springs, cool water, flora, fauna, and wildlife. This area has significant geological and hydrological features and lies in the transitional ecotones of the Eastern deciduous forest and the Western prairies. Chickasaw has classic examples of Civilian Conservation Corps (CCC) architectural craftsmanship and ingenuity, including one of the largest and most intact designed cultural landscapes of that period. A trail system designed and constructed during this period is still actively used today. Chickasaw has been the setting for generations of traditional family activity that represents part of our American heritage. It adds measurably to the quality of life for visitors and area residents by providing opportunities to experience a wide range of outdoor experiences, such as swimming, boating, fishing, hiking, and observing nature, hunting, camping, and picnicking.

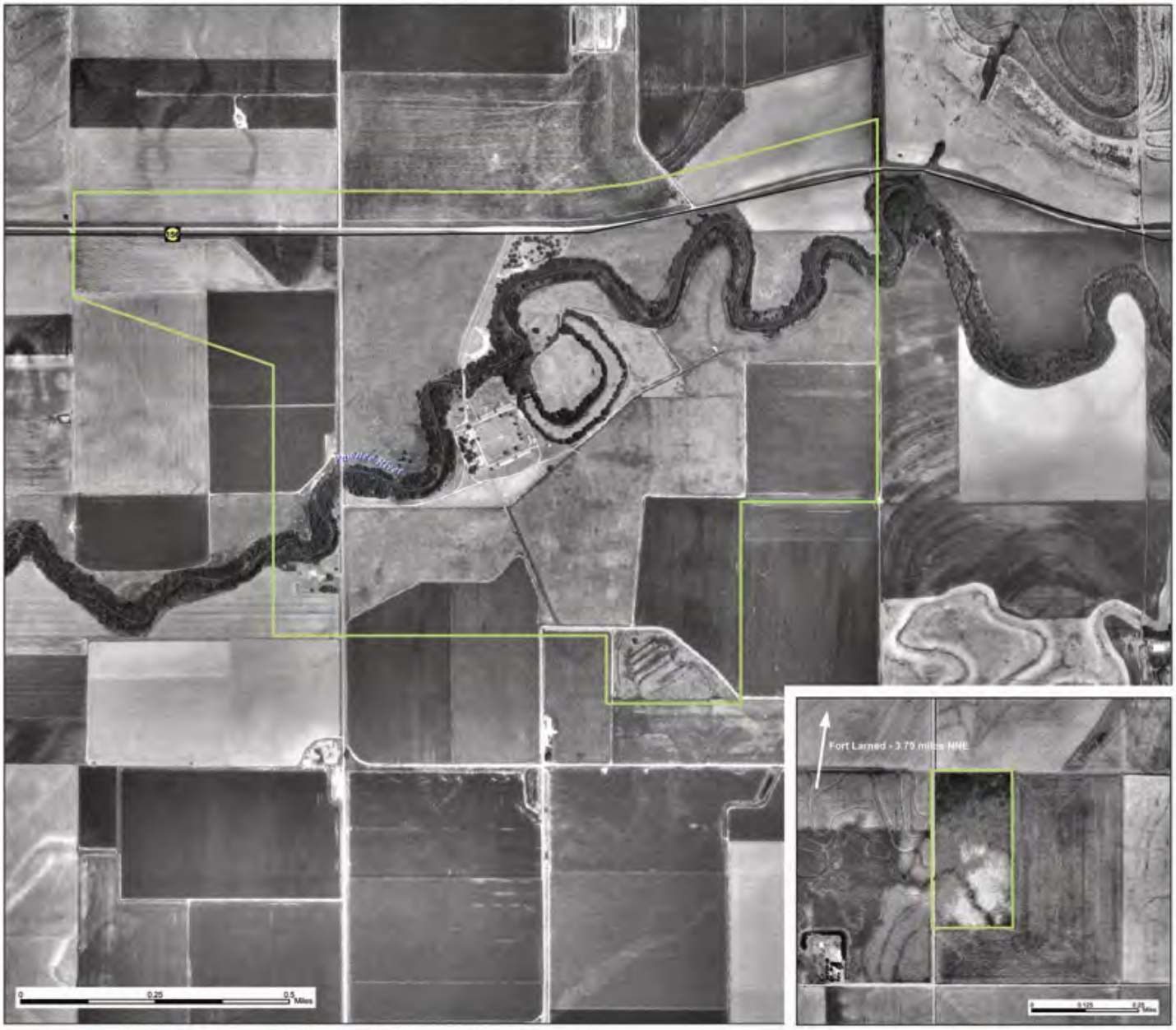
N
W E
S

Park Boundary
Oklahoma
Texas

State Parks
Forest Service
Fish and Wildlife Service

Interstate
State Highways
Secondary Roads

# Fort Larned National Historic Site



## Park Information

Fort Larned was established in 1859 as a base of military operations against hostile Indians of the Central Plains. The fort also provided protection for traffic along the Santa Fe Trail and acted as an agency for the administration of the Central Plains Indians by the Bureau of Indian Affairs. The historic site has nine restored buildings and survives as one of the best examples of Indian Wars period forts. The barracks, commissary, officers quarters have all been furnished to their original appearance. Ruts created from traffic along the Santa Fe trail are present in a site located approximately 3.75 miles south of the fort.

- Park Boundary
- Pawnee River
- Lakes and Reservoirs
- Army Corp of Engineers
- Bureau of Reclamation
- Fish and Wildlife Service
- Interstate
- State Highways
- Secondary Roads

Produced by Southern Plains I&M Program

November 2004

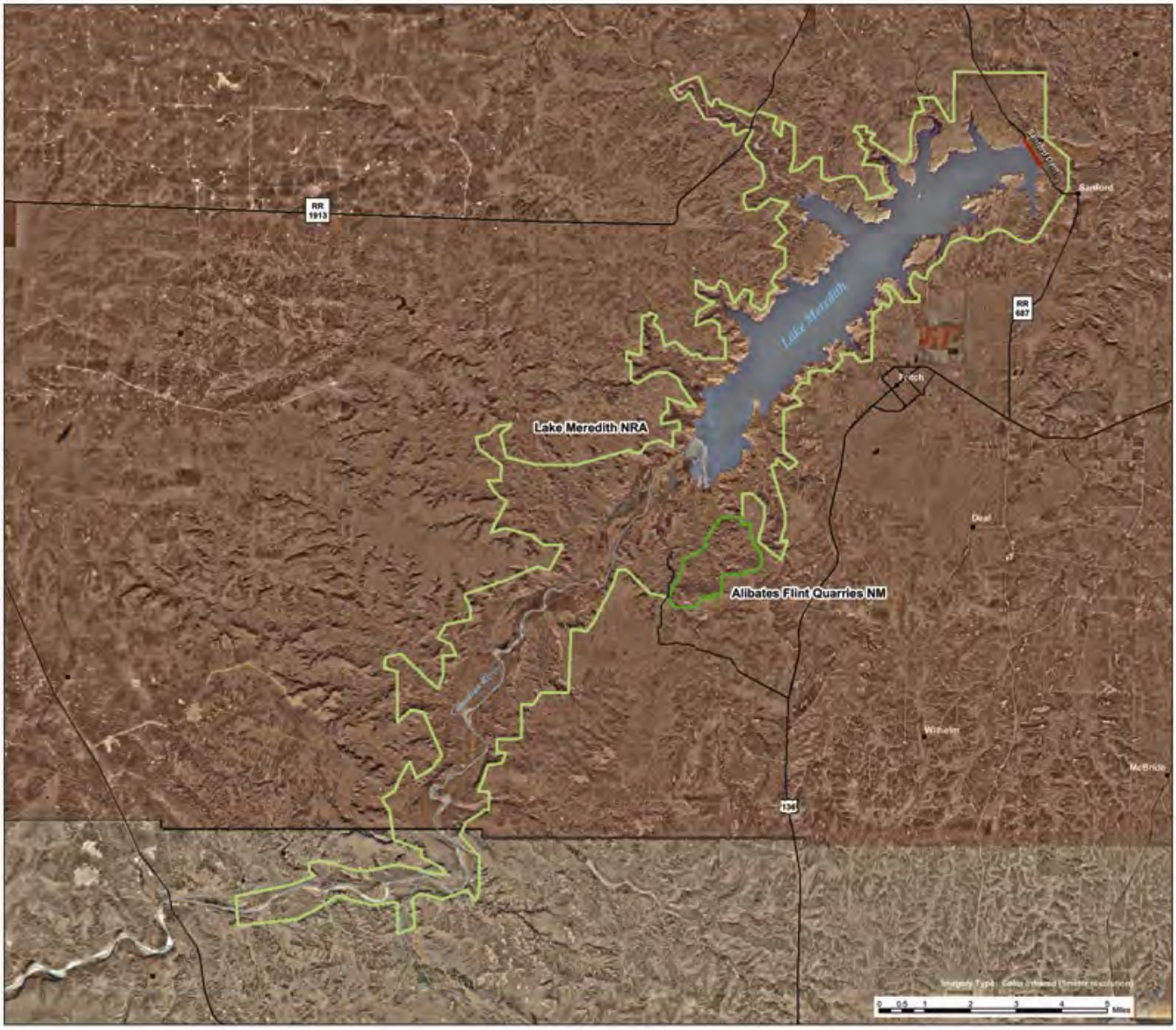
# Fort Union National Monument

<u>Park Information</u>

Fort Union was established in 1851 by Lieutenant Colonel Edwin V. Sumner as a guardian and protector of the Santa Fe Trail. During it's forty-year history, three different forts were constructed close together. The third and final Fort Union was the largest in the American Southwest, and functioned as a military garrison, territorial arsenal, and military supply depot for the southwest. Today, visitors use a self-guided tour path to visit the second fort and the large, impressive ruins of the third Fort Union. The largest visible network of Santa Fe Trail ruts can be seen here.

Park Boundary
Bureau of Indian Affairs
Fish and Wildlife Service
Forest Service
Bureau of Land Management
State Parks
Interstate
State Highways

# Lake Meredith NRA and Alibates Flint Quarries NM



## Park Information

Lake Meredith, located in the Texas Panhandle, was created when Sanford Dam flooded the Canadian River. The shores are dotted with mesquite, prickly pear, yucca, and grasses of arid plains. Cottonwoods, soapberry, and sandbar willows stand on sheltered creek beds. On November 28, 1990, Congress transferred Lake Meredith Recreation Area from the Bureau of Reclamation to the National Park Service. The area was redesigned as a National Recreation Area. The 50,000-acre national recreation area includes a 10,000-acre reservoir where visitors can enjoy a variety of recreational opportunities.

For thousands of years, people came to the red bluffs above the Canadian River for flint, vital to their existence. Demand for the high quality, rainbow-hued flint is reflected in the distribution of Alibates Flint through the Great Plains and beyond. Today this area is protected by the National Park Service and is the only National Monument in Texas. The monument can only be viewed by ranger-led guided tours.

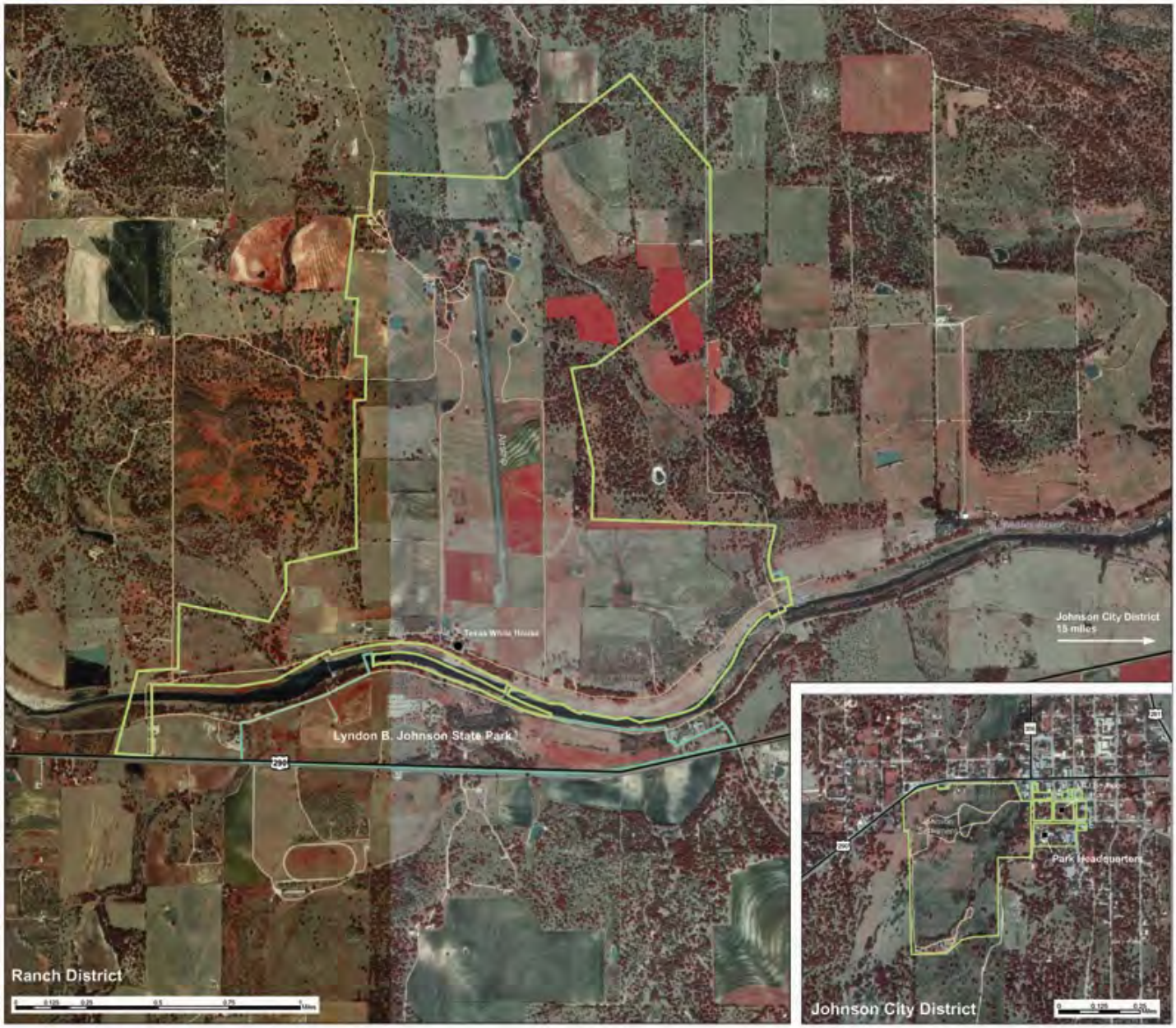
N
W E
S

Lake Meredith NRA
Alibates Flint Quarries NM

Forest Service
Fish and Wildlife Service
State Park

Interstate
Highways
Canadian River
Lake Meredith

# Lyndon B. Johnson National Historical Park



## Park Information

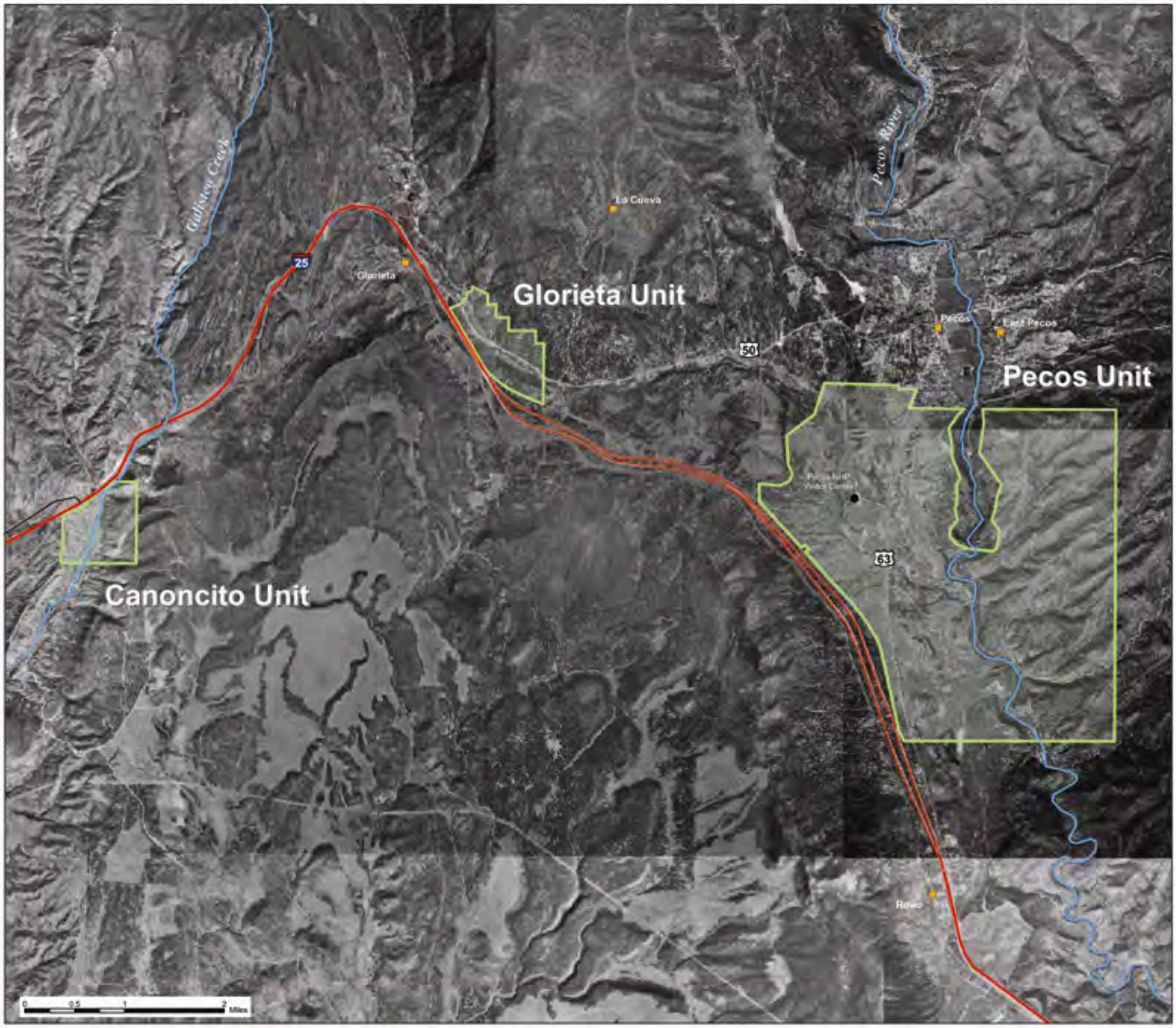
Lyndon B. Johnson National Historical Park tells the story of our 36th President. The story begins with Lyndon Johnson's ancestors, tracing the influences his family and his beloved Texas Hill Country had on the boy and the man. In Johnson City, the visitor can see how LBJ influenced his home town by bringing the resources of the U.S. Government to bear on improving the lives of his friends and neighbors. The park also affords a special opportunity to visit a working cattle ranch, preserved in the late 1960s time period. On the LBJ Ranch it is possible to experience the serenity and beauty from which the former president drew his strength and comfort. It is here that his final resting place is located.

The park was authorized on December 2, 1969 and was redesignated from a historic site to a national historical park on December 28, 1980. Present holdings are approximately 1,570 acres, 674 of which are federal. The Johnson family generously continues to add to this property; their most recent donation of acreage was in April, 1995.

N
W E
S

Park Boundary
State Park Boundary
Lakes
Department of Defense
Fish and Wildlife Service
Rivers
Interstate
State Highways
Park Roads/Trails
Dams

# Pecos National Historical Park



Park Information

Pecos preserves 12,000 years of history including the ancient pueblo of Pecos, two Spanish Colonial Missions, Santa Fe Trail sites, 20th century ranch history of Forked Lightning Ranch, and the site of the Civil War Battle of Glorieta Pass.

The ruins trail, picnic area, and visitor center are the only areas currently open to visitors at this time. Closed areas such as the Forked Lightning Ranch, the Santa Fe Trail, and the Civil War Battlefield of Glorieta are available only through ranger guided tours.

N
W E
S

- Park Boundary
- Bureau of Indian Affairs
- Department of Defense
- Department of Energy
- Fish and Wildlife Service
- National Park Service (inset)
- Forest Service
- Interstate
- State Highways
- Streams

Produced by Southern Plains I&M Program

November 2004

# Sand Creek Massacre National Historic Site

## Park Information

On November 29, 1864, Colonel John M. Chivington led approximately 700 U.S. volunteer soldiers to a village of about 500 Cheyenne and Arapaho people camped along the banks of Big Sandy Creek in southeastern Colorado. Although the Cheyenne and Arapaho people believed they were under the protection of the U.S. Army, Chivington's troops attacked and killed about 150 people, mainly women, children, and the elderly. Ultimately, the massacre was condemned following three federal investigations.

Sand Creek Massacre National Historic Site was authorized by Public Law 106-465 on November 7, 2000. The purposes of the Act are to recognize the national significance of the massacre in American history, and its ongoing significance to the Cheyenne and Arapaho people and descendents of the massacre victims. The Act authorizes establishment of the national historic site once the NPS has acquired sufficient land from willing sellers to preserve, commemorate, and interpret the massacre. Acquisition of a sufficient amount of land has not yet occured. Currently, the majority of land within the authorized boundary is privately owned and is not open to the public. The NPS is working in partnership with The Conservation Fund, the Cheyenne and Arapaho Tribes, and the State of Colorado towards establishment of the Sand Creek Massacre National Historic Site.

N
W E
S

Park Boundary
Authorized Park Boundary (Lands in Private Ownership)
Army Corps of Engineers
Bureau of Land Management
Forest Service
Interstate
Highways
Park Area Roads
Big Sandy Creek

# Washita Battlefield National Historic Site

Park Information

Washita Battlefield National Historic Site protects and interprets the site of the Southern Cheyenne village of Peace Chief Black Kettle. Just before dawn on November 27, 1868, the village was attacked by the 7th U.S. Cavalry under Lt. Col. George A. Custer. The controversial strike was hailed at the time by the military and many civilians as a significant victory aimed at reducing Indian raids on frontier settlements. Washita remains controversial because many Indians and whites labeled Custer's attack a massacre. Black Kettle is still honored today as a prominent leader who never ceased striving for peace even though it cost him his life.

Park Boundary
Washita River
Lakes
Army Corp of Engineers
US Forest Service
Fish and Wildlife Service
State/County Parks
Interstate
State Highways
Trails

**APPENDIX G. STATE AND FEDERALLY LISTED SPECIES AND ENDEMIC SPECIES THAT ARE FOUND (X) OR POTENTIALLY FOUND (P) IN SOUTHERN PLAINS NETWORK PARKS**

| Common Name | Scientific Name | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Federal Status | States Listed | Endemic To: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reptiles** | | | | | | | | | | | | | | | |
| Northern earless lizard | *Holbrookia maculata maculate* | | | | | | | | | | | X | | OK | |
| Texas horned lizard | *Phrynosoma cornutum* | X | X | | X | | | X | P | | | X | | CO, OK, TX | |
| Texas map turtle | *Graptemys versa* | | | | | | | | X | | | | | Endemic | Edwards Plateau |
| **Mammals** | | | | | | | | | | | | | | | |
| Black-tailed prairie dog | *Cynomys ludovicianus* | | X | | | X | | X | | | X | | | NM | |
| Marsh rice rat | *Orzomys palustris* | | | | X | | | | | | | | | OK | |
| Mountain lion | *Puma concolor* | | | | | | | P | | | | P | | OK | |
| Palo Duro Canyon mouse | *Peromyscus truei Comanche* | | | | | | | P | | | | | | TX, Endemic | Texas Panhandle |
| Swift fox | *Vulpes velox* | | | P | | | | P | | | P | | | CO, OK, NM | |
| Townsend's big eared bat | *Corynorhinus townsendii* | | | X | | | | | | | | | | NM | |
| **Birds** | | | | | | | | | | | | | | | |
| Bald eagle | *Haliaeetus leucocephalus* | | | | | | | X | X | | | | Threatened | CO, KS, OK, NM, TX | |
| Burrowing owl | *Athene cunicularia* | | P | | | X | | | | | X | | | CO, OK | |
| Ferruginous hawk | *Buteo regalis* | | X | | | | | | | | P | | | CO, OK | |
| Lesser prairie chicken | *Tympanuchus pallidicnctus* | | | | | | | P | | | P | | Candidate | CO, OK, NM | |
| Mountain plover | *Charadrius montanus* | | | | | | | | | | X | | Proposed and removed | CO, OK, NM | |
| Southwestern willow flycatcher | *Empidonax traillii extimus* | | | | | | | | | P | | | Endangered | TX, CO, NM | |
| Swainson's hawk | *Buteo swainsonii* | | | | X | | X | | | | | X | | OK | |

| Common Name | Scientific Name | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Federal Status | States Listed or Endemic | Endemic To: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fish** | | | | | | | | | | | | | | | |
| Arkansas darter | *Etheostoma cragini* | | P | | | | | | | | X | | Candidate | KS, CO, OK | |
| Arkansas river shiner | *Notropis girardi* | | | | | | | X | | | | | Threatened | KS, OK, NM, TX | |
| Guadalupe bass | *Micropterus treculi* | | | | | | | | X | | | | | Endemic | Edwards Plateau |
| **Invertebrates** | | | | | | | | | | | | | | | |
| Alberta arctic butterfly | *Oeneis alberta capulinensis* | | | X | | | | | | | | | | Endemic | Northeastern New Mexico Mountains |
| Giant mole cricket | *Gryllotalpa major* | | | | | | | X | | | | | | OK | |
| **Plants** | | | | | | | | | | | | | | | |
| Dwarf Milkweed | *Asclepias uncialis* | | | | | | | | | P | | | | Endemic | Northern New Mexico |
| Streaked Ragweed | *Ambrosia linearis* | | | | | | | | | | P | | | Endemic | Southeastern Colorado |

**APPENDIX H EXOTIC PLANTS FOUND IN SOUTHERN PLAINS NETWORK PARKS WITH THEIR APPLICABLE NOXIOUS WEED DESIGNATIONS**

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Abutilon theophrasti* Medik. | velvetleaf | CO | | ● | | ● | ● | | | | | | | |
| *Acroptilon repens* (L.) DC. | knapweed, Russian | CO, KS, NM | | ● | | | | | | | | | | |
| *Aegilops cylindrica* Host | goatgrass, jointed | CO, NM | | ● | | ● | ● | | ● | | | | | |
| *Agropyron cristatum* (L.) Gaertn. | wheatgrass, crested | | | | ● | | | | | | ● | | | |
| *Agrostis gigantea* Roth | bentgrass, redtop or water | | | | | | | ● | ● | | ● | | | |
| *Albizia julibrissin* Durazz. | mimosa | | | | | ● | | | | | | | | may be escaped |
| *Alyssum minus* (L.) Rothm. | alyssum, European | | | | | | | | | | ● | | | |
| *Amaranthus blitoides* S. Wats | amaranth, prostrate | | | | | | | | ● | | | | | |
| *Amaranthus retroflexus* L. | amaranth, redroot | | ● | ● | | ● | | | ● | | | | | |
| *Arctium minus* Bernh. | burdock | CO | | | | | | | | | ● | | | |
| *Arenaria serpyllifolia* L. | sandwort, thyme-leaf | | | | | ● | | | | ● | | | ● | |
| *Arundo donax* L. | reed, giant | TX | | | | | | | | ● | | | | |
| *Asparagus officinalis* L. | asparagus, garden | | | ● | | ● | | | | ● | ● | | | |
| *Atriplex rosea* L. | saltbush, redscale | | | | | | | | | | ● | | | |
| *Bothriochloa bladhii* (Retz.) S.T. Blake | beardgrass, Australian | | | | | | ● | | | | | | | |
| *Bothriochloa ischaemum* var. *songarica* (Rupr. ex Fisch. & C.A. Mey.) Celarier & Harlan | bluestem, King Ranch | | | | | ● | | | ● | ● | | | ● | |
| *Brassica nigra* (L.) Koch | mustard, black | | | | | | | | | ● | | | | |
| *Bromus catharticus* Vahl | rescue-grass | | | | | ● | | ● | ● | ● | ● | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bromus commutatus* Schrad. | brome, meadow | | | ● | | | ● | | | | | | | |
| *Bromus hordeaceus* ssp. *hordeaceus* L. | brome, soft | | | | | | | | | | | | ● | syn: Bromus mollis |
| *Bromus inermis* Leyss. | brome, smooth | | | ● | ● | | ● | | ● | | ● | | | |
| *Bromus japonicus* Thunb. ex Murr. | brome, Japanese | | | ● | ● | ● | ● | ● | ● | ● | ● | | ● | |
| *Bromus lanceolatus* Roth | brome, big-spike | | | | | | | | | ● | | | | syn: Bromus macrostachys |
| *Bromus tectorum* L. | cheatgrass | CO | | ● | ● | ● | ● | ● | | | ● | ● | | |
| *Broussonetia papyrifera* (L.) L'Her. Ex Vent. | mulberry, paper | | | | | ● | | | | | | | | |
| *Buglossoides arvensis* (L.) I.M. Johnston | bugloss, false | | | | | ● | | | | ● | | | | |
| *Capsella bursa-pastoris* (L.) Medik. | shepherd's purse | CO | | | | ● | ● | | | ● | ● | | ● | |
| *Cardaria draba* (L.) Desv. | hoary cress | CO, KS, NM | | ● | | | | | | | ● | | | |
| *Carduus nutans* L. | musk thistle, nodding | CO, KS, NM, OK | | | | | | | | ● | | | | |
| *Carduus tenuiflorus* W. Curtis | thistle, slenderflower | | | | | | | | | ● | | | | |
| *Centaurea melitensis* L. | star-thistle, short-spine | NM | | | | | | | | ● | | | | |
| *Cerastium glomeratum* Thuill. | chickweed, bunch-flower | | | | | ● | | | | ● | | | | |
| *Chenopodium ambrosioides* L. | wormseed | | | | | ● | | | | ● | | | | |
| *Chenopodium glaucum* L. | goosefoot, oakleaf | | | | | | | | ● | | | | | |
| *Chorispora tenella* (Pallas) DC. | mustard, purple | CO | | ● | | | | | | | ● | | | |
| *Cichorium intybus* L. | chicory | CO | | | ● | | | | | | | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cirsium arvense* (L.) Scop. | thistle, Canada | CO, KS, NM, OK | | ● | | | | | | | | ● | | |
| *Conium maculatum* L. | poison-hemlock | CO, NM | | ● | | | ● | | | ● | ● | | | |
| *Convolvulus arvensis* L. | bindweed, field | CO, KS, NM, TX | | ● | ● | ● | ● | ● | ● | | ● | | ● | |
| *Coronilla varia* L. | crownvetch, purple | | | | | ● | | | ● | | | | | |
| *Cynodon dactylon* (L.) Pers. | Bermuda grass | | | ● | | ● | ● | ● | ● | ● | | | ● | |
| *Cynoglossum officinale* L. | houndstongue | CO | | | ● | | | | | | | | | |
| *Cyperus rotundus* L. | nutgrass, purple | | | | | | | | | ● | | | | |
| *Dactylis glomerata* L. | orchardgrass | | | ● | | | ● | | | | ● | | | |
| *Datura stramonium* L. | jimsonweed | | | | | ● | | | | | | | | |
| *Descurainia sophia* (L.) Webb ex Prantl | herb sophia | CO | | ● | ● | | ● | | ● | | | | | |
| *Dichanthium annulatum* (Forsk.) Stapf | bluestem, Kleburg | | | | | | | | | ● | | | | |
| *Dipsacus fullonum* ssp. *sylvestris* (Huds.) Clapham | teasel | | | ● | | | | | | | | | | syn = Dipsacus sylvestris |
| *Echinochloa colona* (L.) Link | jungle-rice | | | | | ● | | | | ● | | | | |
| *Echinochloa crus-galli* (L.) Beauv. | barnyardgrass | | | ● | ● | ● | ● | | ● | ● | | | ● | |
| *Elaeagnus angustifolia* L. | olive, Russian | CO, NM | | ● | | | ● | | ● | | ● | | | |
| *Eleusine indica* (L.) Gaertn. | goosegrass, Indian | | | | | | ● | | | | | | | |
| *Eragrostis barrelieri* Daveau | lovegrass, Mediterranean | | | | | | | | ● | ● | ● | | ● | |
| *Eragrostis cilianensis* (All.) Vign. ex Janchen | lovegrass, stinky | | ● | | | ● | ● | | ● | ● | | | ● | |
| *Eragrostis curvula* (Schrad.) Nees | lovegrass, weeping | | | | | | | | ● | | | | ● | |
| *Erodium cicutarium* (L.) L'Her. ex Ait. | filaree; stork's bill | CO | | | | ● | | ● | ● | ● | ● | | ● | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Euphorbia davidii* Subils | spurge, David's | | | | ● | | | ● | ● | | | | | |
| *Euphorbia esula* L. | spurge, leafy | CO, KS, NM | | | | | | | | | | ● | | |
| *Facelis retusa* (Lam.) Schultz-Bip. | trampweed, annual | | | | | | | | | ● | | | | |
| *Fatoua villosa* (Thunb.) Nakei | crabweed, hairy | | | | | | | | | ● | | | | |
| *Geranium pusillum* L. | geranium, small | | | | | | | | | | | | ● | |
| *Hibiscus trionum* L. | flower of an hour | CO | | ● | | | ● | | | | | | ● | |
| *Hordeum murinum* L. | barley, mouse | | | | | | | | | ● | | | | |
| *Hordeum vulgare* L. | barley, common | | | | | | | | | ● | | | | |
| *Kochia scoparia* (L.) Schrad. | kochia, common | CO | | ● | ● | | ● | ● | | | ● | | ● | |
| *Kummerowia stipulacea* (Maxim.) Makino | clover, Korean | | | | | ● | | | | | | | | escaped cultivation? |
| *Lactuca serriola* L. | lettuce, prickly wild | | | ● | | ● | ● | ● | ● | ● | ● | | ● | |
| *Lamium amplexicaule* L. | henbit | | | | | ● | ● | | ● | ● | | | ● | |
| *Lathyrus hirsutus* L. | pea-vine, rough | | | | | ● | | | | ● | | | | |
| *Lepidium latifolium* L. | pepperweed, broadleaf | CO, NM | | ● | | | | | | | | | | |
| *Lespedeza cuneata* (Dum.–Cours.) G. Don | lespedeza, Chinese | CO, KS | | | | ● | | | | | | | | |
| *Ligustrum sinense* Lour. | privet, Chinese | | | | | | | | | ● | | | | |
| *Ligustrum vulgare* L. | privet, European | | | | | ● | | | | | | | | |
| *Lolium arundinaceum* (Schreb.) S.J. Darbyshire | fescue, tall | | | | | | | | | ● | ● | | | syn = Festuca arundinacea |
| *Lolium perenne* L. | ryegrass, perennial | | | | | ● | ● | | ● | ● | ● | | ● | |
| *Lolium pratense* (Huds.) S.J. Darbyshire | ryegrass, meadow | | | | | ● | | | | | | | | |
| *Lolium temulentum* L. | ryegrass, darnel | | | | | | | | ● | | | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lonicera japonica* Thunb. | honeysuckle, Japanese | | | | | ● | | | | ● | | | | |
| *Lonicera maackii* (Rupr.) Herder | honeysuckle, Amur | | | | | ● | | | | | | | | |
| *Malva neglecta* Wallr. | common mallow | | | | | | | | | | ● | | | |
| *Malva parviflora* L. | mallow, little 0r cheeseweed | | | | | | | | | ● | | | | |
| *Marrubium vulgare* L. | horehound | | | | ● | ● | | ● | | ● | ● | | | |
| *Medicago lupulina* L. | medic, black | | | | | ● | ● | | | ● | ● | | | |
| *Medicago minima* (L.) L. | medic, burclover | | | | | ● | | | ● | ● | | | ● | |
| *Medicago polymorpha* L. | bur-clover, California | | | | ● | | | | | ● | | | | |
| *Medicago sativa* L. | alfalfa | | | | | ● | ● | ● | ● | | ● | | | |
| *Melia azedarach* L. | chinaberry | | | | | ● | | | | ● | | | | cultivated escapee? |
| *Melilotus alba* Medikus | sweetclover, white | | | | ● | | ● | | ● | ● | | | ● | |
| Melilotus lupulina | *no listing in IT IS* | | | | | ● | | ● | | | | | | cultivated? |
| *Melilotus officinalis* (L.) Lam. | sweetclover, yellow | | | | ● | ● | ● | ● | ● | | ● | | ● | |
| Mollucella laevis | | | | | | | | | ● | | | | | |
| *Morus alba* L. | mulberry, white | | | | | | ● | | ● | ● | | | ● | |
| *Myriophyllum spicatum* L. | watermilfoil, Eurasian | CO, NM, TX | | | | | | | ● | | | | | |
| *Nepeta cataria* L. | catnip | | | | | ● | ● | | | | ● | | | escapee? |
| *Onopordum acanthium* L. | thistle, Scotch | CO, NM, OK | | | | | | | | | ● | | | |
| *Panicum coloratum* L. | Klein grass | | | | | | | | | ● | | | | |
| *Panicum miliaceum* L. | millet, wild proso | CO | | | | | | | ● | | | | | |
| *Parthenium hysterophorus* L. | whitetop | | | | | ● | | | | | | | | |
| *Paspalum dilatatum* Poir. | Dallis-grass | | | | | ● | | | | ● | | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Paspalum urvillei* Steud | Vasey grass | | | | | | | | | ● | | | | |
| *Pennisetum glaucum* (L.) R. Br. | millet, pearl | CO | | | | ● | | | | | | | | |
| *Phleum pratense* L. | timothy | | | | | | | | | | ● | | | |
| *Plantago lanceolata* L. | plantain, narrowleaf | | | | | ● | | ● | | | ● | | | |
| *Poa annua* L. | bluegrass, annual | OK | | | | ● | | | | ● | | | | |
| *Poa compressa* L. | bluegrass, Canada | | | | | | | | | | ● | | | |
| *Polygonum arenastrum* Jord. Ex Boreau | knotweed, ovalleaf | | | | | | ● | | ● | | | | ● | |
| *Polygonum aviculare* L. | knotweed, prostrate | | | | | | | | | | ● | | ● | |
| *Polygonum convolvulus* L. | bindweed, black | | | | ● | ● | | | | | ● | | | |
| *Polypogon monspeliensis* (L.) Desf. | grass, rabbit's-foot | | | ● | | | | | ● | ● | | | | |
| *Potentilla recta* L. | cinquefoil, sulfur | CO | | | | ● | | | | | | | | |
| *Psathyrostachys juncea* (Fisch.) Nevski | wildrye, Russian | | | | | | | | | | ● | | | |
| *Rumex crispus* L. | dock, curly | | | | | ● | ● | | ● | | ● | | ● | |
| *Rumex obtusifolius* L. | dock, bluntleaf | | | ● | | | | | | | | | | |
| *Rumex patientia* L. | dock, patience | | | | | | ● | | | | | | | |
| *Rumex pulcher* L. | dock, fiddle | | | | | ● | | | | | | | | cultivated? |
| *Rumex stenophyllus* Ledeb. | dock, narrowleaf | | | | | | ● | | ● | | | | | |
| *Salsola collina* Pallas | Russian thistle, slender | CO | | | | | | | ● | | | | | |
| *Salsola kali* L. | Russian thistle, prickly | | | ● | | | ● | | | | | | | |
| *Salsola tragus* L. | Russian thistle, prickly | CO | ● | ● | ● | | | ● | ● | | ● | | ● | syn = Salsola iberica |
| *Saponaria officinalis* L. | bouncingbet | CO | | | | ● | | | | | | | | |
| *Scorzonera laciniata* L. | vipergrass, cutleaf | | | | | | | | ● | | ● | | | |
| *Setaria pumila* (Poir.) Roemer & J.A. Schultes | bristlegrass, yellow | FED | | | ● | | ● | | ● | | | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Setaria viridis* (L.) Beauv. | bristlegrass, green | CO | | ● | ● | | ● | | | | ● | | ● | |
| *Sherardia arvensis* L. | fieldmadder, blue | | | | | | | | | ● | | | | |
| *Sinapis arvensis* L. | mustard, charlock | | | | | ● | | | | | | | | |
| *Sisymbrium altissimum* L. | mustard, tumble | | | | | ● | | | | | ● | | | |
| *Sisymbrium irio* L. | mustard, London rocket | | | | | | | | | ● | | | | |
| *Sonchus asper* (L.) Hill | sowthistle, prickly or spiny | | | | | ● | ● | ● | ● | ● | ● | | ● | |
| *Sonchus oleraceus* L. | sowthistle, common | | | | | | | | | ● | | | | |
| *Sorghum almum* Parodi | sorghum, perennial | | | | | | | | ● | | | | | |
| *Sorghum halapense* (L.) Pers. | Johnson-grass | CO, KS | ● | ● | | ● | ● | | ● | ● | | | ● | |
| *Stellaria media* (L.) Vill. | chickweed, common | | | | | ● | ● | | | ● | | | ● | |
| *Tamarix chinensis* Lour. | tamarisk, fivestamen | NM, TX | | | | ● | | | ● | | | | | |
| *Tamarix ramosissima* Ledeb. | tamarick, saltcedar | CO, NM, TX | | ● | | | | | ● | | ● | | ● | |
| *Taraxacum laevigatum* (Willd.) DC. | dandelion, rock | | | | | ● | | | | | | | | |
| *Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang | wheatgrass, tall | | | | | | | | | | ● | | | syn = Elymus elongatus |
| *Thlaspi arvense* L. | pennycress, field | | | | | | ● | | | | | | ● | |
| *Torilis arvensis* (Huds.) Link | hedgeparsley, beggerlice | | | | | ● | | | | ● | | | | |
| *Torilis nodosa* (L.) Gaertn. | hedgeparsley, knotted | | | | | | | | | ● | | | | |
| *Tragopogon dubius* Scop. | salsify, yellow or western | | | ● | ● | ● | ● | ● | ● | | ● | | ● | |
| *Tragopogon pratensis* L. | salsify, meadow | | | | ● | | | ● | | | | | | |

| Scientific Name | Common Name | Noxious Weed | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Triadica sebiferum* (L.) Small | tallow-tree, Chinese | TX | | | | | | | | ● | | | | syn = Sapium sebiferum |
| *Tribulus terrestris* L. | puncturevine, goathead | CO | | ● | | ● | ● | | ● | | ● | | ● | |
| *Trifolium campestre* Schreb. | hop clover, large | | | | | ● | | | | | | | | |
| *Trifolium dubium* Sibthorp | hop clover, small | | | | | ● | | | | | | | | |
| *Trifolium pratense* L. | clover, red | | | | | | | | | | ● | | | |
| *Trifolium repens* L. | clover, white | | | | | | | | | | ● | | | |
| *Tritacum aestivum* L. | wheat, common | | | | | ● | ● | | | | | | ● | |
| *Ulmus pumila* L. | elm, Siberian | NM | | ● | | | ● | ● | ● | | ● | | ● | |
| *Verbascum thapsus* L. | mullein, common | CO | | ● | ● | ● | | ● | | ● | ● | | | |
| *Verbena brasiliensis* Vell. | vervain, Brazilian | | | | | | | | | ● | | | | |
| *Veronica agrestis* L. | speedwell, field | | | | | ● | | | | | | | | |
| *Veronica arvensis* L. | speedwell, common or corn | | | | | | | | | ● | | | ● | |
| *Vicia sativa* L. | vetch, narrowleaf | | | | | ● | | | | ● | | | | |
| *Vicia villosa* Roth | vetch, winter or hairy | | | | | | | | | ● | | | | |

## APPENDIX I EXOTIC ANIMALS FOUND IN SOUTHERN PLAINS NETWORK PARKS

| Common Name | Scientific Name | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Amphibians** | | | | | | | | | | | | |
| Bullfrog | *Rana catesbeiana* | | X | | | | X | | | | | |
| **Mammals** | | | | | | | | | | | | |
| Blackbuck | *Antilope cervicapra* | | | | | | | | X | | | |
| Axis deer | *Axis axis* | | | | | | | | X | | | |
| Fallow deer | *Dama dama* | | | | | | | | X | | | |
| Big brown bat | *Eptesicus fuscus* | | | | | | X | | | | | |
| Domestic cat | *Felis domesticus* | | | | X | | | | X | X | | |
| Domestic dog | *Canis familiarus* | | | | | | | | | X | | |
| Feral Hog | *Sus scrofa* | | | | | | | | | | X | |
| House mouse | *Mus musculus* | | | | | X | | | | | | |
| Nutria | *Myocastor coypus* | | | | | | | | X | | | |
| Norway rat | *Rattus norvegicus* | | | | | | | | X | | | |
| Red fox | *Vulpes vulpes* | | | | | | | | X | | | |
| Mediterranean gecko | *Hemidactylus turcicus* | | | | | | | | X | | | |
| **Birds** | | | | | | | | | | | | |
| House finch | *Carpodacus mexicanus* | | | | | X | | | | X | | |
| Rock dove | *Columba livia* | | X | | | X | | | | | | |
| House sparrow | *Passer domesticus* | | X | X | X | X | | X | | X | | |
| Ring-necked pheasant | *Phasianus colchicus* | | X | | | X | | X | | | | |
| European starling | *Sturnus vulgaris* | X | X | | X | X | X | X | | | | |
| **Fish** | | | | | | | | | | | | |
| Redear sunfish | *Lepomis microlophus* | | | | | | | X | | | | |
| Largemouth bass | *Micropterus salmoides* | | X | | | | | X | | | | X |
| Striped bass | *Morone saxatilis* | | | | | | | | | | | X |
| Golden shiner | *Notemigonus crysoleucas* | | | | | | | | X | | | |
| Yellow perch | *Perca flavescens* | | X | | | | | | | | | |
| River shiner | *Notropis blennius* | | | | | | | X | | | | |
| Bigeye shiner | *Notropis boops* | | | | X | | | | | | | |
| Rainbow trout | *Oncorhynchus mykiss* | | | | | | | X | | X | | |
| Brown trout | *Salmo trutta* | | | | | | | | | X | | |
| Fathead minnow | *Pimephales promelas* | | | | | | | | | X | | X |
| Bullhead minnow | *Pimephales vigilax* | | | | | | | X | | | | |
| White crappie | *Pomoxis annularis* | | X | | | | | | | | | |
| Black crappie | *Pomoxis nigromaculatus* | | X | | | | | | | | | |
| Walleye | *Stizostedion vitreum* | | | X | | | | | X | | | |
| Brook silverside | *Labidesthes sicculus* | | | | | | | | X | | | |
| Warmouth | *Lepomis gulosus* | | | | | | | | X | | | |
| Bluegill | *Lepomis macrochirus* | | X | | | | | | | | | |
| Longear sunfish | *Lepomis megalotis* | | | | | | | X | | | | |

| Common Name | Scientific Name | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fish** | | | | | | | | | | | | |
| American gizzard shad | *Dorosoma cepedianum* | | | | | | | X | | | | |
| Mosquitofish | *Gambusia affinis* | | X | | | | | | | | | |
| Common carp | *Cyprinus carpio* | | X | | | X | | X | X | | | X |
| Longnose sucker | *Catostomus catostomus* | | X | | | | | | | | | |
| Rio Grande perch | *Cichlasoma cyanoguttatum* | | | | | | | | X | | | |
| Pirate perch | *Aphredoderus sayanus* | | | | | | | | X | | | |

# Southern Plains Network

# Biological Inventory and Vital Signs Monitoring Program

# CHARTER

## I. Background and Purpose

This charter describes the process used to plan, manage, and evaluate the inventory and monitoring (I&M) program within the Southern Plains Network (SOPN)in accordance with the intent and purpose of the National Park Service (NPS) Natural Resource Challenge (NRC). The NRC strategy requires the development of an integrated monitoring program that includes short-term tactical monitoring as well as long-term monitoring.

The I&M program will provide scientifically sound information for managing park resources and informing the public. Such information will allow managers to confront and mitigate threats to the parks and operate more effectively in regulatory, legal, and political arenas. The program will develop broad-based scientific information on the current status and long-term trends in the composition, structure and function of park ecosystems.

In an October 13, 2000 memorandum, the Associate Director, Natural Resource Stewardship and Science, outlined the vision and implementation plan for vital signs monitoring in parks and networks (Attachment A). This NPS strategy implementing the Natural Resource Challenge includes the creation of 32 park networks linked by geography and shared natural resource characteristics. The networks will facilitate collaboration, information sharing, and economies of scale in natural resource management. Each network will receive approximately 8-9 new positions, supplemented by additional positions for air and water quality monitoring where appropriate, and a set amount of funding each year to develop a core program for park vital signs monitoring. Parks in each network will share these positions and funds. The level of funding available will not allow comprehensive monitoring in all parks, but will provide parks with a foundation for natural resource monitoring that can be built upon through future efforts. This program will be leveraged with additional personnel and funding from other sources to build a successful inventory and long-term monitoring program.

The SOPN is comprised of 11 park units in the states of Colorado, Kansas, New Mexico, Oklahoma and Texas. All of the parks are located in the Intermountain Region (IMR) with the exception of Fort Larned National Historic Site, which is located in the Midwest Region (MWR).

| | |
|---|---|
| ***Southern Plains Network*** | Bent's Old Fort National Historic Site (BEOL)<br>Capulin Volcano National Monument (CAVO)<br>Chickasaw National Recreation Area (CHIC)<br>Fort Larned National Historic Site (FOLS)<br>Fort Union National Monument (FOUN)<br>Lake Meredith National Recreation Area (LAMR)<br>Alibates Flint Quarries National Monument (ALFL)<br>Lyndon B. Johnson National Historical Park (LYJO)<br>Pecos National Historical Park (PECO)<br>Sand Creek Massacre National Historic Site (SAND)<br>Washita Battlefield National Historic Site (WABA) |

A Study Plan for Inventories, which directs the multi-year inventory effort in the SOPN, was completed in November 2000. Inventory funding is provided through the NRC. Inventory efforts have been coordinated by representatives of SOPN parks under the guidance of the IMR I&M Coordinator.

The purpose of this charter is to define how the SOPN Network is organized to carry out an exemplary I&M Program.

## II. Organization and Responsibilities

A multi-level organizational structure will ensure the effectiveness of the SOPN I&M Program. The organization is comprised of a Board of Directors, Technical Committee, Scientific Panels, and Network Staff.

### *Board of Directors (BOD)*

The SOPN Board of Directors provides *guidance*, *oversight* and *advocacy* toward development and implementation of the I&M Program for 11 park units within the network.

*Major responsibilities of the BOD are as follows*:

- Approve the five-year strategic plan and review it annually.
- Promote accountability by reviewing progress and quality control for the network.
- Review and approve program budgets.
- Review and approve hiring and work plans developed by the Technical Committee.
- Review network charter every three years.
- Provide oversight for NEPA/NHPA compliance and research permits.
- Hold annual BOD meeting.
- Advocate an active and effective I&M Program in the network.
- Decide on strategies for leveraging network funds and personnel to best accomplish the natural resource inventory, long-term monitoring, and other needs of network parks.
- Provide input to supervisor of the Technical Committee Chairperson for performance appraisals.

- Promote collaboration with Cooperative Ecosystem Studies Units.
- Ensure that the network work is integrated with park resource management programs and other NPS natural resource funding initiatives.
- Facilitate communication and coordination about network activities with park managers in the network and region. Serve as liaison to Cluster Leadership Councils and Natural Resource Communication Advisory Team.
- Identify and develop internal and external partnerships to further the goals of the NRC and I&M Program.

*Membership.* The BOD represents Superintendents from the 11 parks within the SOPN, and should reflect the diversity in size and character of the network parks. The membership of the BOD includes three superintendents, who shall serve three-year terms. Additional members shall include a resource manager or, in the case of a park that does not have a resource manager, a representative designated by the superintendent. All resource managers shall serve two-year terms. The terms of each superintendent and resource manager shall begin on January 1 of any given year and end on December 31. The terms of the superintendents and resource managers are initially staggered to achieve the desired rotation; these terms are delineated in Attachment B.

Additional members of the BOD are the SOPN Network Coordinator and the IMR I&M Coordinator. To facilitate coordination with Cooperative Ecosystem Studies Units (CESU), the unit leaders from the Great Plains and Gulf Coast CESUs are designated as ex-officio members. There will be no officers of the BOD. A park superintendent shall serve as the chair and will be elected by the BOD. The chair will be elected for a one-year term corresponding to the fiscal year.

*Procedures.* The BOD will foster an atmosphere of professionalism and cooperation throughout the SOPN Network. It will operate in an atmosphere of fairness, trust, and respect. Procedural and reporting requirements are coordinated at the network level adhering to guidelines established by the WASO I&M program. The SOPN Network Coordinator facilitates meetings and communications to BOD members.

Formal BOD meetings will occur annually. Additionally, three members of the BOD can jointly request meetings of the BOD. Formal meetings require distribution of a written agenda at least two weeks before the meeting. At the end of each meeting, members of the BOD responsible for arranging the logistics and agenda for the next meeting will be designated. Network members are welcome to attend any meeting. Any BOD member may call telephone conference meetings. Electronic mail messages will provide information to all members and resolve simple matters.

Any BOD member who cannot attend or otherwise participate in a BOD meeting may assign an alternate. A BOD member cannot serve as the alternate, or carry the proxy for an absent member. Four BOD members constitute a quorum. Ex-officio members may designate an alternate if desired.

The BOD shall strive for consensus decision. Consensus is defined as an outcome that all BOD members can live with if not ideal from any one viewpoint. When consensus decisions cannot be reached, a majority vote would be sufficient. In case of a tie vote, the BOD will table the

issue at hand and the three superintendents will poll all network superintendents. A majority vote of the network superintendents shall decide the issue at hand. Superintendents representing more than one park unit will be allotted one vote.

Recommendations will identify the responsible individual(s) and deadlines as appropriate. Meeting minutes will be distributed to BOD members, the SOPN superintendents, the Technical Committee and the SOPN Network staff.

***Technical Committee (TC)***

The SOPN Technical Committee is responsible for developing the specific I&M program plans, budgets and hiring proposals that are presented to the BOD for review and approval. Where the BOD has responsibility for approval of program goals on a broad scale, the TC is responsible for the detailed technical formulation and execution of the program. The TC is accountable to the BOD for all activities and products.

*Major responsibilities of the TC are as follows:*

- Prepare a five-year strategic plan for BOD review and approval.
- Compile and summarize existing information about park resources.
- Host scoping workshops and other outreach efforts as needed to develop the Network monitoring plan.
- Solicit professional guidance, from scientific panel members, individuals, and other organizations, as needed.
- Review proposals for hiring network staff prior to BOD approval.
- Review annual network accomplishment report and annual work plan in detail prior to BOD approval.
- Develop vital signs monitoring plan in collaboration with SOPN Coordinator; complete detailed review of long-term and annual I&M plans prior to BOD approval.
- Develop and foster partnerships that support overall I&M objectives.
- Organize and facilitate periodic program reviews.
- Integrate environmental compliance activities, as required by federal law and NPS policy, into the development of study plans and the park project approval process.
- Work with park staff in areas such as cultural resources or interpretation to build support for an integrated I&M program.
- Ensure that the network work is fully integrated with park resource management programs and other NPS natural resource funding initiatives.

*Membership.* The TC is comprised of a representative from each park in the SOPN Network and the SOPN Network Coordinator. Park superintendents will appoint representatives. They will serve on the TC until the appointing official designates a new member.

*Procedures.* The TC will meet in person at least once per year, which may include the annual BOD meeting. These meetings will be supplemented by conference calls as necessary. The resource manager currently serving on the BOD chairs the TC. The chair will serve a two-year term. Serving as the TC Chair will represent a substantial commitment of time and effort, which will be reflected in a task agreement between the BOD Chair and the TC Chair' supervisor. The

task agreement will be developed outline the responsibilities of the technical committee chair and include an estimate of the time commitment and other expectations of the position.

The SOPN Network Coordinator will assist the TC chair in scheduling and organizing meetings. Five TC members constitute a quorum. TC meetings are open to all interested park staff and BOD members. It is the goal that all decisions are made by consensus. Where this is not feasible, a majority vote will be used as an alternate means of arriving at a decision. Meeting notes will document all committee decisions for circulation to the TC members and the BOD.

***Scientific Panels***

Scientific panels assist the network with planning for vital signs monitoring and provide scientific peer review. Panels will be appointed as needed and configured to address scientific topics and issues, which will be stated at the time of the panel's establishment. Panels may vary in size and length of service. Scientific panel members represent key disciplines (biological, physical, etc.) and may include federal scientists, academic institutions and other relevant organizations. Panel members should have knowledge of sampling procedures, monitoring techniques and statistical methods in order to evaluate conceptual designs, monitoring strategies and the ecological relevance of monitoring proposals.

The primary purpose of the scientific panels will be to provide guidance to the TC in the design and implementation of inventory projects and vital signs monitoring. It is expected that the CESUs will help facilitate linkages with the local scientific community. Meetings with panel members will be scheduled as needed. The SOPN Network Coordinator will facilitate and chair panel meetings. The products and recommendations of the scientific panels will be presented to the BOD for review and final approval.

***Network Staff***

Staffing the SOPN Network is limited by funding realities. Current and projected funding requires the SOPN Network to work with reduced staffing. A fully funded network I&M program is envisioned to have a staff of 8 to 9 FTEs. It may take several years for the SOPN to receive funding to reach this ideal level of staffing. Some positions will likely be housed in a central network location and others will be stationed in individual parks. Details of staffing needs, including supervision and duty stations, will be addressed in the network monitoring plan and approved by the BOD.

The SOPN Network Coordinator works to support the BOD and TC in meeting the goals of the I&M Program for the Network. In addition to serving on the BOD and TC, the Network Coordinator will chair any scientific panels that are established. The Network Coordinator will be responsible for many of the administrative and communication functions of the Network. The network coordinator will prepare annual network I&M accomplishment report and work plan for Technical Committee and BOD review and approval. The network coordinator will also oversee the development of the network vital signs monitoring plan (long-term and annual plans) for Technical Committee and BOD review and approval.

Other critical staff for the SOPN Network includes a data manager, applied scientists and technicians for monitoring the physical environment. As the SOPN I&M program develops, these positions will be established to adapt to the growing needs of the Network.

***Other Ad-hoc and Standing Committees***

The BOD may form ad-hoc or standing committees to guide SOPN Network activities or implement SOPN Network projects. An Information and Education Committee comprised of interpretation, education, and public affairs staff may be formed at a later date.

## III. Network Operations

*Administrative Costs.* In addition to the guidance provided by the "Vision and Implementation Plan" for vital signs monitoring, the SOPN Network will use the guidance provided in the November 30, 2001 memorandum regarding administrative policies from the Associate Director, Natural Resource Stewardship and Science (Attachment C). Administrative costs for personnel, administrative support and services, office space and equipment, and vehicles will be borne by the SOPN I&M program only as provided for in this memorandum or superseding guidance.

*Annual Work Plan.* Working with the SOPN Network Coordinator, the SOPN TC will present a proposed Annual Work Plan to the BOD for review and approval no later than September 15 of each year. The Annual Work Plan will assign specific accomplishments and products, responsible individuals, deadlines, and fiscal resources to parks or offices in furtherance of the strategic plan. Final funding allocations will be added to the Annual Work Plan once a budget for the SOPN Network is authorized. The BOD must approve substantial changes to the Annual Work Plan.

*Annual Accomplishment Report.* Working with the SOPN Network Coordinator, the SOPN TC will present an Annual Accomplishment Report to the BOD for review and final approval no later than September 15 of each year. The Annual Accomplishment Report will provide details on specific accomplishments and products, lessons learned, collaborative activities supported by alternate funding sources, and a budget summary. A detailed accounting of all I&M funds assigned to each park and office will be appended to the report. This report will be widely distributed. The Annual Accomplishment Report will be released no later than October 31 of each year. The report format will conform to WASO reporting requirements. The Network Coordinator will distribute copies of the report to the IMR, WASO and other interested parties.

*Program Review.* The SOPN will conduct periodic comprehensive reviews of the inventory and monitoring program to evaluate the completeness of the inventories and the adequacy of the monitoring program. The initial review will take place during the Phase III Report peer review process and will follow WASO Inventory and Monitoring national standards and administrative protocols. After the Phase III report is completed, SOPN will decide the appropriate time for the next comprehensive review.

*Funding.* NRC funding for the I&M program will be managed via the NR-PRO program. Funds will be distributed to the network per the network annual work plan. All I&M funds will be strictly accounted for and applied only to I&M activities approved by the BOD. In general, I&M funds will not be used for existing park positions and projects. Exceptions may be made where providing temporary salary and travel support is advantageous to meeting network work objectives. Funds contributed by parks, other NPS programs and sources that are used for I&M related work will be tracked and reported. Travel funds will be made available to members of the BOD, TC and Scientific Panels as available; however, parks are encouraged to cover their own travel costs when possible.

*Data Management.* Data management is an active process requiring continuous maintenance and a high degree of attention to detail. Under the I&M Program biological data management will be standardized across all SOPN parks and will comply with national data standards where applicable. The SOPN Data Manager will work with all network parks in developing a multi-year data management plan to ensure that biological spatial, tabular and bibliographic data are comparable and of high quality. It is envisioned that data repositories will be centralized, but available to all network parks. Data management responsibilities will be shared between network and park staff.

The basic goal of the NPS biological I&M program is to provide park managers with comprehensive scientifically based information about the nature and status of selected biological resources in an easily useable form. The network will place a high priority on the use of new technologies to ensure that data are easily accessible and useable.

Data management for I&M activities will conform to the philosophy that integrity, security and availability of current data sets are high priorities. All data will be certifiably accurate and be associated with metadata that describes (1) the purpose of the data, (2) the history of when, where, why, and how the data was collected and by whom, and (3) all changes and additions to established datasets.

*Communication and Information Sharing*. Open communication and information sharing will be emphasized in all network activities. BOD members are encouraged to participate in the work of the TC. The Network Coordinator will keep BOD and TC members and others apprised of pertinent developments relating to I&M. The Network Coordinator is responsible for maintaining the administrative record of the SOPN Network at his/her duty station, with a back-up copy kept with the IMR I&M Coordinator.

*Supervision and Administrative Support.* Staff hired for the SOPN Network will be supervised and administratively supported as determined by the BOD. Administrative support, not to exceed 5% of total costs, will be provided by the Network to parks hosting I&M positions. Guidance on administrative procedures can be found in Attachment C.

*Budget.* Each year the SOPN Network Coordinator, with the assistance of the TC, will prepare a budget to be approved by the BOD for the travel, per diem, and any other costs associated with the conduct of meetings. These costs will be summarized in the Annual Work Plan.

*Monitoring Plan.* A monitoring plan that identifies the management and scientific issues facing each park, the vital signs to be monitored, where they will be monitored, and why they will be monitored shall be prepared by the TC and approved by the BOD. In addition, the monitoring plan will specify the overall sampling design, staffing plan, and data management strategy.

*Partnerships.* The Network I&M program may evolve to include other land and resource managers (e.g. Federal, State, or Tribal) in the Southern Plains Network area. The Monitoring Plan will look into the advantage of including non-NPS partners on the network BOD. In no case will this be done without unanimous approval of the BOD as well as approval by the Intermountain Region Associate Regional Director of Resources and Science.

## IV. General Provisions

*Term of Charter*. This charter will remain in effect throughout the duration of the NPS I&M Program.

*Amendments*. Any signatories, BOD members or TC member may propose changes to this charter. Proposed amendments will be considered at a meeting of the BOD within 60 days of receipt of the proposal by the BOD chair. Any change will be in the form of an amendment that must be approved by the BOD, and will not take effect until all signatories have agreed to and signed – electronically or by hard copy - the amendment.

*Periodic Review*. The signatories and/or BOD will review this charter at least every three years to assess its adequacy, effectiveness, and continuing need.

## V. Attachments

*Attachment A.* Memorandum from Associate Director, Natural Resource Stewardship and Science, "New Park/Network Monitoring Program: Vision and Implementation Plan." October 13, 2000.

*Attachment B.* Assignments to SOPN Board of Directors.

*Attachment C.* Memorandum from Associate Director, Natural Resource Stewardship and Science, "Policies Concerning Administrative Charges to Inventory and Monitoring Funding," November 30, 2001 (with forwarding memorandum from Director, IMR).

## V. Approval Signatures

| | |
|---|---|
| Superintendent, Alibates Flint Quarries National Monument & Lake Meredith National Recreation Area | 11/29/04 Date |
| Superintendent, Bent's Old Fort National Historic Site | 10/7/04 Date |
| Superintendent, Capulin Volcano National Monument | 9/20/04 Date |
| Superintendent, Chickasaw National Recreation Area | 11/01/04 Date |
| Superintendent, Fort Larned National Historic Site | 12/27/04 Date |
| Superintendent, Fort Union National Monument | 9/23/04 Date |
| Superintendent, Lyndon B. Johnson National Historical Park | 11-19-04 Date |
| Superintendent, Pecos National Historical Park | 9/29/04 Date |
| Superintendent, Sand Creek Massacre National Historic Site | 10/27/04 Date |
| Superintendent, Washita Battlefield National Historic Site | 12/20/04 Date |

## VI. Concurrence

| | |
|---|---|
| Inventory and Monitoring Coordinator, Intermountain Region | Date |

Administration of the network approach and the NR-PRO funding model

Additional input and review is needed to explore creative solutions to managing a cooperative, collaborative network of monitoring programs and the best administrative structure for sharing technical expertise and infrastructure burdens among parks. Currently, network monitoring programs are coordinated by the Servicewide Inventory and Monitoring Program with assistance from other divisions of the Natural Resource Program Center of the Washington Office. The Servicewide I&M Program provides funding to each region for a full-time I&M coordinator, and each network is expected to hire a network coordinator, when funded.

**The initial networks will be guided by a Board of Directors made up of park superintendents, the Regional I&M Coordinator, and the Network Coordinator, who will specify desired outcomes and evaluate performance for the network's monitoring program. The Board of Directors will make decisions regarding the development and implementation of the monitoring strategy, including decisions on hiring, budgeting, and scheduling, and will promote accountability for the monitoring program. The committee should be chaired by one of the superintendents, with the network I&M coordinator acting as staff to the chair to help arrange meetings and logistics, produce agendas, and coordinate between the Board of Directors and the Science Advisory committee. In general, the Board will be responsible for ensuring the overall effectiveness and success of the network's monitoring efforts. These working relationships and descriptions of the procedures the Board will use to make decisions should be codified in the form of a "Network Charter" signed by each superintendent on the Board.**

**A Science Advisory or technical committee comprised of natural resource managers and scientists, including scientists from outside of the NPS who work in the parks and are familiar with park issues, should be formed to provide technical assistance and advice to the Board of Directors. The Science Advisory committee should be chaired by the network monitoring coordinator and will be responsible for compiling and summarizing existing information about park resources and developing the materials needed at the scoping workshop, and will draft the workshop report and monitoring strategy for review and approval by the Board of Directors. Care needs to be taken to avoid conflicts with the Federal Advisory Committee Act in using outside scientists on advisory committees. Any non-Federal scientists should serve as ad hoc members of the committee and be limited to providing advice, rather than participating in concensus recommendations, unless the committee is established in compliance with the Federal Advisory Committee Act.**

**The minimum critical staff for each network will include, but not be limited to, a network coordinator and data manager, 3 or 4 applied scientists, and several technicians for monitoring the physical environment (e.g., weather, air and water quality, soil erosion), aquatic/marine systems, vegetation, and wildlife. Each network will decide on the job series, grade, and duty station of network personnel. In some cases, network personnel will be based in parks and may be supervised by a park Superintendent, whereas in other networks, network personnel will be based in a central location such as a town or university and be supervised by someone in the regional office. This will be a decision between the Regional Director and the park networks. The positions and support will be**

**funded through the new NR-PRO program in which funding is held in base by the Servicewide I&M program and other national resource programs and will be transferred to each network on an annual basis to support the monitoring.**

**It is important to keep flexibility in the administrative structure because the program is expected to grow and adapt as the Service gains more experience with monitoring during the next several years. The configurations of personnel and their duty stations that provide the best support to all of the network parks will probably change over time. As the programs mature, larger parks will be able to support base-funded programs, whereas smaller parks may continue to find it advantageous to carry out monitoring through the networks. Regardless of future changes, however, networking will facilitate both efficiencies and integration of monitoring efforts, both among parks and with neighboring land managers.**

Emphasis on data management and making information more available and useful

A major emphasis of the inventory and monitoring effort is to make information more readily available to decision makers and the public and to integrate natural resource information with other park operations such as interpretation and maintenance. Tools such as Synthesis, the GIS Theme Manager (aka GIS Databrowser), and Servicewide databases such as the NPSpecies database and the Natural Resource Bibliography will make information more readily available and useful to park managers, resource professionals, and others in the field. During preparations for both inventory and monitoring, the large body of existing data will be cataloged and evaluated, and the more useful datasets will be converted to modern databases and GIS products.

The public also needs better information. The public does not generally recognize or understand the significance of parks as preserves of our nation's natural heritage. The disciplines of natural resources and interpretation/education need to be better integrated throughout the National Park Service, and the public needs to be informed of the status and trends of its natural heritage preserved in the parks in simple, clear-language reports.

Recommended approach for developing a network monitoring program

The recommended approach that each network of parks should take to develop their strategy for monitoring natural resources involves seven steps:

1. Form a network Board of Directors and a Science Advisory committee.
2. Summarize existing data and understanding.
3. Prepare for and hold a scoping workshop.
4. Write a report on the workshop and have it widely reviewed.
5. Hold meetings to decide on priorities and implementation approaches.
6. Draft the monitoring strategy.
7. Have the monitoring strategy reviewed and approved.

1. **Form a network Board of Directors and a Science Advisory committee**.

- A Board of Directors comprised of park superintendents or their designee, the regional I&M coordinator, and the network monitoring coordinator, should be formed to oversee the development of the monitoring strategy for the network. The committee will make decisions regarding the development and implementation of the monitoring strategy, including decisions on hiring, budgeting, and scheduling, and will promote accountability for the monitoring program. The committee should be chaired by one of the superintendents, and all members should have authority to make on-the-spot decisions on personnel, budgets, office space, and commitments of existing park personnel and funding to the monitoring effort. A charter should define the roles and functions of the different members and outline the process to be used to make decisions related to monitoring within the network. The charter must be signed before funding is released to the network. The network I&M coordinator should act as staff to the chair to help arrange meetings and logistics, produce agendas, and coordinate between the Board of Directors and the technical committee.
- A Science Advisory or technical committee comprised of natural resource managers and scientists, including scientists from outside of the NPS who work in the parks and are familiar with park issues, should be formed to provide technical assistance and advice to the Board of Directors. The Science Advisory committee should be chaired by the network monitoring coordinator and will be responsible for compiling and summarizing existing information about park resources and developing the materials needed at the scoping workshop, and will draft the workshop report and monitoring strategy for review and approval by the Board of Directors.

2. **Summarize existing data and understanding.**
   - One of the most important steps in the process of developing a monitoring strategy is the task of identifying, summarizing, and evaluating existing information and understanding of park ecosystems. Much of this needs to be done before the scoping workshop is held.
   - To accomplish this task, it is anticipated that most networks will need to hire, assign or contract at least one or two full-time persons (e.g., a Monitoring Coordinator and data management specialist) and allow at least a year prior to the scoping workshop for this step to be accomplished.
   - This step will include a literature review, a review of the Resource Management Plan (RMP), General Management Plan (GMP), and other applicable plans for each park, and an inventory of existing datasets and other information on park ecosystems.
   - Superintendents and other park managers should be interviewed regarding the key management issues facing their park and the types of information they need from the monitoring program.
   - Current or historical monitoring of natural processes and resources in each park should be summarized, including data from monitoring of fire effects, T&E species, water quality, air quality, physical processes/changes, and other resources. Data sets and the sampling design used should be evaluated to determine whether the monitoring is meeting the needs of park managers and is providing reliable and credible data to help manage the park. Maps showing the locations where monitoring has occurred should be prepared.
   - Monitoring that is being conducted by neighboring agencies, partners, and related parks should be identified and summarized to help determine where comparable data sets and sampling protocols exist.

- Where understanding exists regarding cause-effect relationships between environmental stressors and the park's natural resources, or where the linkages among ecosystem components are understood, draft conceptual models should be prepared to help summarize this understanding.

3. **Prepare for and hold a scoping workshop.**
   - A scoping workshop should be held to obtain additional input and peer review of existing information and understanding of park ecosystems from park managers and subject experts from within and outside of the NPS.
   - In preparation for the workshop, the monitoring coordinator and technical committee will be responsible for preparing handouts, maps, and presentations of the material summarized in Step #2.
   - The monitoring coordinator and technical committee should define the goals and preliminary objectives of the monitoring program prior to the scoping workshop. The goals and objectives should be approved by the Board of Directors.
   - Additional material that should be developed prior to the scoping workshop include:
     - ✓ Draft lists of important management issues for each park;
     - ✓ Draft lists of important natural resources and focal species or processes for each park;
     - ✓ Draft lists of known stressors that may cause changes in park resources;
     - ✓ Draft conceptual models of portions of the park ecosystem;
     - ✓ Draft list of measurable objectives for the monitoring program;
     - ✓ Criteria for indicator selection.
   - Workshop participants will be asked to review the material prepared for the workshop and provide additional input and understanding, including additional development and modification of conceptual models.
   - Participants will also be asked to identity and provide an initial prioritization of potential indicators to be monitored by the network. Include short-term, tactical monitoring as well as long-term monitoring needs.
   - Participants will also indicate where appropriate sampling methodologies exist, and where there is a need to develop new sampling protocols for the high-priority indicators that are identified.
   - A three-day workshop with facilitated breakout sessions focusing on different components of the park ecosystem is recommended.

4. **Write a report on the workshop and have it widely reviewed.**
   - The results of the scoping workshop should be widely circulated for additional input and comment. It should be sent to all interested parties, including people that did not attend the scoping workshop.
   - The additional input provided through the review process should be incorporated into the final version of the workshop report.

5. **Hold one or more meetings to decide on priorities and implementation approaches.**

- The Board of Directors, based on recommendations of the Science Advisory committee, should meet to make decisions regarding priorities for monitoring and how to implement the monitoring strategy within the network

- The set of indicators that will be monitored by the network should be selected based on the preliminary list of indicators developed during the scoping and review process, and the availability of funding and personnel from the I&M program and other sources (e.g., base funding from parks, partnerships).
- Decisions should be made on which sampling protocols are most appropriate for the network. Where protocols already exist, they may need to be adapted for the particular conditions within the network. In cases where no suitable protocol exists, the committee and managers should decide on an approach for developing these protocols through contracts or technical workshops.
- Staffing issues should be addressed at this meeting. Each network will hire a number of professional-level monitoring specialists and technicians that will be shared by the network parks, and decisions should be made regarding the appropriate job series and grade level of these positions and where they should be stationed.
- The Science Advisory committee and Board of Directors should discuss data management and reporting issues. Experience from the prototype monitoring parks indicates that at least 30% of the total resources should be allocated to data management and reporting. A data management plan needs to be developed before the final monitoring strategy is approved.

6. **Draft the monitoring strategy.**
   - A report describing the monitoring strategy and the various tasks and decisions that contributed to the final selection of indicators to be monitored by the network should be written by the technical committee. This document describing the monitoring strategy should include the following:
     - ✓ An overview of each park and its natural resources, including a summary of the park's enabling legislation, the park's natural resources in a regional or national context, and a summary of the important natural resources in each park;
     - ✓ A summary of the management issues and scientific issues facing each park, including stressors or other agents of change that affect park resources;
     - ✓ A summary of the understanding of the park ecosystem, including conceptual models developed during the scoping and review process;
     - ✓ Descriptions of the indicators to be monitored by the network and the sampling protocols that will be used, including justification for why these were selected. The report should also list and describe the indicators that were considered but not selected for monitoring, and the reasons why they were not selected;
     - ✓ The overall statistical sampling design for the network;
     - ✓ The staffing plan;
     - ✓ Data management plan, including how often reports will be generated and who will be responsible for ensuring that results are provided to managers in a timely manner.

7. **Have the monitoring strategy reviewed and approved.**
   - The draft monitoring strategy document should undergo a peer review by the managers and scientists involved in its development and the network Board of Directors, and then be forwarded through the regional office to the Servicewide I&M Program for final review and acceptance before it is fully implemented.

## Attachment B Assignments to SOPN Board of Directors

| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SUPERINTENDENTS** | | | | | | | | | | | | |
| BEOL/SAND | X | X | | | | X | X | X | | | | X |
| FOLS | | | X | X | X | | | | X | X | X | |
| PECO/FOUN | | | X | X | | | | X | X | X | | |
| CAVO | X | X | X | | X | X | X | | | | X | X |
| CHIC | X | X | | | | | | | | | | |
| WABA | | | | | | | X | X | X | | | |
| LAMR/ALFL | | | | X | X | X | | | | | | |
| LYJO | | | | | | | | | | X | X | X |
| **RESOURCE MANAGER** | | | | | | | | | | | | |
| BEOL/SAND | | | | | | | | | | X | X | |
| FOLS | X | | | | | | | | | | | |
| PECO/FOUN | | | | | | | | | | | | X |
| CAVO | | | | | | | | | | | | |
| CHIC | | | | | | X | X | | | | | |
| WABA | | | | X | X | | | | | | | |
| LAMR/ALFL | | X | X | | | | | | | | | |
| LYJO | | | | | | | | X | X | | | |

Memorandum

To: Superintendents, Intermountain Region

From: Director, Intermountain Region

Subject: Policies Concerning Administrative Charges to Inventory and Monitoring Funding

Intermountain Region parks and networks will receive more than $3.6 million dollars for Inventory and Monitoring (I&M) in FY 02, primarily through the Natural Resource Challenge. NPS has committed to spend these funds directly on I&M activities and funding for the Challenge in FY 03 and 04 depends partly on keeping this commitment.

Please carefully review the attached memo from the Associate Director for Natural Resource Stewardship and Science, which provides guidance on appropriate administrative costs parks and networks can charge to Inventory and Monitoring funds. The overarching policy "for assistance and support expenditures is that the resources (goods, services, and personnel) that are planned and funded as part of the park's normal, ongoing ONPS budget may NOT be charged against inventory or park vital signs monitoring funding provided by the Washington Office." However, some administrative charges are allowed. The rule of thumb is that the total amount of funding allocated to general administrative support and assistance should not be more than 5 percent of the total funding provided to a park or network for inventories or park vital signs monitoring…" Vehicle and leasing costs are specifically addressed in the memo.

Specific guidance:

- Backfilling behind a permanent park employee who is working on I&M projects or programs is permitted by hiring a temporary employee for six months or less. Overtime pay is not authorized.
- Lapse money from vacant I&M funded positions may not be used for anything other than inventories of vital signs monitoring.
- Office space for I&M staff should come from existing space in parks, CESUs, regional offices, etc. If no options exist, leasing office space at local market rates is permitted, not to exceed 5% of total I&M funding.
- Spending I&M funds to renovate existing office space is permitted but must be approved at the Regional level.
- New construction and purchase of space (e.g. trailers) is not permitted.
- Leasing I&M vehicles is permitted.
- Purchase of I&M vehicles is permitted when the total cost is less than the cost to lease a vehicle. Purchase of vehicles must be approved at the Regional level.
- All planned expenditures for biological inventories or vital signs monitoring should be included in each network's Annual Administrative Report and Workplan, due October 30th each year.

If you have questions or need to discuss administrative costs or any other aspect of the I&M program, please contact Mike Britten, Inventory and Monitoring Coordinator for the Intermountain Region (303-987-6705).

November 30, 2001

N22 (2370)

Memorandum

To: Regional Directors
Attention: Regional I&M Coordinators

From: Associate Director, Natural Resource Stewardship and Science /s/

Subject: Policies Concerning Administrative Charges to Inventory and Monitoring Funding

One of the major components of the Natural Resource Challenge (NRC) relates to the inventory and monitoring of natural resources throughout the Service. In fiscal 2000, the Service received a base increase of approximately $7.3 million for accelerating the completion twelve natural resource inventory data sets being acquired or produced by the Natural Resource Inventory and Monitoring (I&M) Program. In fiscal 2001, the I&M Program received an additional base increase of $4.2 million to begin the implementation of park vital signs monitoring programs. This funding represents a significant step forward for the Service in full implementation of the Natural Resource Challenge. However, to fully implement the park vital signs monitoring component of the Natural Resource Challenge, the Service will need to obtain an additional $22 million in base increases through fiscal year 2004.

A significant portion of the inventory funds and all of the park vital signs monitoring funds are being transferred annually to regional offices and parks where most of the I&M projects are being formulated and managed. Accountability for the use of those funds rests primarily at the regional or park level. Recently, some regional offices and parks have asked about the appropriateness of charging certain administrative expenses against the inventory and monitoring funds they have received. Understandably, significant increases in staffing or contracting bring with them increased support needs. Challenge increases have also affected the Washington Office in this manner and we understand the issues. However, it is important that the Challenge funding be seen as directly contributing to resource activities and that we can demonstrate this.

Because these inventory and park vital signs monitoring funds represent specific line items in the NRC and have been appropriated by Congress specifically for those purposes, we have a mandate to demonstrate accountability for these funds and to insure that they are used only for the intended inventory and monitoring activities. Evidence of that mandate is shown by the fact that the Service is required to provide a report to Congress during November of each year that details how the funds were used during the previous fiscal year and what planned expenditures are for the upcoming fiscal year. The high level of interest in these funds could lead to audits concerning their use. Any problems with the use of I&M funds will reflect on and affect other funding as well. For these reasons, the Washington Office will closely monitor how inventory and park vital signs monitoring funds are utilized to ensure that the funds are not diverted to inappropriate uses. The purpose of this memo is to provide you with requested guidance on what we believe are appropriate and inappropriate uses of these funds.

Network Implementation Strategy for Inventory and Monitoring

The Service has long recognized the need to conduct comprehensive inventory and monitoring of natural resources in parks. Management policies have been in effect since the 1980's which stipulate that we will undertake inventories of natural resources in park to determine their nature and status and monitor changes in the condition of those resource over time. The scientific information developed through these efforts must provide the basis for any successful natural resource management and preservation program. However, estimates made a few years ago concerning funding needs suggest that perhaps as much as $200

million would be needed to implement comprehensive inventory and monitoring in all natural resource parks, an amount nearly six times what we hope to obtain through the NRC. Therefore, parks and regions are cautioned that the funding they receive from the Washington Office for inventory and park vital signs monitoring purposes is not designed to fund *all* of the work that needs to be accomplished. Parks and regions should look for ways to supplement these funds from other NPS base accounts or to leverage the funding by exploring cost-sharing opportunities with non-NPS partners and cooperators whenever possible.

To facilitate those cost sharing and leveraging efforts, parks have been organized into 32 networks linked by geography and shared resource characteristics. This arrangement should encourage collaboration, information sharing, and economies of scale in natural resource inventory and monitoring among parks. Each network will receive up to 8-9 new positions and a set amount of funding to conduct inventory and park vital signs monitoring projects. These positions, which should include taxonomic and technical experts, will provide credibility for NPS in its role as managers of plants and animals species. Parks within each network are expected to share these funds and positions as well as administrative workloads and burdens (e.g. processing travel and personnel actions, providing office space and equipment, conducting data management, and maintaining museum records and collections). It may be more efficient or cost-effective to accomplish some of the monitoring through contracts or cooperative agreements, rather than NPS positions. The ability to absorb positions without resulting in a significant administrative burden should be considered in determining where positions should be stationed or whether NPS positions or alternatives are the best strategy to accomplish monitoring.

Each network is managed by a Board of Directors, composed of the superintendents or their designee from each park in the network. Procedures related to the operation and administration of the network and how they plan to share resources and workloads are to be described in a Network Charter signed by all members of the Board of Directors.

Parks needing administrative or logistical support and assistance in order to accomplish their inventory and park vital signs monitoring projects should follow a step down process to satisfy those needs. First, the park should try to work out arrangements with other parks in their network to see if sharing of personnel, vehicles, equipment, or other resources at various times of the year would be offsetting, thus negating any need to assess project funding to meet their needs. Where assistance cannot be fully offset by sharing personnel and resources between parks within the network, the park should coordinate with nearby parks in other networks, other federal and state agencies, or local colleges and universities to see if cooperative arrangements can be made.

Finally, when the above steps have been taken and the required administrative assistance and support needs have not been met, the park or network may consider using a portion of the funding provided by the Washington Office to met the identified need. The following sections briefly describe the types of administrative and support costs that may be allowed. A general guiding philosophy for assistance and support expenditures is that the resources (goods, services, and personnel) that are planned and funded as part of the park's normal, ongoing ONPS budget may NOT be charged against inventory or park vital signs monitoring funding provided by the Washington Office. **As a rule of thumb, the total amount of funding allocated to general administrative support and assistance (discussed below) should not exceed 5 percent of the total funding provided to the network for inventories or park vital signs monitoring (excludes vehicle and leasing costs described below)**.

**Personnel**

Inventory and monitoring in parks and networks must be conducted by individuals (e.g. systematic biologists, physical scientists, data managers) having professional qualifications commensurate with the planned work. Furthermore, in addition to having the necessary professional qualifications, those individuals must be allowed to devote time to working on inventory and monitoring projects. If this policy is not followed, there will likely be a constant tendency to use the I&M personnel to resolve any ongoing or newly identified resource management need in the park. The result could be that the goal of an established,

long-term program of data collection, analysis, and reporting will be jeopardized, eventually resulting in program failure.

Salaries and Benefits for Project Staff – The technical support and staffing needed to conduct inventories and park vital signs monitoring by parks have not been ignored. In addition to providing funding to cover salaries, benefits, and support cost, the Washington Office also provides FTE's so that parks may hire the additional staff they need to conduct inventory and park vital signs monitoring projects. In some instances, these individuals may be asked to devote up to 10 percent of their time assisting with non-I&M duties. However, any non-I&M duties must be directly related to the individual's monitoring expertise and not something totally unrelated. Employees whose regular time is funded from an I&M account should NOT be reassigned to other natural resource duties in the park or network.

Back filling – In some cases, the individual best qualified to provide support for an inventory or park vital signs monitoring project may be an existing member of the park staff but who is assigned to other park operations. Back filling refers to the process of charging salary, benefits, and related support costs to an I&M account for temporary staff hired to cover the duties of permanent park personnel who have been temporarily reassigned to work on an inventory or monitoring project. Back filling authority is hereby granted to allow parks to minimize any disruptions to normal park operations that may occur as a result these types of temporary personnel reassignments. But, under normal circumstances, back-filling arrangements should not exceed a period of 6 months. Back filling cannot exceed the number of duty hours that would have been worked by the reassigned employee during his/her normal duties. Overtime pay is not authorized.

Vacant Positions – Vacant positions are expected to be a normal part of any long-term inventory and park vital signs monitoring program. But, park supervisors should recognize that, when position vacancies do occur, those positions need to be filled as quickly as possible to minimize the impact on the inventory or monitoring program. Because the hiring process can be slow in some instances, supervisors should have completed most of the advanced work needed to fill the position in the least amount of time. This may include: updating position descriptions, getting approval of position management plans, writing KSA's, maintaining a list of eligible and interested job candidates, preparing cooperative agreements with universities, etc.

When position vacancies do occur, the funding provided by the Washington Office to cover the salary and benefits for those positions may lapse. Those lapsed salary funds may not be used for any project or activity not directly related to the ongoing inventory or park vital signs monitoring project. Position vacancies must be clearly identified in the Annual Administrative Report and Work Plan submitted by the network to the Washington Office. If it becomes apparent that positions are being allowed to remain vacant in an attempt to increase the amount of funding available for other park or network needs, an adjustment may be made in the amount of funding transferred annual to the network.

**Administrative Support and Services**

In some instances, implementation of inventory and/or park vital signs monitoring programs may increase the workload for various existing park staff including, contracting specialists, program analysts, personnel officers, and secretaries. We believe that parks should be able to address the majority of these additional workload burdens through the network implementation strategy described above. The Washington Office also plans to obtain additional contracting assistance, support which will be available to any park or network needing that assistance. However, if the additional workloads cannot be accommodated by sharing the burden among parks, then a small portion of the funding provided by the Washington Office may be used to meet that need, not to exceed the 5 percent overall limit, as indicated above. Additionally, administrative costs connected with park rangers, law enforcement personnel, or maintenance staff may not be charged to inventory and park vital signs monitoring funding, although direct costs incurred by such staffs in I&M work may be. For example, boat operations connected with monitoring would be an allowable cost; charging a portion of the permanent salaries of maintenance and rangers would not.

Office Space and Equipment

The addition of several new positions to a park or network for inventories or park vital signs monitoring could result in a situation were there is an inadequate amount of office space and/or equipment to accommodate those individuals. Again, the policy is that parks should first try to meet those additional needs by stationing the new positions at various parks in the network or at some other appropriate location, such as a regional office, CESU, or university. However, if the additional space and equipment needs cannot be accommodated in this manner, the network may consider using a portion of the funding provided by the Washington Office to obtain the necessary office space and/or equipment. Office equipment that may be considered includes personal computers and furniture.

When it is necessary to obtain additional office space for new employees assigned to inventory or park vital signs monitoring efforts, parks should first consider remodeling existing space within the park(s). If adequate office space cannot be obtained through renovation efforts, then leasing space should be considered. Under no circumstances will new construction be allowed. The acquisition of permanent housing space (e.g. trailers, etc.) for individuals while in the field is also not approved for inventories. The need for temporary housing in the field for park vital signs monitoring should be addressed in monitoring plans that require approval before funding. Any plans to renovate existing office space or lease new space in a park must be approved in advance by the Regional Office; similar expenses proposed for a regional office must be approved by the Associate Director, Natural Resource Stewardship and Science. When leasing office space is being considered, evidence must be shown that the anticipated leasing costs are within the normal range for comparable space in the area and that alternative locations are not available. **Costs associated with lease of office space should not exceed five percent of the total funding provided to the network for inventories or park vital signs monitoring (this is in addition to administrative support and assistance costs)**.

**Vehicles**

As in the case of office space and equipment, parks or networks conducting inventories or park vital signs monitoring may need to acquire additional vehicles. Whenever possible, parks should make full utilization of existing vehicles, either owned by the park or leased through GSA. If additional vehicles are required, those vehicles should be leased only for the duration of the project UNLESS the total cost of leasing the vehicle for that period exceeds the vehicle purchase cost. In that instance, vehicle purchase is justified. In general, purchasing vehicles for inventories would not be considered cost-effective, while purchasing vehicles for park vital signs monitoring might be. Parks or networks planning to lease or purchase vehicles to support inventory or park vital signs monitoring crews must obtain prior approval from the Regional Office.

In summary, we think that the policies and guidance outlined above will cover most of the administrative support and needs encountered by parks or networks undertaking either natural resource inventories or park vital signs monitoring. However, if additional needs or situations are identified, those needs should be brought to the attention of Washington Office personnel. The point that needs to be stressed is that parks and networks should make every attempt possible to minimize administrative charges and overhead costs associated with inventories and park vital signs monitoring projects and assess project funding only when necessary. With your continued support and commitment we will have created the Service's first comprehensive systematic inventory and monitoring system. Thank you for your enthusiasm in joining this effort. If you have questions or need additional clarification about these policies, please contact Dr. Gary Williams, the NPS Inventory and Monitoring Program Manager on email or at (970) 225-3539.

File Name:I&M OVERHEAD POLICY
FNP:A.Miller:ld:11/8/01
Cc: 2370 Reading File 2370 Chron File Gary William, Abby Miller

## APPENDIX K SOUTHERN PLAINS NETWORK WATER RESOURCE REPORT

Prepared by Karie Cherwin and Dusty Perkins

Lake Meredith, Texas

"***Of all our natural resources, water has become the most precious…***
***In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference."***

-Rachel Carson, Silent Spring

Table of Contents ..... A-125
K.1. ABSTRACT ..... A-126
K.2. INTRODUCTION ..... A-126
K.3. OVERVIEW OF WATER RESOURCES WITHIN SOPN ..... A-127
K.4. WATER RESOURCE LEGISLATION APPLICABLE TO SOPN PARKS ..... A-129
*K.4.1. Federal ..... A-129*
K.4.1.1. Clean Water Act ..... A-129
K.4.1.2. Safe Drinking Water Act ..... A-133
*K.4.2. State ..... A-134*
K.4.2.1. Colorado ..... A-134
K.4.2.2. Kansas ..... A-135
K.4.2.3. New Mexico ..... A-136
K.4.2.4. Oklahoma ..... A-136
K.4.2.5. Texas ..... A-137
*K.4.3. National Park Service ..... A-138*
K.5 SOUTHERN PLAINS NETWORK PARK WATER RESOURCE NARRATIVES.. A-138
*A. Alibates Flint Quarries National Monument ..... A-138*
*B. Bent's Old Fort National Historic Site ..... A-140*
*C. Capulin Volcano National Monument ..... A-142*
*D. Chickasaw National Recreation Area ..... A-144*
*E. Fort Larned National Historic Site ..... A-146*
*F. Fort Union National Monument ..... A-148*
*G. Lake Meredith National Recreation Area ..... A-150*
*H. Lyndon B. Johnson National Historical Park ..... A-152*
*I. Pecos National Historical Park ..... A-154*
*J. Sand Creek Massacre National Historic Site ..... A-156*
*K. Washita Battlefield National Historic Site ..... A-158*
K.6. ACKNOWLEDGMENTS ..... A-160
K.7. LITERATURE CITED ..... A-160

## K.1. ABSTRACT

This document facilitates the development of a water quality monitoring plan for the Southern Plains Network (SOPN) Vital Signs Inventory and Monitoring Program by describing the status of water resources within each of the eleven network parks. Furthermore, this report discusses existing data, data gaps, water legislation, and management issues for SOPN Park water resources. The two most significant concerns for SOPN water resources are pollution, primarily from point sources, and insufficient water quantity. Primary network needs include data collection, analysis, and feedback, as well as the prioritization of management strategies. SOPN will fully incorporate the funding and monitoring plan given by the Water Resources Division with the broader Vital Signs Inventory and Monitoring Program to more efficiently track the progress of the NPS long term strategic goal of improving Park water quality and quantity.

## K.2. INTRODUCTION

The National Park Service (NPS) has long recognized that protection and restoration of national park waters, watersheds, and aquatic life is critical for maintaining the integrity of all the resources and visitor experiences within the park system. In particular, the Water Resource Division (WRD) is funding water quality monitoring in the national parks through the Inventory and Monitoring Program to track the progress of the NPS long-term strategic goal of significantly reducing the amount of water pollution in park water bodies. Furthermore, the NPS is committed to preserving pristine water quality in parks where it now exists, including waters classified as Outstanding National Resource Waters (ONRW) or state-equivalent listed waters. As part of this initiative, in FY2005 the WRD began to provide $29,000 per year to the SOPN for water resource monitoring.

The purpose for water quality and quantity monitoring arises from several overarching needs:

- documentation of water quality parameters that are vulnerable to alteration from various sources of contamination or land use practices
- protection of designated waters
- establishment of water quality parameters useful for indicating ecosystem integrity of particular water resources
- establishment of baseline conditions
- provide park managers with science to guide decision making

To fulfill the obligations and reach the goals of the water resource monitoring initiative and address legal mandates under the Clean Water Act (CWA), SOPN will provide data to:

- support management of SOPN water resources
- support management in relation to 303(d) listed waters, designation of ONRW, and to protect designated waters
- assess the status and trend in selected indicators of the condition of aquatic/riparian/wetland ecosystems
- indicate early warning of water resource decline to direct management in the mitigation improvement of these conditions

The water quality monitoring initiative, funded by the WRD, will be fully integrated into the broader SOPN Vital Signs Inventory and Monitoring Program. Incorporating the two monitoring programs will benefit the SOPN in several ways. For example, water quantity is an important hydrological concern for the SOPN, but is not discretely emphasized in the WRD monitoring plan. Because water quantity plays a role in shaping and maintaining landscape features and ecological habitats, SOPN will likely include appropriate monitoring program. Other advantages for incorporating the WRD monitoring plan with the general vital signs monitoring plan include streamlining operations, synthesizing data, and increasing partnership opportunities.

## K.3. OVERVIEW OF WATER RESOURCES WITHIN SOUTHERN PLAINS NETWORK

Water resources are relatively scarce in the Great Plains, including the SOPN (Figure 1). However, due in large part to the cultural reasons that the parks were established, eight of the eleven SOPN parks contain significant water bodies (Tables 1 and 2).

**Table 1. Major water bodies found within SOPN parks.**

| Park Name | Code | Water Bodies |
|---|---|---|
| Alibates Flint Quarries National Monument | ALFL | None |
| Bent's Old Fort National Historic Site | BEOL | Arkansas River, Arch Wetland, several small ponds |
| Capulin Volcano National Monument | CAVO | None |
| Chickasaw National Recreation Area | CHIC | Lake of the Arbuckles, Veterans Lake, several streams & ponds |
| Fort Larned National Historic Site | FOLS | Pawnee River |
| Fort Union National Monument | FOUN | None within the park (Wolf Creek is adjacent to park) |
| Lake Meredith National Recreation Area | LAMR | Lake Meredith, Canadian River, several streams & creeks |
| Lyndon B. Johnson National Historical Park | LYJO | Pedernales River, Town Creek and stock ponds |
| Pecos National Historical Park | PECO | Pecos River, restored wetland, Glorieta Creek, Pecos tributaries |
| Sand Creek Massacre National Historic Site | SAND | Big Sandy Creek and wetland |
| Washita Battlefield National Historic Site | WABA | Washita River |

Rivers in the SOPN generally flow eastward and are characterized by extreme turbidity, high evaporation rates, moderate flow velocity and dynamic channels. Great Plains streams fall into three categories: the shallow stream with shifting sand beds; clear brooks, ponds, and marshes supported by seeps and springs; and residual pools of intermittent streams (Cross and Moss 1987). In general, streams in the southern Great Plains are characterized by irregular flows, small-particle substrates, and distinct wet-dry cycles.

Much of the water originates from the western mountains while many sediments originate from thunderstorm runoff on the Great Plains, often causing extreme turbidity during low flows. High salinity levels are also characteristic of rivers in the Great Plains due to salt- and gypsum-laden groundwaters. Like the plains themselves, river temperatures can fluctuate widely with summer, open-river water temperatures exceeding 86°F (30°C).

The water table is high in many areas of this region, producing poor drainage conditions and in some areas, a high proportion of ephemeral-perennial wetlands (Bailey 2001). The Ogallala Aquifer consists of one or more geological units connected belowground under the central Great Plains, and is essential to agricultural, urban, and environmental resources. This aquifer contains about 20% of the irrigated farmland in the High Plains and about 30% of the water used for irrigation (Huntzinger 1996). Precipitation is the principal source of natural groundwater recharge, but recharge can also result from seepage loss from streams and lakes. Natural discharge occurs as evaporation from plants and soils where the water table is near the surface or as seepage to springs.

There have been significant changes in the amount and permanency of surface and ground water since pre-Columbian times as a result of ranching (e.g., stock ponds), irrigation, flood control, and

other anthropogenic changes. Few major rivers in the Great Plains still exhibit the conditions evident before agricultural development and water management had occurred. Altered river hydrographs from dams, irrigation and municipal withdrawals, groundwater depletion, and other land use changes are a significant impact to aquatic systems in the Great Plains (Cross and Moss 1987, Longo and Yoskowitz 2002). Sediment deposition is part of reservoir design but remains a maintenance concern. In virtually all the river systems, dewatering has altered the timing and extent of flows, downstream temperatures, levels of dissolved nutrients, sediment transport and deposition, and the structure of plant and animal communities. Dams exist at three SOPN parks, LAMR, CHIC, and LYJO, and aquatic resources at other parks are affected by altered flows, primarily from agriculture and development.

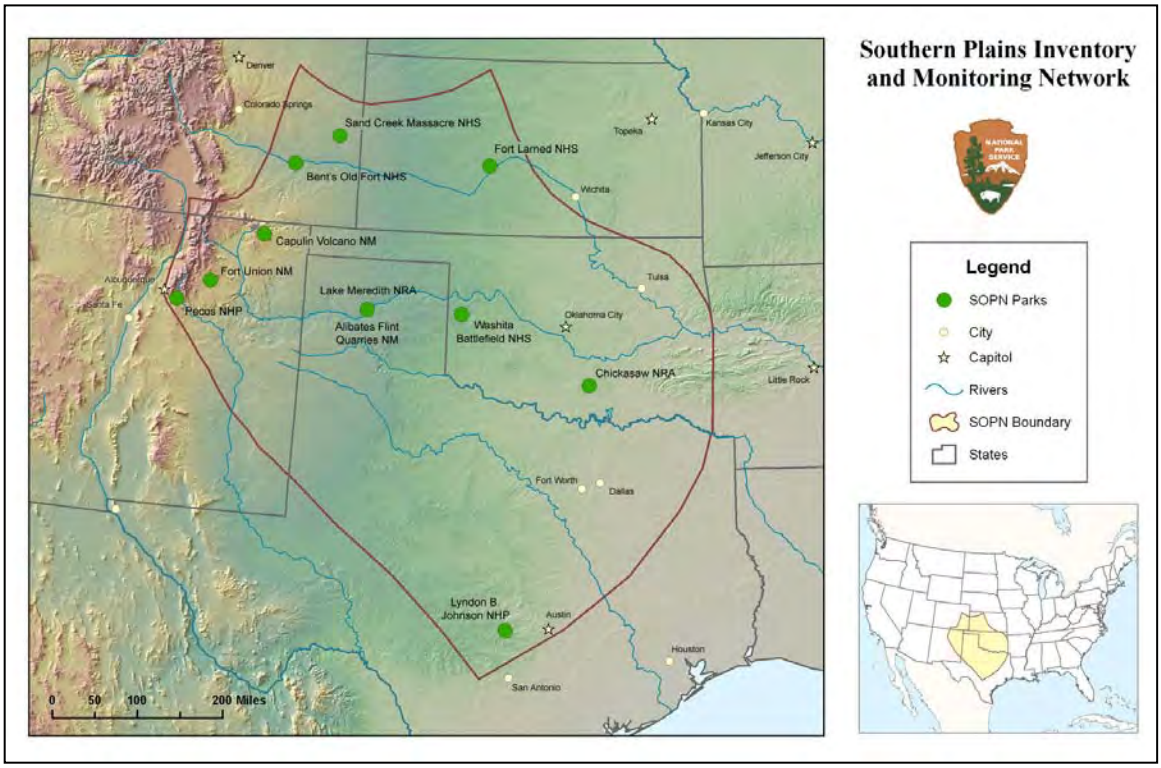



**Figure 1. Southern Plains Inventory and Monitoring Network**

Water quality throughout the Great Plains has been affected by herbicides and other pollutants, and SOPN parks are no exception. Agricultural use of nitrogen fertilizers is the largest source of nitrates in near-surface aquifers in the mid-continent (Koplin et al. 1994). A report summarizing data from 1991 indicated over 100,000 metric tons of pesticides (herbicides, insecticides, and fungicides) were applied in the mid-continent often to control non-indigenous plants and animals. Effects of these pollutants on the quality of human life and on the integrity of the ecological community are still largely unknown. The U.S. Environmental Protection Agency (EPA) has initiated an effort to develop stressor information to help recognize areas where urban development, agricultural non-point pollution (pesticides, toxic chemicals, nutrient pollution), and agricultural development may exacerbate ecological decline. Elevated *E. coli* levels, indicators of fecal contamination, are also a concern at CHIC.

Groundwater depletion is of regional concern for both Great Plains ecology and society. Kromm and White (1992) observed that groundwater depletion has destroyed much of the water-supported habitat for fish and mammals in parts of the Great Plains. They reported that more than 700 miles (1,127 km) of once permanently flowing rivers in Kansas no longer flow year round. The Ogallala aquifer has declined from 1940 to 1980 by an average area-weighted, water-level

decline of 10 feet (3 m) (3 inches [7 cm] per year; Dugan et al. 1994). Local area declines have varied, exceeding 98 feet (30 m) in some parts of the central and southern High Plains; 20 feet (6 m) in southwestern Kansas, east-central New Mexico, and the Oklahoma and Texas panhandles (Dugan et al. 1994). Subsurface water quantity and quality is an important resource and management issue at CHIC, FOLS, and BEOL due to groundwater depletion from neighboring lands (primarily for irrigation and development).

**Table 2. Water resources within the Southern Plains Network Parks**

| | Perennial Rivers | | Intermittent Rivers | | Adjacent Perennial Rivers | | Lakes / Reservoirs | | Lake / Reservoir Shoreline | | Canal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Park | Length (Miles) | Impaired Length (Miles) | Length (Miles) | Impaired Length (Miles) | Length (Miles) | Impaired Length (Miles) | Length (Acres) | Impaired Length (Acres) | Length (Miles) | Impaired Length (Miles) | Length (Miles) | Impaired Length (Miles) |
| ALFL | | | 3.6 | 0 | | | | | | | | |
| BEOL | 2.3 | 2.3 | | | | | | | | | | |
| CAVO | | | | | | | | | | | | |
| CHIC | 7.0 | 0 | 5.8 | 0 | | | 2503 | 0 | 36.8 | 0 | | |
| FOLS | 2.0 | 0 | 2.7 | 0 | | | | | | | | |
| FOUN | | | | | | | | | | | | |
| LAMR | 17.9 | 0 | 24.7 | 0 | | | 16242 | 16219 | 109 | 108 | | |
| LYJO | 0.1 | 0 | 2.5 | 0 | 4.9 | 0 | 13 | 0 | 2.7 | 0 | | |
| PECO | 6.2 | 2.86 | 12.1 | 0.1 | | | | | | | | |
| SAND | 2.7 | 0 | 11.4 | 0 | | | | | | | 3.1 | 0 |
| WABA | 0.9 | 0 | | | | | | | | | | |
| TOTAL | 39.1 | 5.1 | 62.7 | 0.1 | 4.9 | 0 | 18758 | 16219 | 148.4 | 107.7 | 3.1 | 0 |
| NPS Hydrographic and Impairment Statistics, 2004 | | | | | | | | | | | | |

## K.4. RESOURCE LEGISLATION APPLICABLE TO SOPN PARKS

### *K.4.1. Federal Legislation*

#### K.4.1.1 The Clean Water Act

The Clean Water Act, adopted by Congress in 1972, required that states, territories, and authorized tribes develop water quality standards for the protection and restoration of waters within their jurisdictions. Section 305(b) of the Clean Water Act requires that states assess the health of their waters and the extent to which water quality standards are being met (Table 3). To satisfy this requirement each state must submit a water quality inventory report, the 305(b) Water Quality Report, every two years to the EPA. This report provides descriptions of the water quality of all navigable waters within the state to the extent that these waters provide for the protection and propagation of a balanced population of shellfish, fish, and wildlife, and allow recreational activities. Each state must also determine the extent of pollutant discharge elimination required and the level of water quality required for the protection and propagation of a balanced population of shellfish, fish, and wildlife and allows for recreational activities. Each state will also provide estimates of environmental impacts, economic and social costs necessary to achieve these objectives, the economic and social benefits of such achievements, and an estimate of the date these achievements will be met. Finally, each state must describe the nature and extent of non-point source pollutants and recommendations as to the programs to control these sources, including an estimate of the costs of implementing these programs. The water quality report submitted by the state to the EPA is referred to as the 305(b) Water Quality Report and identifies the impairments, if existing, for waters within that state. Waters listed in the 305(b) report are referred to as 305(b) listed waters and can be found on the EPA's Water Quality Inventory Electronic 305(b) Report website (http://www.epa.gov/waters/305b/index.html). This list includes the attainment status (whether or not the waterbody is supporting designated uses) for designated uses (*e.g.* aquatic life support, fish consumption, primary contact recreation) for specific waterbodies.

**Table 3. Summary of designated uses for the major water bodies in the Southern Plains (derived from 305(b) Water Quality Reports)**

| Park | State | Waterbody[1] | WBID | Designated Use Category | State Designated Use | Attainment of Use |
|---|---|---|---|---|---|---|
| BEOL | CO | Arkansas River | COARLA01B_3700* | Fish, Shellfish, and Wildlife | Aquatic Life Warm | Not Supporting |
| | | | | Aquatic Life Harvesting | Fish Consumption | Not Assessed |
| | | | | Recreation | Primary Contact (Recreation) | Fully Supported |
| | | | | Public Water Supply | Drinking Water Supply | Not Supporting |
| | | | | Agricultural | Agriculture | Fully Supported |
| CHIC | OK | Lake of the Arbuckles | OK310800020100_00 | Fish, Shellfish, and Wildlife | Warm water aquatic community | Insufficient information |
| | | | | Recreation | Primary Contact (Recreation) | Insufficient information |
| | | | | Public Water Supply | Public/Private Water Supply | Insufficient information |
| | | | | Aesthetic Value | Aesthetics | Fully Supporting |
| | | | | Agricultural Value | Agriculture | Insufficient information |
| | | | | Public Water Supply | SWS-Sensitive Water Supply | Not Assessed |
| | | | | Industrial | Industry | Insufficient information |
| CHIC | OK | Veterans Lake | OK310800020120_00 | Fish, Shellfish, and Wildlife | Warm water aquatic community | Not Assessed |
| | | | | Recreation | Primary Contact (Recreation) | Not Assessed |
| | | | | Aesthetic Value | Aesthetics | Not Assessed |
| | | | | Agricultural | Agriculture | Not Assessed |
| | | | | Industrial | Industry | Not Assessed |
| WABA | OK | Washita River | OK310840020010_00 | Fish, Shellfish, and Wildlife | Warm water aquatic community | Not Supporting |
| | | | | Recreation | Primary Contact (Recreation) | Insufficient information |
| | | | | Public Water Supply | Public/Private Water Supply | Not Assessed |
| | | | | Aesthetic Value | Aesthetics | Insufficient information |
| | | | | Agricultural | Agriculture | Fully Supporting |
| | | | | Industrial | Industry | Fully Supporting |
| FOLS | KS | Pawnee River | KS110300052585 | Recreation | Non-contact Recreation | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | Acute Aquatic Life | Not Supporting |
| | | | | Public Water Supply | Domestic Water Supply | Fully Supporting |
| | | | | Agricultural | Irrigation Water Use | Fully Supporting |
| | | | | Agricultural | Livestock Watering Use | Fully Supporting |
| LAMR | TX | Lake Meredith | TX0102_01* | Fish, Shellfish, Wildlife | Aquatic Life Use | Fully Supporting |
| | | | | Recreation | Contact Recreation Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | General Use | Fully Supporting |
| | | | | Aquatic Life Harvesting | Fish Consumption Use | Partial Support |
| | | | | Public Water Supply | Public Water Supply Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | Overall Use Support | Partial Support |

[1] Every State must assign a Water Body Identification (WBID) code to each body of water listed on their 305 and 303(d) lists.

| Park | State | Waterbody[2] | WBID | Designated Use Category | State Designated Use | Attainment of Use |
|---|---|---|---|---|---|---|
| LAMR | TX | Lake Meredith | TX0102_02* | Fish, Shellfish, Wildlife | Aquatic Life Use | Not Assessed |
| | | | | Recreation | Contact Recreation Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | General Use | Fully Supporting |
| | | | | Aquatic Life Harvesting | Fish Consumption Use | Partial Support |
| | | | | Public Water Supply | Public Water Supply Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | Overall Use Support | Partial Support |
| LYJO | TX | Pedernales River | TX1414_04 | Fish, Shellfish, Wildlife | Aquatic Life Use | Fully Supporting |
| | | | | Recreation | Contact Recreation Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | General Use | Fully Supporting |
| | | | | Aquatic Life Harvesting | Fish Consumption Use | Not Assessed |
| | | | | Public Water Supply | Public Water Supply Use | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | Overall Use Support | Fully Supporting |
| PECO | NM | Pecos River | NM-2214.A_002* | Fish, Shellfish, Wildlife | Wildlife Habitat | Fully Supporting |
| | | | | Fish, Shellfish, Wildlife | High Quality Coldwater Fishery | Partial Support |
| | | | | Aquatic Life Harvesting | Fish Culture | Fully Supporting |
| | | | | Recreation | Secondary Contact | Fully Supporting |
| | | | | Public Water Supply | Domestic Water Supply | Fully Supporting |
| | | | | Agricultural | Livestock Watering | Fully Supporting |
| | | | | Agricultural | Irrigation | Fully Supporting |
| SAND | CO | Big Sandy Creek | COARLA02_4300 | Fish, Shellfish, Wildlife | Aquatic Life Warm 2 | Fully Supporting |
| | | | | Recreation | Secondary Contact (Recreation) | Fully Supporting |
| | | | | Agricultural | Agriculture | Fully Supporting |

* = Water Unit is listed as "impaired" under section 303(d) of the Federal Clean Water Act

[2] Every State must assign a Water Body Identification (WBID) code to each body of water listed on their 305 and 303(d) lists.

In addition to the 305(b) Water Quality Report, The Clean Water Act, Section 303(d), requires that states develop an Impaired Waterbodies List for waterbodies that do not meet the water quality standards that the states have set. States must establish priority ranking for these waters and develop Total Maximum Daily Load (TMDL) programs for these waters. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loadings among point and non-point sources. The EPA must approve the TMDL (EPA 2002). While TMDLs have been required by the Clean Water Act since 1972, many states, territories, or authorized tribes have not developed them until recently, a result of recent legal action against the EPA by citizens groups seeking the listing of waters and development of TMDLs. States, territories, or authorized tribes are required to submit their list of 303(d) waters in every even numbered year (referred to as the 2-year listing cycle). The 303(d) list is referred to as the 303(d) Impaired Waterbodies List and must be based on documented methodology that includes an evaluation of existing and readily available data. Waterbodies that have been identified as impaired and have a scheduled development for, or existing TMDL are then added to the 303(d) Impaired Waters List for that state. Waterbodies continue to be included on subsequent Impaired Waterbodies Lists until TMDLs are completed, applicable criteria are met, or the original basis for the listing is shown to be flawed.

There are several designated uses of water quality for which the states are required to monitor. Each designated use has a unique set of water quality criteria, set individually by each state that must be met for the designated use to be realized. In the 305(b) Water Quality Report, the state must identify the type of assessment (monitored or evaluated) that was used to make each designated support determination. Monitored assessments are based on data collected within the past 5 years. Evaluated assessments are based on qualitative information (if no monitoring data are available) or on monitoring data that are more than 5 years old (EPA 2000). If available, specific water quality, biological and physical data can be obtained from STORET (short for STOrage and RETrieval): http://www.epa.gov/STORET/index.html

The 305(b) Designated Uses are as follows (EPA 2000):

> *Aquatic Life Support*: The water body provides for suitable habitat for protection and propagation of desirable fish, shellfish, and other aquatic organisms.
> *Drinking Water Supply*: The water body can supply safe drinking water with conventional treatment.
> *Fish Consumption*: The water body supports fish free from contamination that could pose a significant human health risk to consumers.
> *Shellfish Harvesting*: The water body supports a population of shellfish free from toxicants and pathogens that could pose a significant human health risk to consumers.
> *Primary Contact Recreation – Swimming*: People can swim in the water body without risk of adverse human health effects (such as catching waterborne diseases from raw sewage contamination).
> *Secondary Contact Recreation*: People can perform activities on the water (such as boating) without risk of adverse human health effects from incidental ingestion or contact with the water.
> *Agriculture*: The water quality is suitable for irrigating fields or watering livestock.
> Many states designate their waters for additional uses such as:
> *Ground Water Recharge*: The surface water body plays a significant role in replenishing ground water; surface water supply and quality are adequate to protect existing or potential uses of ground water.
> *Wildlife Habitat*: Water quality supports the water body's role in providing habitat and resources for land-based wildlife as well as aquatic life.
> *Culture*: Water quality supports the water body's role in tribal culture and preserves the water body's religious, ceremonial, or subsistence significance.

Since each state sets its own water quality standards, the definition of attainment of the EPA Designated Use Support (*i.e.* fully supporting, fully supporting but threatened, partially supporting, not supporting, not assessed) is slightly different for each state. Prior to 2002, data collection and interpretation efforts under the Clean Water Act were not always coordinated. The EPA is now recommending that states submit an Integrated Water Quality Monitoring and Assessment Report (EPA 2002) to satisfy the requirements for both Sections 305(b) and 303(d) of the Clean Water Act (EPA 2000). The Integrated Report will combine the non-regulatory requirements of the 305(b) Water Quality Report with the regulation driven (mandated TMDL development) 303(d) Impaired Waterbodies List. The EPA has established several basic categories for an Integrated List.

Information for the 305(b) and 303(d) summary tables can be obtained from the Environmental Protection Agency (EPA) Waters website http://www.epa.gov/waters/ which provides both 305(b) and 303(d) information and state issued 305(b) Water Quality Reports and 303(d) Impaired Lists. For the majority of waterbodies the EPA Water Quality Inventory website (http://www.epa.gov/waters/305b/index.html) had the most current and complete information for 305(b) assessment and attainment status (whether or not the water quality for a specific waterbody was supporting its designated use). Information for 303(d) Impaired Waterbodies Lists was summarized from both the EPA Total Maximum Daily Load (TMDL) Reports (http://www.epa.gov/waters/tmdl/index.html) and state issued 303(d) Impaired Waters Lists (from individual state websites).

Applicability to SOPN - SOPN has three waterbodies that are designated as 303(d) impaired (Table 4 and Figure 2). These waters are the Arkansas River at Bent's Old Fort NHS, Lake Meredith at Lake Meredith NRA, and the Pecos River at Pecos NHP. Once a waterbody is listed, the state must bring it into compliance with water quality standards by developing a Total Maximum Daily Load (TMDL) for the pollutant(s) of concern. TMDLs are designed to restore the health of waters and to establish acceptable levels of point and non-point inputs. Pollution controls prescribed by the TMDLs are implemented through the National Pollution Discharge Elimination System (NPDES) for point sources and through Best Management Practices (BMPs) for non-point sources.

**Table 4. 303(d) Listed Waters of Southern Plains Network**

| Park | State | WBID[3] | Water Body | Portion Impaired | Impairment |
|---|---|---|---|---|---|
| BEOL | CO | COARLA01B | Arkansas River | From above Fountain Creek to Stateline (problems increase downstream); 2.27 miles | Selenium |
| LAMR | TX | TX-0102 | Lake Meredith | Nearly all of lake; 16,218.84 acres | Mercury in Fish Tissue |
| PECO | NM | NM-2214.A_003 | Pecos River | From Canon de Manzanita to Alamitos Canyon; 2.86 miles | Temperature & Turbidity |

K.4.1.2. The Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) was passed in 1974 and amended in 1986 and 1996. This act directs the U.S. Environmental Protection Agency to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. Primary enforcement responsibilities lie with the states. The act also protects underground sources of drinking water with primary enforcement responsibilities again resting with the states. Federal agencies having jurisdiction over public water systems must comply with all requirements to the same extent as any non-governmental entity. Source water protection means preventing contamination and reducing the need for treatment of drinking water

3

supplies. Source water protection also means taking positive steps to manage potential sources of contaminants and contingency planning for the future by determining alternative sources of drinking water.

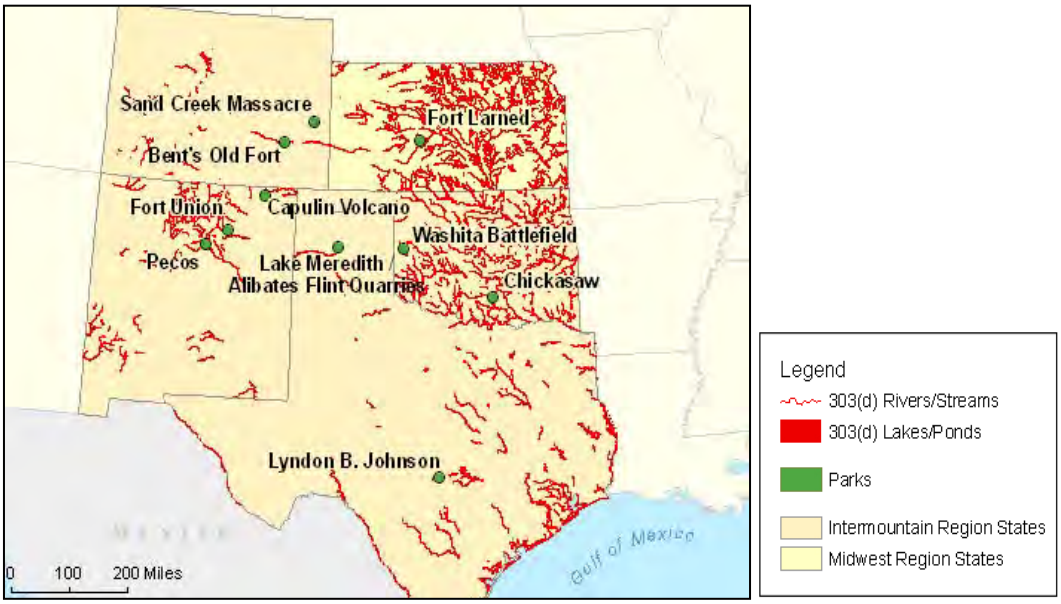



**Figure 2. Map of 303(d) waters in Colorado, Kansas, New Mexico, Oklahoma, and Texas, the states in which the SOPN lies. 303(d) bodies of water are colored red. Three 303(d) listed waters fall within park boundaries.**

Applicability to SOPN - The SDWA protects rivers, lakes, reservoirs, springs, and ground water wells (if they serve more than 25 people) that serve as drinking water sources. SOPN parks that are affected by this legislation are Lake Meredith National Recreation Area, which provides drinking water to 11 surrounding communities, and Chickasaw National Recreation Area, which was originally established with the intent of providing drinking water to local areas.

*K.4.2. State Legislation*

The NPS is required to comply with state laws for water quality standards and management, regardless of other jurisdictional status or landownership. The following describes legislation of each of the five states that the SOPN covers (Colorado, Kansas, Oklahoma, New Mexico, and Texas).

K.4.2.1. Colorado

SOPN parks in Colorado are Bent's Old Fort National Historic Site and Sand Creek Massacre National Historical Site.

State Agencies Responsible for Water Management -The Colorado Department of Public Health and Environment oversees the protection of the state's waters, and is charged with conserving the state's waters and protecting, maintaining, and improving the their quality for the wildlife and aquatic life, for domestic, agricultural, industrial, recreational and other beneficial uses. The Water Quality Control Commission (WQCC) is the administrative agency responsible for developing specific state water quality policies. The WQCC adopts water quality classifications and standards for surface and ground waters of the state, as well as various regulations aimed at achieving compliance with those classifications and standards. The Water Quality Division serves as staff to the commission and provides them with recommendations based on assessment of the state's waters. Within the Department of Natural Resources, the Division of Water Resources, headed by the State Engineer, ensures the competent distribution of water, and administers

water rights through the appropriation doctrine. This division also controls permits for ground water wells, provides water supply statistics, and surface flow data. The Colorado Water Conservation Board ensures the development, protection, and management of Colorado's waters. It is the only entity that can hold an instream water right.

Primary Pieces of State Water Legislation - The state notes nine designated uses of water including 2 levels each for Aquatic Cold Water and Warm waters, domestic water supply, three different uses for Recreation and Agriculture. Their anti-degradation relates to those waters where existing water quality shall remain the same, and discharges to the waters will not cause impairment unless economic and social needs outweigh the benefits of maintaining the existing water quality. Colorado does not have a list of Tier III waters, but instead refers to them as Outstanding Waters. The State of Colorado has no streamflow or biological criteria or guidance with which to protect existing uses.

State Surface Water Quality Standards - Colorado fulfills its obligation to the federal CWA by assessing and reporting on the quality of its waters in the report, "Status of Water Quality in Colorado". This report details the water quality within the watersheds that make up the four major river systems, the Arkansas River, Colorado River, Platte River, and the Rio Grande, all of which originate within the state. The Water Quality Control Division (WQCD) is responsible for monitoring, assessing, and managing the waters based on the state's water quality standards.

Surface water quality standards are established to protect classified uses. In Colorado, waterbodies may be assigned any of four categories of classification: aquatic life, water supply, recreation, and agriculture. In the latest biennium, Colorado made changes in the use classifications of many streams.

The causes and sources of impairment to CO water bodies were also reported in the latest report. The most important pollutant for Colorado surface waters is metals and pH. Other major pollutants include nitrate and sulfate. The major sources of these pollutants have not been identified in most cases, and are therefore classified as "unknown".

K.4.2.2. Kansas

The SOPN Park in Kansas is Fort Larned National Historical Site.

State Agencies Responsible for Water Management - Several state agencies are responsible for managing and monitoring water quality within Kansas. The Kansas Water Office (KWO) is the water planning agency for the state. The Kansas Water Authority is within the KWO and is responsible for advising the Governor, the Legislature, and the Director of the KWO on issues of water policy. Other agencies that cooperate in water quality management are the Kansas Department of Agriculture (KDA), Kansas Department of Health and Environment (KDHE), State Conservation Commission (SCC), and Kansas Department of Wildlife and Parks (KDWP).

Primary Pieces of State Water Legislation - The Kansas Water Plan was completed in 1999 and is one of the primary tools used by the state to coordinate development, conservation, and management of its water resources.

State Surface Water Quality Standards - Kansas Surface Water Quality Standards are incorporated in Kansas administrative Regulations KAR 28-16-28b through 28-16-28f. The official regulations are published by the Kansas Secretary of State. However, the official publication of the Kansas Regulations only takes place once per year and lags behind official adoption of new regulations by as much as a year. Since parts of the Kansas Surface Water Quality Standards have been amended annually, an up-to-date official version of the Standards is rarely available in a single publication. To obtain a complete set of the official Standards one must access to the official Kansas Administrative Regulations, the annual Supplement to the Kansas Administrative Regulations, and the most recent year's *Kansas Register*. The Kansas Surface Water Quality Standard, K.A.R. 28-16-28g, was adopted by Secretary Roderick L. Bremby, Kansas Dept. of

Health and Environment, on April 25, 2005. The Kansas Surface Water Register (dated November 5, 2004) is adopted by reference in K.A.R. 28-16-28g. Copies of the regulation, the register and the 2003 stream and lake recreational UAAs were submitted to U.S. EPA on May 26, 2005. By regulation, the U.S. EPA has 60 days to approve the regulation and 90 days to disapprove.

K.4.2.3. New Mexico

SOPN Parks in New Mexico are Capulin Volcano National Monument, Fort Union National Monument, and Pecos National Historical Park.

*State Agencies Responsible for Water Management* **-** The Water Quality Control Commission (WQCC) is the state water pollution control agency that oversees all actions relating to the federal CWA and Safe Drinking Water Act (SWDA).

Primary Pieces of State Water Legislation - The State Water Quality Act provides the main authority for water quality management in New Mexico, in addition to federal legislation. This law establishes the Water Quality Control Commission (WQCC) and specifies its duties and powers.

*State Surface Water Quality Standards* - New Mexico's Surface Water Quality Standards (WQS) define water quality goals by designating uses for waterbodies, setting criteria to protect those uses, and establishing provisions to preserve water quality. To meet the requirements of Section 303 (c) of the federal Clean Water Act, the WQS are examined for changes on a 3-year rotating basis in a process known as the Triennial Review.

On April 12, 2005, the WQCC adopted its Statement of Reasons and final revisions to the WQS. The WQCC filed the amendments to the WQS with the New Mexico State Records Center on April 21, 2005. The final amendments to the WQS were published in the May 13, 2005 *New Mexico Register* and became effective on May 23, 2005 (consistent with the New Mexico Water Quality Act requirement at 74-6-6(E). The WQCC filed a corrections notice with the New Mexico State Records Center on June 15, 2005. The corrections were published in the June 30, 2005 *New Mexico Register* and are effective on July 17, 2005.

The integrated revision of the WQS incorporates changes through July 17, 2005 were included in the New Mexico Administrative Code on August 1, 2005. The United States Environmental Protection Agency (EPA) provides approval, policy and guidance for New Mexico's WQS. As required by federal regulation, New Mexico submitted the revised WQS and supporting documentation to EPA on July 7, 2005. According to 40 CFR 131.21(a), EPA is required to approve the WQS revisions within 60 days or disapprove the WQS revisions within 90 days of receipt.

K.4.2.4. Oklahoma

SOPN Parks in Oklahoma are Chickasaw National Recreation Area and Washita Battlefield National Historical Site.

State Agencies Responsible for Water Management - The Water Quality Division develops and maintains Oklahoma's Water Quality Standards and routinely collects physical, chemical and biological data to support the document. The Division directs Oklahoma's Beneficial Use Monitoring Program (BUMP) to document beneficial use impairments, identify impairment sources (if possible), detect water quality trends, provide needed information for the Water Quality Standards and facilitate the prioritization of pollution control activities. The Tribal Nations claim ownership and sovereign authority to regulate all water (surface water and groundwater) within their original tribal boundaries (all or parts of 22 counties in southeast Oklahoma).

Primary Pieces of State Water Legislation - The State/Tribal Water Compact, which is the predominant legislation guiding water resource management, addresses three major subjects: (1)

water rights administration, (2) water quality standards administration, and (3) economic development.

State Surface Water Quality Standards - The Oklahoma Water Resources Board's statutory authority and responsibility concerning establishment of state water quality standards are provided under 82 O.S.,§1085.30. Under this statute the Oklahoma Water Resources Board is authorized to promulgate rules *which establish classifications of uses of waters of the state, criteria to maintain and protect such classifications, and other standards or policies pertaining to the quality of such waters* [82:1085.30(A)]. These Standards are designed to maintain and protect the quality of the waters of the state. The standards specify numerical and narrative criteria to protect beneficial uses designated for certain waters of the State. The purpose of the Standards is to promote and protect as many beneficial uses as are attainable and to assure that degradation of existing quality of waters of the State does not occur.

K.4.2.5. Texas

SOPN Parks in Texas are Alibates Flint Quarries National Monument, Lake Meredith National Recreation Area, and Lyndon B. Johnson National Historical Park.

State Agencies Responsible for Water Management - There are many organizations within Texas that monitor the state's water resources. The Texas Natural Resource Conservation Commission (TNRCC) oversees the state's air, water, and waste management. Texas Water Conservation Association the leading organization in Texas devoted to conserving, developing, protecting, and using the water resources of the state for all beneficial purposes. The Lower Colorado River Authority (LCRA) is responsible for overseeing the lower Colorado River basin region in which LYJO lies. The Canadian River Municipal Water Authority manages the basin in which LAMR lies.

Primary Pieces of State Water Legislation - Current water laws for the state of Texas are the result of over 200 years of legislation and litigation. Overall, the state of Texas divides its water policies into two categories: groundwater and surface water. Groundwater laws are more limited, as this type of water is typically considered the property of the owner of the surface property from which it is pumped. Surface water on the other hand, is generally owned by the state.

State Surface Water Quality Standards - The state of Texas has established standards that protect the purposes for which the water bodies in the state will be used, and defined measurements that will assure the water quality is acceptable to attain those uses. Based on the standards, the Texas Commission on Environmental Quality (TCEQ), along with other federal, regional, and local agencies, carries out a regular program of monitoring and assessment to determine which water bodies are meeting the standards set for their use, and which are not. The state produces a periodic report, the "Texas Water Quality Inventory and 303(d) List," that compares water quality conditions to established standards, as required by federal Clean Water Act (CWA) Sections 305(b) and 303(d).

Texas Surface Water Quality Standards (WQS) have established the designated uses, or purposes, for which the state's water bodies should be suitable. Furthermore, they have provided numerical and narrative goals for water quality throughout the state. Also, the Texas Surface WQS provides a basis upon which regulatory programs may be developed.

Four major water use categories are defined by the Texas State WQS: aquatic life use; contact recreation (swimming); public water supply; and fish and shellfish (oyster) consumption. A variety of other general uses are also explained such as, navigation, water supply for agriculture and industry, and wetland functions.

*K.4.3. National Park Service*

K.4.3.1. Government Performance and Results Act (GPRA)
Established in 1993 (Public Law 103-62), this Act requires parks to have means of measuring or quantifying results of management activities, including those in relation to water resources. In particular, the GPRA goal for water resources requires parks to report impaired waters as defined by Section 303(d) of the Clean Water Act.

Applicability to SOPN - All parks within the SOPN are required to follow the regulations mandated by GPA. Three parks have 303(d) listed waters: BEOL, LAMR, and PECO (see 303(d) information above).

K.5. SOPN PARK NARRATIVES

*K.5.1. Alibates Flint Quarries National Monument (ALFL)*

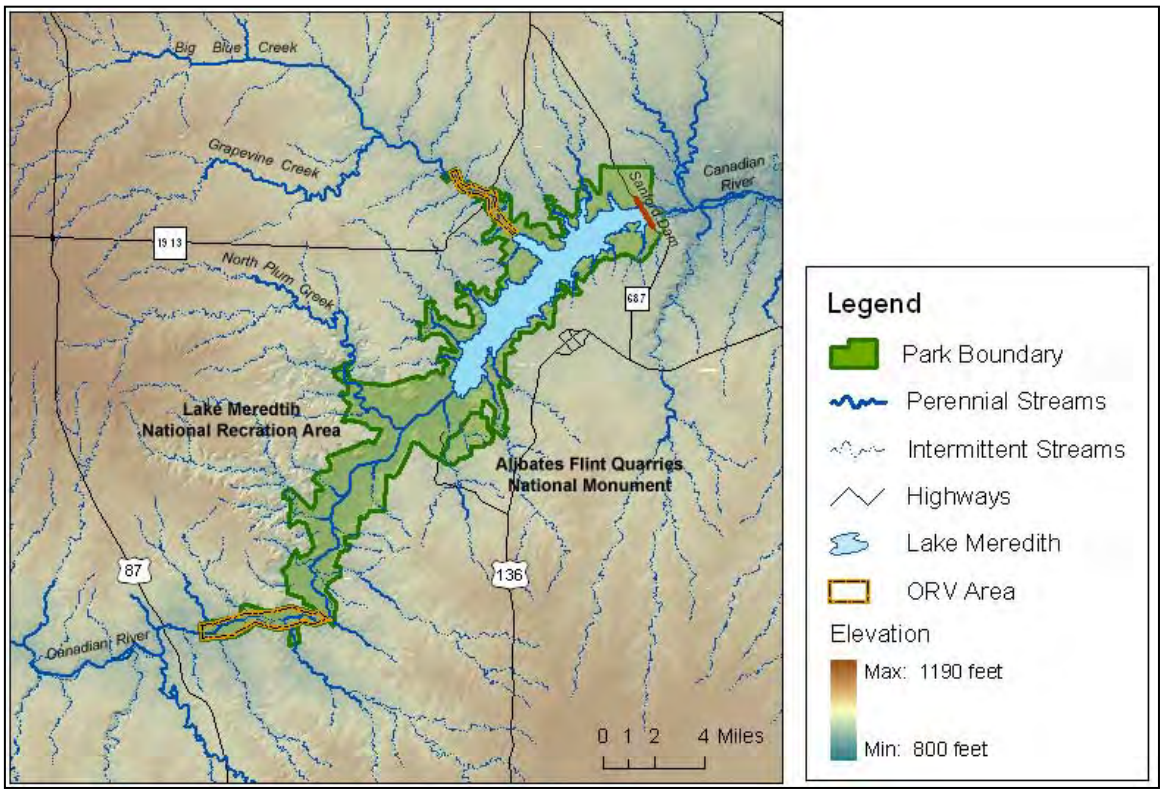



**Figure 3. Map of Alibates Flint Quarries National Monument with water bodies highlighted.**

K.5.1.1. Background
Alibates Flint Quarries National Monument (ALFL) encompasses 1,371 acres (555 ha) adjacent to Lake Meredith National Recreation Area (LAMR) (Figure 3). ALFL falls within the semi-arid steppe climate in the Steppe ecoregion of the high plains and plateaus (Bailey 1995). The average annual rainfall at ALFL is 20 inches (51 cm), 60-65% of which is lost through evaporation/evapotranspiration. Seventy percent of the precipitation falls during the primary growing season. The terrain is characterized as rough and broken as it has been cut by the Canadian River. Soils in the area range from very fine sandy loams to silty clay loams.

K.5.1.2. Primary Water Resources

ALFL is situated in the Canadian River Basin and within the Lake Meredith watershed. Water from Lake Meredith seasonally fills the breaks created by the Canadian River breaks; however, other than these, no surface water resources fall within the ALFL boundaries.

K.5.1.3. Management and scientific issues

Soil erosion and groundwater conditions are the largest concerns for ALFL park managers. Irrigation that supports nearby agriculture is lowering the water table thereby contributing to soil desertification. Agricultural land use and oil and gas operations are introducing contaminants to the groundwater.

K.5.1.4. Past and Present Monitoring

ALFL has not conducted any independent monitoring projects, although LAMR has included ALFL in some of its monitoring projects. For example, the basic water quality assessment completed by the Water Resources Division included ALFL in its study area as part of the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 2000a).

*K.5.2. Bent's Old Fort National Historical Site (BEOL)*

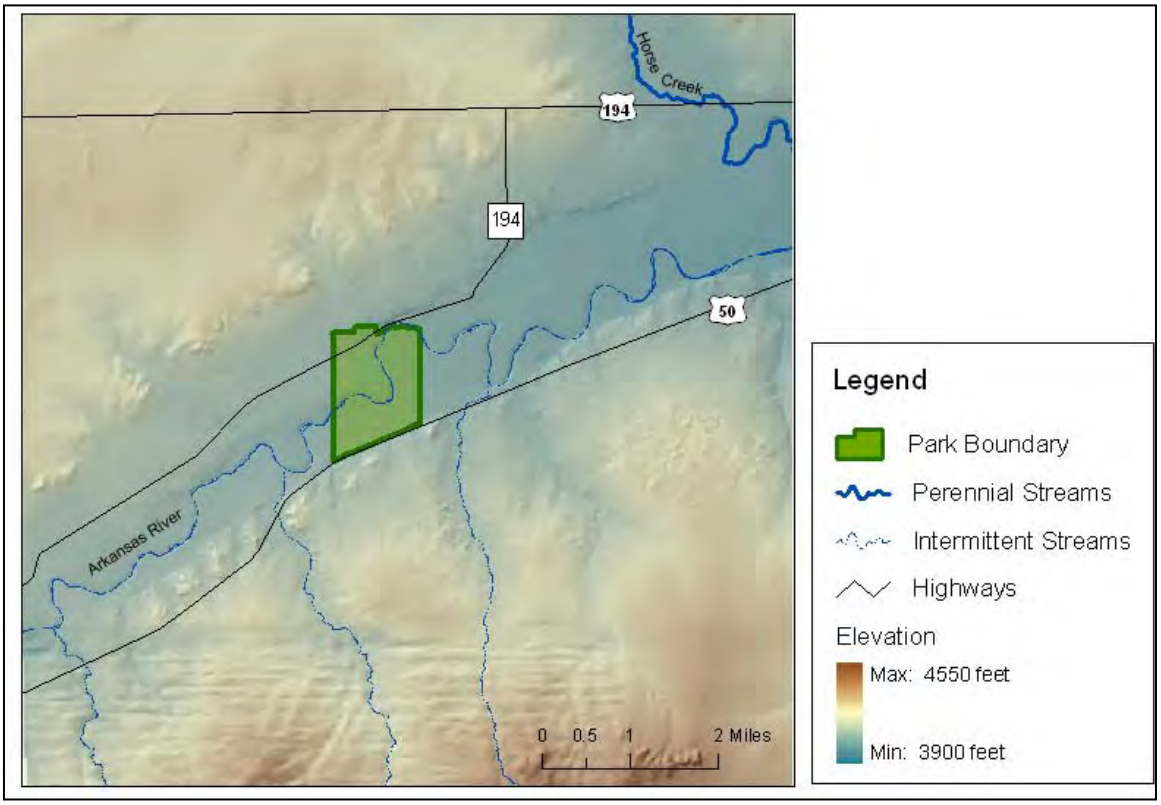



**Figure 4. Map of Bent's Old Fort National Historic Site with water bodies highlighted.**

K.5.2.1. Background

Bent's Old Fort National Historic Site (BEOL), 799-acres (323 ha) in size (Figure 4), is located on the Arkansas River. BEOL is primarily underlain by bedrock comprised of Bridge Creek Limestone (Ladyman 2003). Silty clay loams to sandy loams comprise the soils for the bottomland areas of SAND; well-drained loamy soils are found in the upland areas. BEOL receives approximately 12 inches (30 cm) of annual precipitation.

K.5.2.2. Primary Water Resources

BEOL falls within the Upper Arkansas-John Martin Watershed. Based on the National Hydrography Dataset (NHD), a total of 2.28 miles (3.67 km) of perennial streams are within or adjacent to the BEOL park boundary. Seven small man-made ponds and one 55-acre (22 ha) wetland are also located at this park. State-designated uses for classified waterbodies within or adjacent to the BEOL park boundary include: agriculture, aquatic life warm water – class 2, domestic water source, and recreation primary contact.

BEOL also has a number of wetland sites. Arch wetland is the largest and is located between the river and the fort. River overflow and leakage from Fort Lyon irrigation canal appear to provide water for this area. Case Bolt wetland is less than one-half acre (0.2 ha) of shallow open water south of the fort that is permanently inundated. The water source may be from irrigation overflow or seepage from other man-made ponds. To the south of the river, the abandoned slough receives overflow from the Arkansas River during very large flooding events, with no evidence of prolonged inundation. Cattail Pond also receives water from large flooding events and runoff from summer thunderstorms. Three other wetland areas appear to be man-made depressions that collect runoff (Gionfriddo et al. 2002).

K.5.2.3. Management and scientific issues

Maintaining the wetland areas and riparian zones are the primary aquatic concerns for BEOL. The cottonwood (*Populus deltoides*) /riparian habitats, in particular, receive special attention as they are considered to be a globally rare ecosystem-type. Exotic plants and flooding processes are two of the biggest threats related to water resource concerns at this park. The flooding events can cause erosion, opening an avenue for invasive species and the wet/dry cycles affect both surface water levels and groundwater recharge. Neighboring land uses can impact both water quality, due to potential point-sources, and quantity due to unresolved water rights issues. In addition, nearby extractive activities pose difficulties for water quality through hazardous spills both on-site and on the roadway adjacent to the park.

BEOL listed its most significant natural resource issue as being value/function of the Arch Wetland. Other important natural resource issues are water drainage, hydrology, water effects on adobe forts, upstream dams, and flooding. Of these, floods are the greatest threat facing BEOL.

The State of Colorado designated a portion of the Arkansas River, including the section that runs through BEOL, on its 2002 303(d) list as quality impaired for aquatic life warm water – class 2 and domestic water source. The pollutant responsible for the impairment of the Arkansas River is identified as selenium (Se). For some time iron (Fe) was also listed as a pollutant to the Arkansas River. However, the Environmental Protection Agency (EPA) recently removed this designation as ambient-based conditions of iron in this region are naturally high (Hegeman, personal communication). Standards for acceptable iron levels were set according to existing levels at the time the original pollutant-designation was removed.

K.5.2.4. Past and Present Monitoring

Current research is being conducted by the park on the local water table. Also, USGS is currently monitoring river flows near the park. Historically, circa 1968, there was research done on tamarisks (*Tamarix spp.*) on the south side of river.

A report compiled in by the NPS Water Resources Division retrieved water quality data for the Bent's Old Fort area collected between 1961 and 1994 (NPS 1998a). Within the study area, which included Fort Lyons Canal headgates above La Junta and the La Junta Sewage Treatment plant upstream of BEOL, five industrial/municipal dischargers and ten active or inactive USGS water gauges were found. No stations were located within park boundaries. The most problematic readings with the highest contaminant levels occurred during the 1970s, with scattered reports for various heavy metals. Copper and lead often exceeded limits throughout the study area, while chloride, chlorine and sulfates also had frequent elevated levels. It was concluded that human activities, such as industrial and municipal wastewater discharge, agricultural and mining operations, stormwater runoff and atmospheric deposition all negatively impact the water quality of the Arkansas River as it runs through Bent's Old Fort National Historic Site.

*K.5.3. Capulin Volcano National Monument (CAVO)*

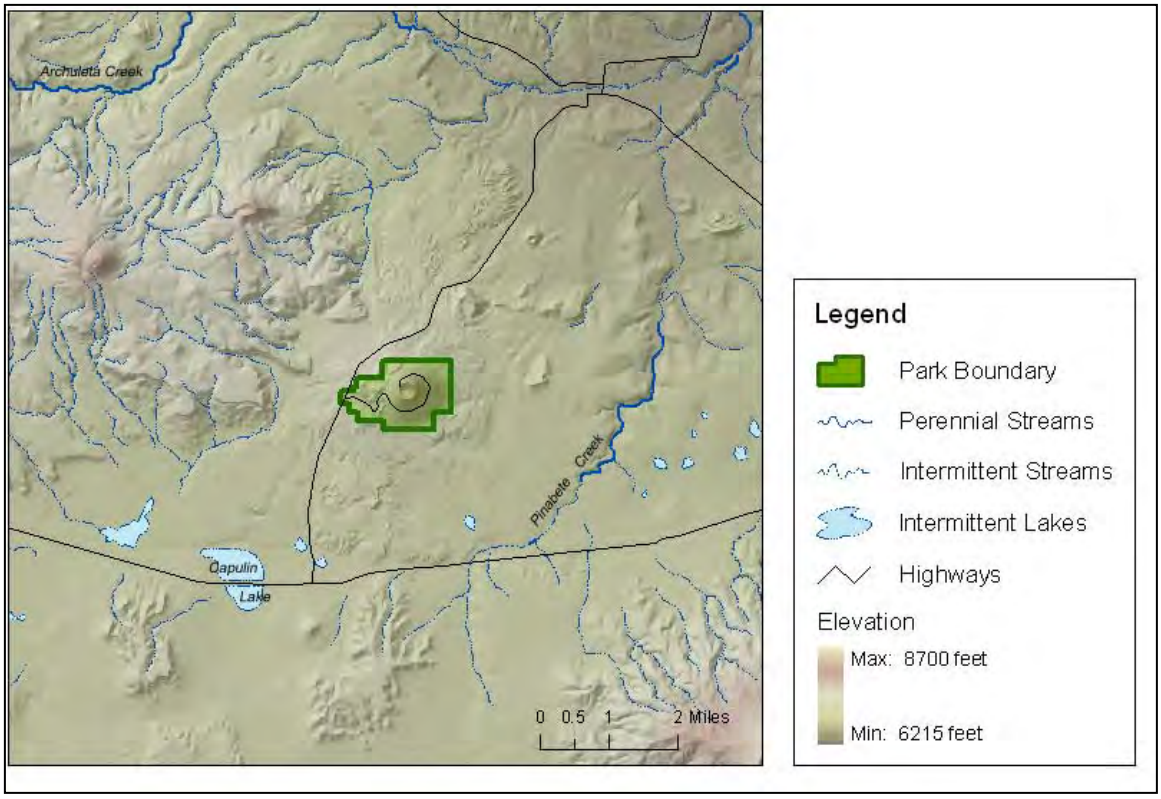



**Figure 5. Map of Capulin Volcano National Monument with water bodies highlighted.**

K.5.3.1. Background

Capulin Volcano National Monument (CAVO) is a 793-acre (321 ha) site in Northeastern New Mexico (Figure 5). Capulin Volcano was formed during its last period of activity, approximately 60,000 years ago. After eruptions ceased and substrate cooled, vegetation began to establish on the volcano and surrounding area. The root matter of the plants helped stabilize the erodible volcano; however erosion still remains a concern. There are three predominant ecosystems that comprise CAVO: piñon-juniper woodlands, which cover most of the volcano; short-grass prairies; and scrublands (Johnson et al. 2003). CAVO falls within the Great Plains-Palouse Dry Steppe ecoregion (Bailey 1995). CAVO receives 16–20 inches (41 - 51 cm) of rain annually.

K.5.3.2. Primary Water Resources

Surface waters within the boundaries of CAVO include only three sewage lagoons (NPS 1999).

K.5.3.3. Management and scientific issues

The most significant water resource issue at Capulin Volcano National Monument is the lack of water. Drought conditions over the past several years have stressed the plant and animal communities. For example, drought, which can serve as a disturbance mechanism, has contributed to exotic plant invasions. Groundwater at CAVO is facing anthropogenic threats, with potential sources being municipal wastewater discharges, ranching operations, mining and quarrying activities, stormwater runoff, recreational use, and atmospheric deposition.

K.5.3.4. Past and Present Monitoring

A basic water quality assessment was completed by the Water Resources Division of the National Park Service in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park. The Baseline Water Quality Data Inventory and Analysis Report based on this water quality assessment revealed that data is completely lacking for any

hydrologic-related parameters, such as groundwater quantity and quality, within CAVO boundaries (NPS 1999).

*K.5.4. Chickasaw National Recreation Area (CHIC)*

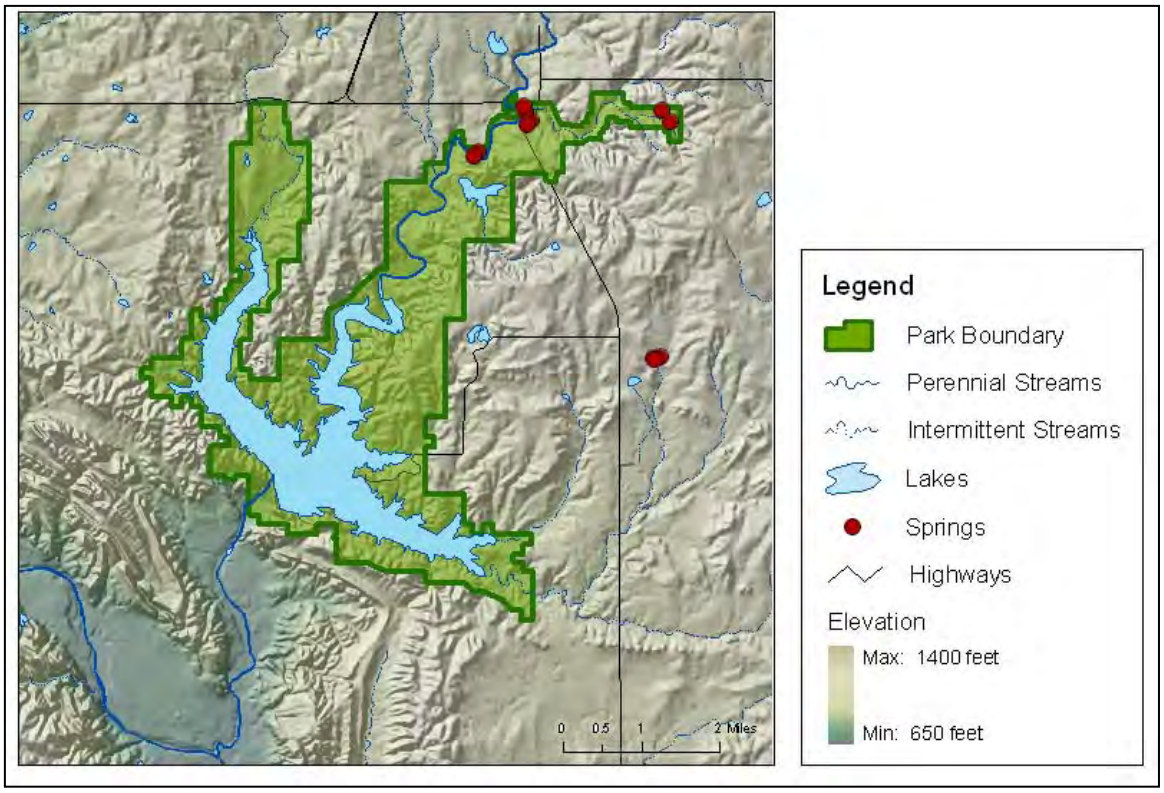



**Figure 6. Map of Chickasaw National Recreation Area with water bodies highlighted.**

K.5.4.1. Background

Chickasaw National Recreation Area (CHIC) covers 9,889 acres (4,002 ha) in south-central Oklahoma (Figure 6). In the late 1800's the Chickasaw and Choctaw Native American tribal units recognized threats to the freshwater and mineral springs and therefore requested that the federal government establish sustainable management practices (Wikle et al. 1998). This request ultimately led to the establishment of CHIC. Today, water-based recreation, such as fishing, boating, and water skiing account for the largest portion of visitation.

CHIC has a moist sub-humid climate, characterized by long warm summers and fairly short and mild winters (Wikle et al. 1998). Average annual precipitation is 38 inches (97 cm). The landscape of CHIC ranges from steep ridges to valley floors.

K.5.4.2. Primary Water Resources

The two largest surface water resources at CHIC are Lake of the Arbuckles, covering approximately 3,127 acres (1,265 ha), and Veteran's Lake, spanning an average of 67 acres (27 ha); both are man-made reservoirs. Lake of the Arbuckles was constructed in 1966 by the US Bureau of Reclamation (BOR). This lake serves recreational needs, facilitates flood control, and serves as a potential water source for local communities. Lake of the Arbuckles is supported by Rock, Guy Sandy, Buckhorn, Wilson, and Travertine Creeks, the five largest streams in CHIC. Wilson Creek, a tributary of Rock Creek, also supplies Veteran's Lake.

Dry periods are significant because of the aquifer's dependence on precipitation for recharge. It has been shown that during and after these dry periods, aquifer water levels experience a decline (Hanson and Cates 1994). It is presumed the drop in the water table has caused some of the springs in CHIC to go through prolonged no-flow periods.

K.5.4.3. Management and scientific issues

Impacts from agricultural, residential, and industrial, as well as transportation of hazardous wastes on nearby highways, and problems associated with illegal disposal sites are posing serious threats to the water quality of CHIC. Internal issues include recreational impacts, exotic plant management, and especially the importance of maintaining groundwater quality and quantity. Eutrophication is also occurring in park waters. Lake of the Arbuckles had only been in existence for ten years when it first started showing signs of eutrophication.

K.5.4.4. Present and Past Monitoring

There are currently several aquatic monitoring projects occurring at CHIC: waterflow, fish surveys, aquatic invertebrate, water quality, lake levels, spring levels, and flow. In addition, a basic water quality assessment was completed in by the Water Resources Division in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 1997).

*K.5.5. Fort Larned National Historical Site (FOLS)*

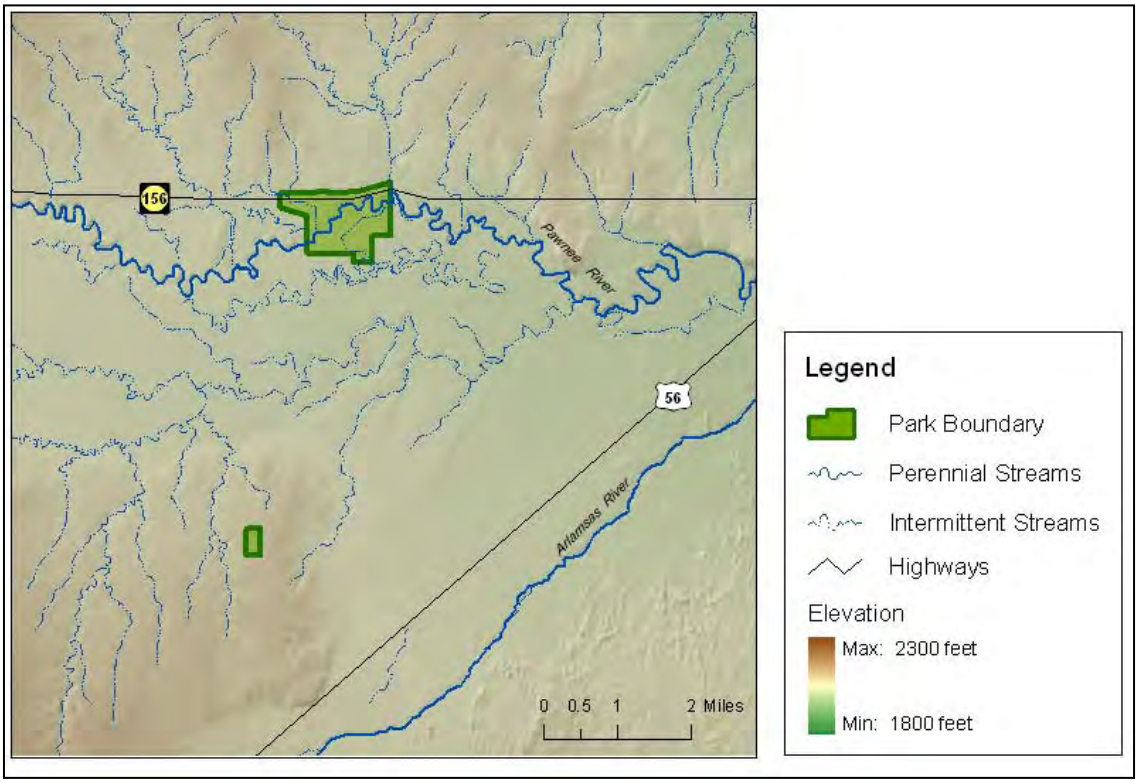



**Figure 7. Map of Fort Larned National Historic Site with water bodies highlighted.**

K.5.5.1. Background

Fort Larned National Historical Site (FOLS) encompasses 718 acres (291 ha) (Figure 7). FOLS is primarily underlain by sandstone and lies within the Central Kansas Uplift. Soils on the site belong to the Harney series, which are moderately erodable. Prior to European settlement, the landscape at FOLS was covered with mixed-grass prairie and some woodland areas, particularly in the riparian areas of the Pawnee River. With the agricultural development of the area, many changes occurred, such as the conversion of prairie to cropland, the destruction of woodlands, and more. The consequences of these changes are still a concern for Park managers today. The climate at FOLS is semi-arid with average annual precipitation of 23 inches (58 cm). Thunderstorms during the growing season contribute most of the moisture. Due to low humidity and a continual breeze, temperatures are typically moderate.

K.5.5.2. Primary Water Resources

FOLS is located along the banks of the Pawnee River and most of the lands occupying the Park are in the Pawnee River floodplain. Historically, this river was a shifting, sand-bottom stream with permanent flow (Delisle and Busby 2004). The increased use of surface and ground waters for irrigation purposes has decreased river flow; complete drying of the streambed in the summer has become common in recent years. The wet/dry climate cycle, which produces large variation in water quantity, has an effect on both the Pawnee River and groundwater recharge, which in turn affects water quality. The conversion of native grasslands to cropland increased soil erosion on the Pawnee River banks and increasing water turbidity. Installation of impoundments along the Pawnee decreased the gradient of the river and left many impounded sections.

When the fort was constructed in the 1800's, water wells were sulphurous and had a high mineral content; consequently, the Pawnee River was the primary source for drinking water. The oxbow just to the east of the fort still functioned as a wetland, capturing floodwaters and providing

filtration services. In 1938, a concrete dam was constructed just downstream from the fort, impounding six miles of stream water for agricultural use. This impounded the river within park boundaries creating a lacustrine (or ponded) environment in the river. The decreased flow of the river combined with erosion of plowed fields resulted in a silted streambed now 12 to 14 feet (3-4 m) higher than in 1860 (Fort Larned National Historic Site 1979).

A flood levee was constructed along the south side of the Pawnee River, isolating the oxbow lake from its floodplain and wetland functions. Water was then pumped into the oxbow to provide water for livestock, altering the wetland ecosystem. The oxbow lake has not been filled since 1974 (Fort Larned National Historic Site 1979) and remains cut off from the Pawnee River. As a consequence, most of the wetland vegetation has been lost (Becker et al. 1986).

Changes in stream gradient and impoundment have led to infrequent flooding, less diversity of substrates and decreased support of floodplain wetlands (Delisle and Busby 2004). These flow alterations, increased stream turbidity, increased toxin and nutrient loads and overall deterioration of water quality has led to several decades of decline in aquatic life (Becker et al. 1986).

K.5.5.3. Management and scientific issues

The highest priority aquatic resource issues at FOLS are water levels in the Pawnee River, the forested riparian community, and erosion. Groundwater contamination from faulty septic systems is also a concern. Flooding events can cause erosion, opening an avenue for invasive species. Neighboring land uses can impact both water quality and availability through water rights.

K.5.5.4. Past and Present Monitoring

Current monitoring projects at FOLS are being conducted by the Kansas Geological Survey and the Kansas Water Resource Division. A basic water quality assessment was completed by the Water Resources Division in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 2000b).

*K.5.6. Fort Union National Monument (FOUN)*

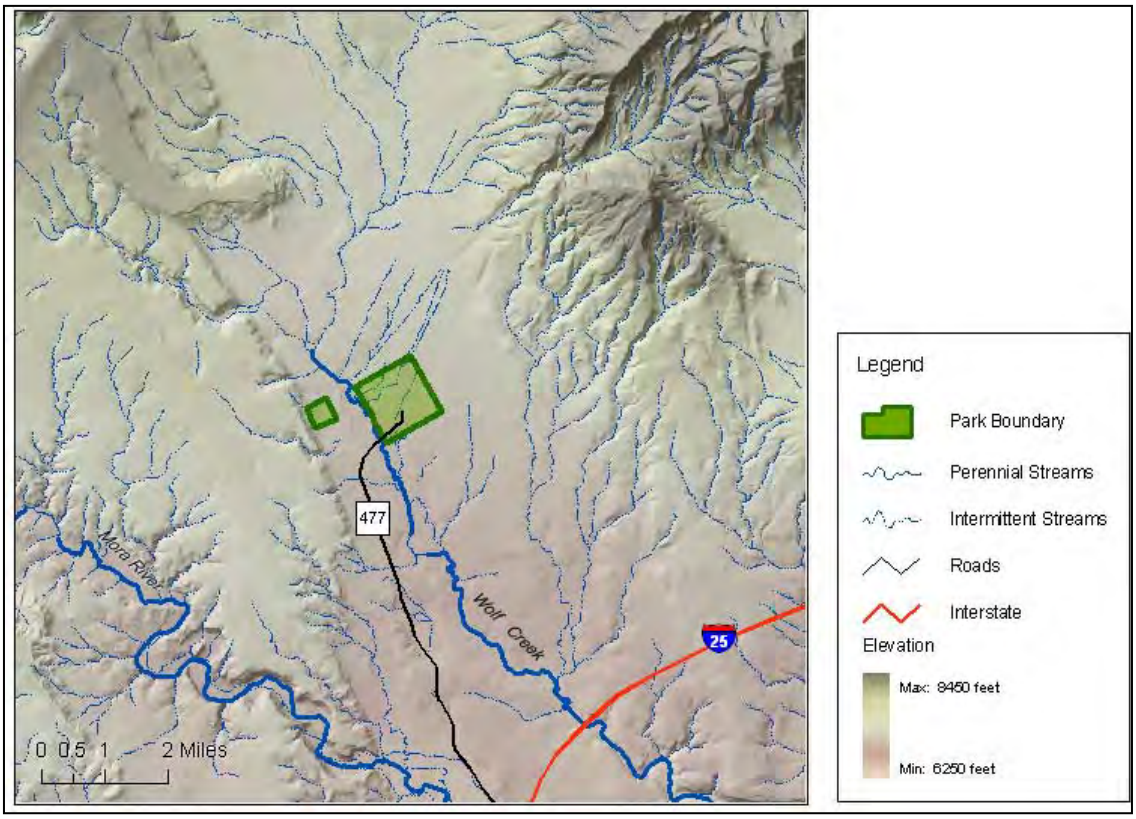



**Figure 8. Map of Fort Union National Monument with water bodies highlighted.**

K.5.6.1. Background

Fort Union National Monument (FOUN) encompasses 721 acres (292 ha) of land in two disjunct parcels of northeastern New Mexico (Figure 8). The large parcel of 637 acres (258 ha) is separated from the small parcel of 84 acres (34 ha), by a corridor of privately-owned land. This corridor, traversed by Wolf Creek, is a valley that is bounded by a 150-200 foot (46-61 m) sandstone mesa to the West and by the Turkey Mountains to the East. The small portion of the park is west of Wolf Creek while the large unit lies east of the creek, all falling within the Mora watershed district. The western-most edge of the large park unit falls within the Wolf Creek floodplain. A 96,000-acre (38,850 ha) cattle ranch that pre-dates the abandonment of the post in 1891 surrounds FOUN, however the monument has been fenced from grazing since its establishment in 1956. The climate at FOUN is semi-arid with approximately 18 inches (46 cm) of average annual precipitation, the majority of which falls during the summer monsoon season. Wind speeds in this area are often extremely high, which at times may cause soil erosion and elevated levels of aerial dust (Freitag 1994)

FOUN falls within three ecoregion-types: Southern Rocky Mountain Steppe, Open Woodland, and Coniferous Forest (Bailey 1995). The primary ecosystem present at FOUN is short-grass prairie. Soils at FOUN consist of a well-drained loam with gentle slopes (1-5%), which was derived limestone, sandstone, and basalt (Southwest Region 1984). Generally, the soils can be classified as aridic argiustols, comprised of silt and stony loams (Freitag 1994).

K.5.6.2. Primary Water Resources

Fort Union National Monument contains no surface water resources within its boundaries. However, Wolf Creek will occasionally produce small springs and seepage areas within the park.

The quality of groundwater at Fort Union is within the recommended limits set by the 1962 Public Health Service Drinking Water standards as adopted by the EPA. Analyses are made every three years by a state approved laboratory. The Park Staff collects water samples twice a month for bacteriological analyses by a state-approved laboratory. Results are consistently in compliance with health standards.

There are no permanent streams or water bodies with the boundaries of Fort Union National Monument. The small riparian area that is Wolf Creek is the principal drainage for the area. Three intermittent drainages crossing the main unit are the result of erosion of old trail ruts (Southwest Region 1984). Spring seeps occur at the western edge of the main unit, above Wolf Creek. These wetlands may likely be categorized as jurisdictional wetlands under US Army Corps of Engineers rules, both as function of species composition and soils conditions (Muldavin et. al. 2004).

K.5.6.3. Management and scientific issues

Potential anthropogenic sources of contaminants include ranching operations; recreational use; storm water runoff; and atmospheric deposition. (NPS 1998b). An additional issue that needs to be addressed is the lack of adequate baseline information on the natural resources at FOUN

K.5.6.4. Past and Present Monitoring

A basic water quality assessment was completed in 1998 by the Water Resources Division of in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 1998b).

*K.5.7. Lake Meredith National Recreation Area (LAMR)*

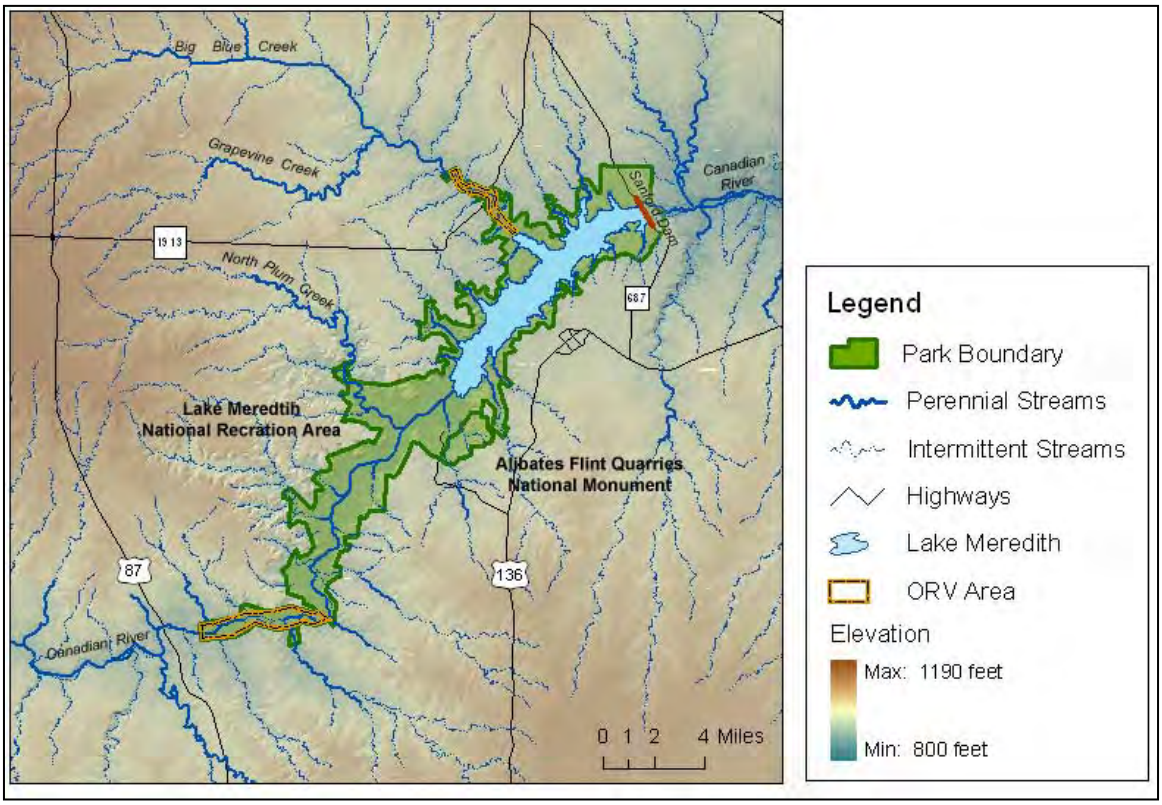



**Figure 9. Map of Lake Meredith National Recreation Area with water bodies highlighted.**

K.5.7.1. Background

Lake Meredith was formed in the 1962 when the Bureau of Reclamation constructed the Sanford Dam on the Canadian River (Figure 9). It was designated as a National Recreation Area in 1990 and the ownership transferred from the BLM to the NPS. The park is 46,349 acres (18,757 ha) in size. The lake was constructed to supply water to eleven surrounding communities, with recreational use of the area as a secondary purpose. The landscape at LAMR is characterized as rough and broken that can be divided into two distinct areas: the upland area including the mesa top with a steep, gravelly slope, and the bottomland area surrounding the reservoir. Soil groups at this site include Burson-Quinlan-Aspermont, Mobeetie-Tascosa, Acuff-Palo Duro-Olton, Tascosa Burson and Dumas-Dalhart. There are four formations of varying geologic ages that outcrop in the immediate vicinity of the recreation area – the Permian Quartermaster Formation; the Tertiary, Pliocene, Ogallala Formation; the quaternary, Pleistocene, Fluvatile terrace deposits; and the Quaternary Holocene Alluvium. The climate at LAMR is semi-arid with an average annual rainfall 20 inches (51 cm), 70% of which falls between April and September.

K.5.7.2. Primary Water Resources

Lake Meredith lies behind a 228-foot (69 m) earthfill dam built on the Canadian River. Approximately 10,000 acres (4,047 ha) in size, it is the largest lake in the Texas and Oklahoma panhandles. In addition to water recreation, visitors utilize LAMR for hunting, fishing, horseback riding, camping and more. The Canadian River flows south and southeast across the Texas panhandle. Below the dam is a perennial stream from two or more springs, but seldom flows more than 100 yards (91 m), except in periods of heavy rainfall. In the Spring Canyon area below the dam are several other small artificial lakes and a large wetland area created by seepage through Sanford Dam. The largest of these reservoirs is the Stilling Basin, which was designed to

still the water when it leaves the flood gates to prevent turbulence and severe erosion downstream. This area is considered the best swimming beach at LAMR.

The Ogallala formation is the most important water-bearing strata to LAMR and the surrounding area. This stratum supplies the region with water for farming, ranching, commercial, and domestic uses. The Ogallala is being pumped at a rate in excess of its recharge in most years, so the water table is lowered by an average rate of 2-3 feet (61-91 cm) per year. Flood hazards at Lake Meredith and Alibates include the entire peripheral area of Lake Meredith; however, the greatest potential for flood hazard to park visitors is from isolated flash floods along side drainages or from flooding on the Canadian River above Lake Meredith. Rising lake levels present little hazard as rises occur slowly. Stands of cottonwood and hackberry trees (*Celtis occidentalis*) are found in the side canyons along the lake. The varying lake levels have encouraged the encroachment of salt cedar in the floodplain areas. LAMR supports are large number of plant and animal species, including two federally listed species: the Bald Eagle (*Haliaeetus leucocephalus*) and Arkansas River Shiner (*Notropis girardi*).

K.5.7.3. Management and scientific issues

Ninety-nine percent of Lake Meredith is designated as impaired on the federal 303(d) list because of mercury contamination. Water quality and quantity are the most important concerns at LAMR. The federally listed Arkansas River shiner occurs in the Canadian River. Erosion, the invasion of exotics such as tamarisk, non- point source pollution and visitor carrying capacity are the biggest threats to water resources at the park. Reclamation of abandoned oil and gas infrastructure sites and prairie restoration can lead to improved groundwater recharge and stewardship of upland areas. These improvements in turn will provide enhanced habitats for many of the species of interest as well as resident communities. Continued pumping of the aquifer for agricultural purposes can potentially lower the water table. The water level of Lake Meredith fluctuates with floods and draw-downs and is subject to non-source point pollution (including erosion within park boundaries and elevated E. coli levels) that could contaminate the fishery.

K.5.7.4. Past and Present Monitoring

A basic water quality assessment was completed by the Water Resources Division in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 2000a). The park is need in of a heavy metals water quality assessment.

*K.5.8. Lyndon B. Johnson National Historical Park (LYJO)*

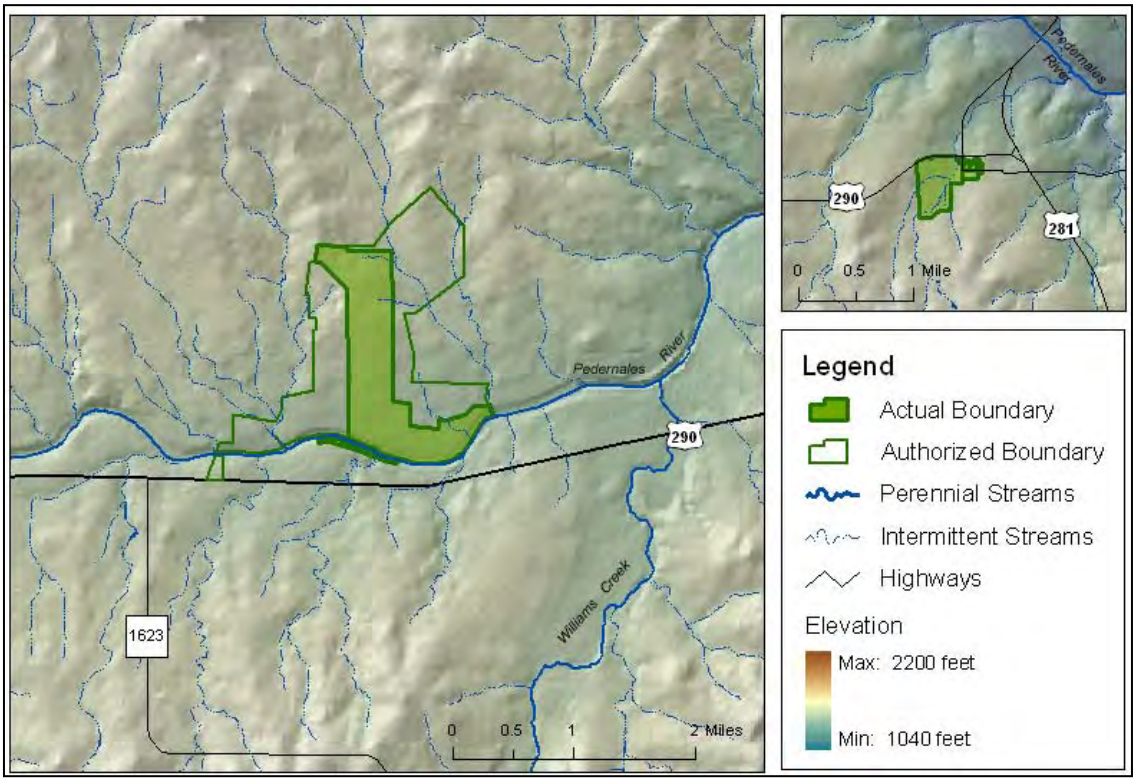



**Figure 10. Map of Lyndon B. Johnson National Historical Park with water bodies highlighted.**

K.5.8.1. Background

The park consists of two units (districts), which lie about 15 miles (24 km) from one another, situated on the Llano uplift, in the Pedernales River Valley of the central Texas Hill Country, in Blanco and Gillespie counties, respectively (Figure 10). LYJO was originally established in 1969 with a combined area of the two districts of 674 acres (270 ha). When this area of the Edwards Plateau was first settled in the mid-1800s, it contained oak savannah bisected by riparian woodland corridors and hillside slopes of ashe juniper (J*uniperus asheii*). Presently, only tiny patches of semi-natural vegetation remain at LYJO: mostly at the prairie restoration site and along Town Creek in the Johnson City District, and along the Pedernales River at the LBJ Ranch District.

The subtropical, sub-humid character of the Edwards Plateau results in a sunny, mild climate, except for summer's high humidity and 100ºF (38ºC) temperatures. Winter temperatures are usually in the 50sºF (10ºC); snow and ice are rare. Annual precipitation averages 32 inches (81 cm), with May and September the wetter months and November, December and January the driest months.

Soils of the Pedernales riverbed contain recently deposited silty and sandy alluvium derived from upstream granites and sandstones, while bottomland terraces are covered with silty and sandy alluviums. Upslope outcrops of sandstone and marly limestone have weathered to pastures of sandy loams and deep redland clay loams. The river valley is surrounded by limestone hills.

K.5.8.2. Primary Water Resources

The primary water bodies at LYJO are the Pedernales River and Town Creek. There are also a few small streams and stock ponds. Flooding along the Pedernales is an annual threat to the

park. At times, the area experiences storms that result in some of the highest precipitation rates in the US. This contributes to the severe erosion present along the river as well as flash floods that are not uncommon.

K.5.8.3. Management and Scientific Issues

One of the most important concerns for LYJO Park managers is the riverine ecosystems. Several aquatic species of concern have been documented at LYJO. Texas map turtle (*Graptemys versa*) and Guadalupe bass (*Micropterus treculii*) are both endemic to the Edwards Plateau. The American bald eagle is federally listed as threatened and is a part-time winter resident. The flood/drought cycle of the Edwards Plateau affects the plant and animal species abundance as well as water quality and quantity. Sandy alluvial soils along the streams can be easily eroded during flash flood events. The suppression of fire has encouraged the encroachment of woody species, changing the nature of the habitat, affecting groundwater recharge and possibly allowing favorable conditions for the introduction and spread of plant and insect disease. The Pedernales River valley continues to succumb to a gradual change from agriculture to development and the onset of light and sound pollution.

K.5.8.4. Past and Present Monitoring

The park has monitored water quality at two sites on the Pedernales River since 1996. The monitoring began due to concerns of high nutrient and bacteria contamination from livestock grazing on lands upstream from the ranch. The monitoring is conducted by park staff as part of the Lower Colorado River Authority (LCRA) River Watch Program. Monitoring has also been implemented on Town Creek in the Johnson City District unit in 2004. Additionally, a hydromet is being installed at the LBJ Ranch unit. A basic water quality assessment was completed by the Water Resources Division in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 2001).

*K.5.9. Pecos National Historic Park (PECO)*

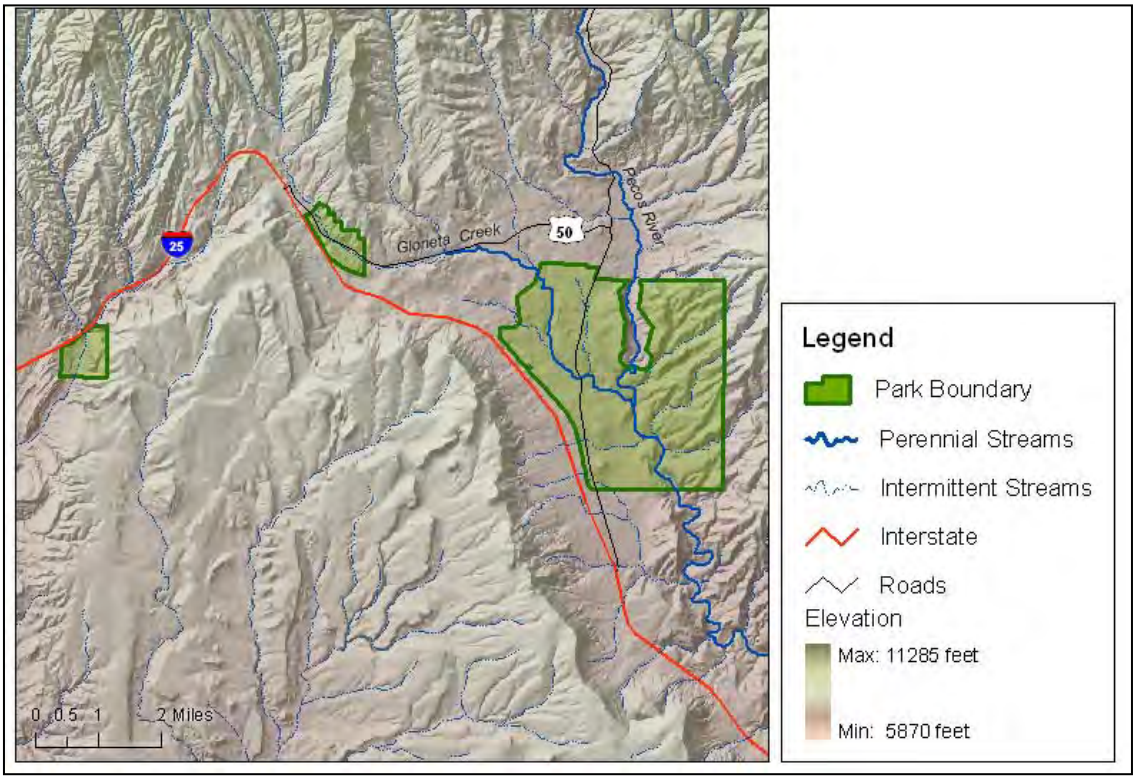



**Figure 11. Map of Pecos National Historic Park with water bodies highlighted.**

K.5.9.1. Background

Pecos National Historic Park (PECO) was designated in 1965. The 6,670-acre (2,699 ha) park is located in New Mexico, on the southern edge of the Sangre de Christo Mountains (Figure 11). Most of the park lies in the Upper Pecos River Valley at an elevation of approximately 7,000 feet (2,134 m). Annual precipitation varies from 16 to 20 inches (41-51 cm) per year, with the majority falling during the summer season. The park's predominant vegetation is piñon-juniper woodland. Neighboring conserved lands include Las Vegas NWR, Santa Fe National Forest, and Villaneuva State Park.

K.5.9.2. Primary Water Resources

Four miles of the Pecos River flows through the park. Additional surface hydrology features include Glorieta Creek, a riparian restoration area, a pond, and marshy habitats.
Water quality and availability will continue to grow in importance in the arid southwest. While the ecosystem has developed with the wet/dry climatic cycle, the capture rate of groundwater is critical.

K.5.9.3. Management and scientific issues

The highest priority water resource issues for PECO are reptile community, large carnivores, riparian community, and a migratory songbird stopover point. The Pecos River is experiencing declining water quality from upstream activities beyond the park boundary, resulting in contaminants in the fishery. Parts of the Pecos River that flow through PECO are listed on New Mexico's 303(d) list due to elevated turbidity and temperature levels. The maintenance of minimum flows and continued exclusion of livestock in both Glorieta Creek and the Pecos River will ensure the persistence of riparian vegetation necessary to many breeding birds.

K.5.9.4. Past and Present Monitoring

A basic water quality assessment was completed by the Water Resources Division in accordance with the Servicewide initiative to obtain baseline data on water resources of every Park (NPS 1995).

*K.5.10. Sand Creek Massacre National Historic Site (SAND)*

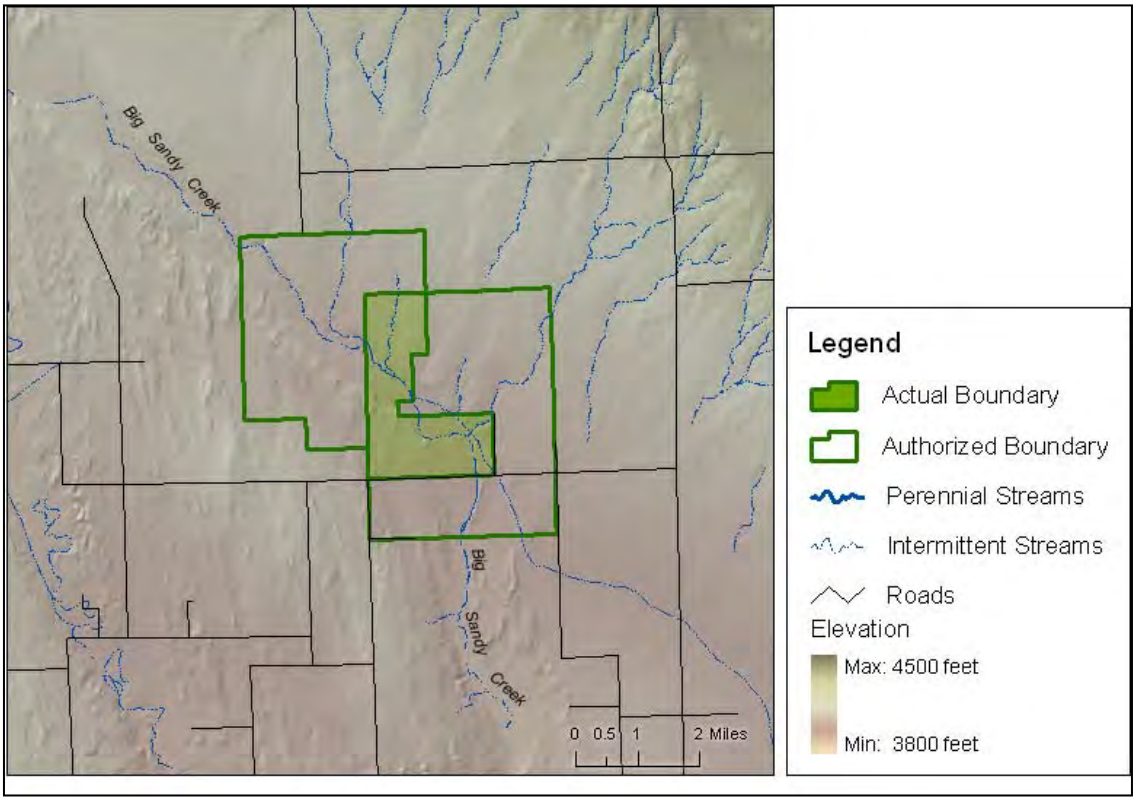



**Figure 12. Map of Sand Creek Massacre National Historic Site with water bodies highlighted.**

K.5.10.1. Background

Sand Creek Massacre National Historic Site (SAND) is a 2,400-acre (971 ha) site that lies along a 5.5 mile (8.9 km) stretch of Big Sandy Creek in southeastern Colorado (Figure 12). The climate at SAND is dry and clear with average annual precipitation of 13-14 inches (33-36 cm). The landscape of SAND is largely short-grass prairies. Trees on the site are eastern cottonwood, found in even-aged groves close to Big Sandy Creek.

K.5.10.2. Primary Water Resources

Big Sandy Creek is the primary water body found within SAND. Big Sandy Creek is an intermittently flowing stream derived from infrequent large spring/summer rainfall events. During normal and dry years, the creek does not substantially flow and has not been reliably used for potable or irrigation use. Recent observations of the creek and associated plant communities suggests that the only water normally found on the site is in creek-scoured depressions that intercept groundwater, several minor seeps, and one major perennial spring.

A narrow strip containing two types of wetlands shown on National Wetlands Inventory map borders Big Sandy Creek throughout the length of the site. A third type of wetland classification is found along the creek bed where more flow character is maintained. Four small pockets or strips of wetland are also indicated on spring and seep areas. Big Sandy Creek water quality varies throughout the year and through particular storm events because of the creek's intermittent character. It is generally of good quality although it has limitations as potable water due to high alkalinity and periodic high-suspended sediments. Groundwater quality in the area of the creek has generally been rated as fair to poor. Few water rights have been established for the surface

water of Big Sandy Creek, and none within SAND. Big Sandy Creek drains the eastern side of a broad southeasterly trending valley composed largely of Quaternary eolian sands overlaying complex and discontinuous Pleistocene sands, silts, and gravels above the chalky Smoky Hill Shale (part of the Niobrara Formation). Dune sands make up the bluffs along and extending back from the western side of the creek, while coarser (and including more silt) valley fill and slopewash materials blanket the terraces and slopes extending eastward. Along Big Sandy Creek, just south of the Dawson South Bend are deep dune and valley fill deposits. Soils along Big Sandy Creek within the floodplain are nearly level and poorly drained.

K.5.10.3. Management and scientific issues

The largest threat currently facing water resources at SAND is erosion along the streambanks. Another significant issue for SAND is the permanent wetland located on the southern edge of the park that contains the federally listed Arkansas Darter (*Etheostoma cragni*). Water resources must be monitored to preserve the upland springs, wetlands and ponds and insure water quality. The wet/dry climate cycle, which produces large variation in water quantity, has an effect on both ponds and groundwater recharge. Flooding events can cause erosion, opening an avenue for invasive species. Neighboring land uses can impact both water quality and availability through water rights. The acquisition of water and mineral rights during land purchase is of major importance. While no extractive activities are currently occurring along the proposed park boundary or within SAND, contingency plans should be developed for future use. Great Plains Reservoirs is a nearby public conservation area.

K.5.10.4. Past and Present Monitoring

Currently, Eads public works is monitoring water flow. Additional water monitoring projects have not occurred as of yet. However, with additional funding, a baseline water quality report, among other monitoring projects, shall be initiated.

*K.5.11. Washita Battlefield National Historic Site (WABA)*

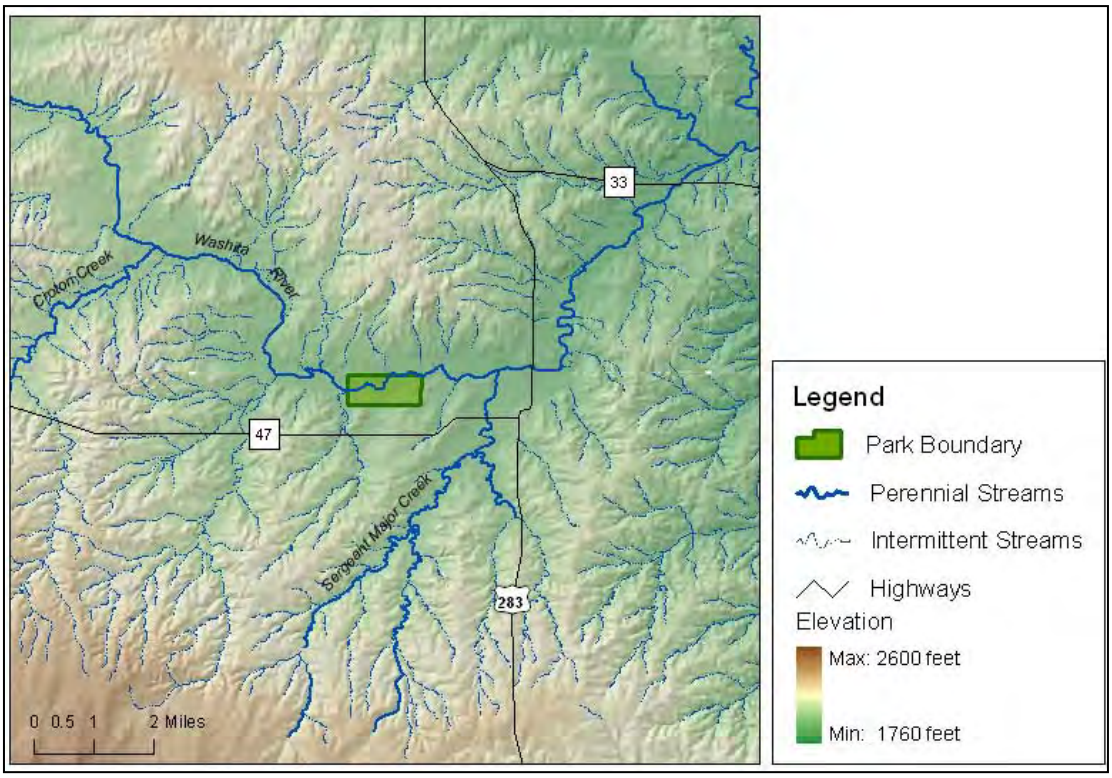



**Figure 13. Map of Washita Battlefield National Historic Site with water bodies highlighted.**

K.5.11.1. Background

Washita Battlefield National Historic Site (WABA) is a 326-acre (132 ha) site located on the banks of the Washita River (Figure 13). The climate at WABA is temperate and characterized by hot, humid summers, mild winters, relatively high wind velocities, and wide fluctuations in rainfall. Average annual precipitation is 25 inches (64 cm) with most of this occurring between April and August. The surrounding landscape is classified as dry plains, steppe with moderate valley slopes (2-20%) and a gently rolling topography (Bergey 2003). Ten distinct soil types occur within the park boundaries; in general, ranging from sands to loams. This site was drastically affected by the "Dust Bowl" in the 1930's (Inglis 2001), which likely caused changes in the local hydrology. The water resources at WABA are important to both the natural environment and the cultural landscape (Reber et al. 1999)

K.5.11.2. Primary Water Resources

The Washita River is the primary water body found within WABA. This eastward-flowing river originates in the high plains of the eastern panhandle of Texas and is a tributary to the Red River (Reber et al. 1999). It is a single-thread sand channel with moderate entrenchment, width/depth ratio, and sinuosity (Inglis 2001). Water depth of the Washita River typically ranges between 4-6 inches (10-15.5 cm) and the channel width is 8-10 feet (2.4-3 m). WABA falls within the Washita Headwaters Watershed, a catchment that is predominantly covered by agricultural land (Andrews 1998).

Currently, the Washita River is considered an undersized stream having a wide valley-bottom floodplain (Inglis 2001) and stream characteristics discordant with its watershed conditions. The unbalanced river conditions today are likely a result of the landscape desertification that occurred in the 1930s' "Dust Bowl". Soil dessication during that time caused high amounts of sedimentary wash-out to the Washita River. Further affecting the river, in the 1950's, numerous flood

control/water conservation structures were designed on tributaries of the Washita. These dams have decreased peak flows along the river. Other contributing factors to the current state of the Washita River are the cultivation and irrigation of croplands, the construction and use of paved roads, the building of residential homes, the introduction of cattle ranching, and the process of oil well operations (Andrews 1998). An on-going goal of WABA is to restore this site to its natural conditions (pre-1860's).

A beaver pond on the western edge of the park has served as a sediment settling pond, resulting in a sandy river bed below the beaver dam. Water salinity is elevated, particularly during the low flow periods of summer. All pools lack the coarser gravels and aquatic plants necessary for a ranking above suboptimal in a recent bioassessment (Bergey 2003).

Groundwater in the vicinity of WABA is generally hard and may contain excessive dissolved solids. Sulfate concentrations are often above the recommended drinking limit and in some cases chloride concentrations may also be high (Washita Battlefield National Historic Site 2001). Groundwater depth varied within the boundaries of WABA, from an average of 18 feet (5 m) below the upland prairie to only 5 feet (2 m) deep on the floodplain.

K.5.11.3. Management and scientific issues

The greatest threats to the water resources at WABA include the effects of dams and silt build-up in the Washita River, both of which decrease the river flow, and water contamination. There are several potential pollutants to the Washita River and the alluvial aquifer in which the river lies (e.g., nutrients, pesticides, petroleum hydrocarbons, bacteria, and metals). An additional concern to WABA is the waste pit facility located 2 miles (1.2 km) west of the park. Until recently, the facility consisted of a commercial saltwater disposal well, primarily used for the injection of saline wastes produced by oil and gas mining. This facility is currently expanding its operations and will add waste fields as close as ¼ mile (0.4 km) up slope from the Washita River (Bergey 2003).

Surrounding land use presents challenges to WABA as the potentially negative effects of these practices are largely beyond the control of Park managers (Inlgis 2001). However, the Park is taking measures to restore the area to the most natural state as possible. The park has removed irrigation wells, replaced cropland with native mixed-grass prairie vegetation, and removed invasive shrubs along the river (Andrews 1998).

Invasive non-native plant species are becoming a problem in the riparian zone of the Washita River are affecting water quality and quantity. Some of the invaders are upland species that consume large amounts of soil water. The invasion of tamarisk, in particular, is drastically reducing the soil water content. This lowers the river flow and creates river bank instability (Inglis 2001).

The Washita Battlefield National Historic Site has riparian water rights for domestic use, not to exceed five acre-feet per year. The park has appropriated all existing groundwater rights that were formerly held by the previous owners. Seven permits for the appropriation rights of groundwater are held by upstream and downstream owners (Washita Battlefield National Historic Site 2001). Results of the recent hydrological assessments at WABA imply that the water resources within the park are sub-par. A baseline water quality report is needed for managers to have data on which to base their restoration and management plans.

K.5.11.4. Past and Present Monitoring

The USGS has gauged the Washita River at a station approximately 2 miles (1.2 km) downstream from WABA for over 60 years. In addition, they collected water-quality samples at the gauging station twice a year from the mid 1930's until 1990. Furthermore, a water quality assessment was performed by the USGS in 1998, in which the Washita River was sampled. An evaluation of the functional condition of the Washita River was performed in 2001 by the Water Operations Branch (WOB) of the Water Resource Division (WRD).

## K.6. ACKNOWLEDGEMENTS

We would like to thank the Southern Plains Network Technical Committee for their cooperation in the scoping interviews. Much of the information provided in the park narratives of this appendix was derived from the scoping interviews. Also, we would like to thank Dr. Timothy Seastedt for his helpful comments during the development of this document. Furthermore, we would like to recognize that portions of this appendix were adapted from water quality reports from other networks such as SCPN, NCCN, NCBN, and SODN.

## K.7. LITERATURE CITED

Andrews, W.J. 1998. Workplan for Assessment of Water Quality in the Washita River at the Washita Battlefield NHS near Cheyenne, OK. U.S. Geological Survey and National Park Service.

Bailey, R.G. 1995. Description of the Ecoregions of the United States. 2nd ed. rev, with separate map at 1:7,500,000. USDA Forest Service, Washington, DC.

Bailey, R.G. 2001. Regional Landscape Ecology and Sustainable Design, Springer-Verlag, Inc., New York.

Becker, D.A., T.B. Bragg, and D.M. Sutherland. 1986. Prairie Management Plan, Vegetation Survey, Fort Larned NHS.

Bergey, E.A., Oklahoma Biological Survey. 2003. Aquatic invertebrates and fishes of the Washita River in the Washita Battlefield NHS: Final Report.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pp. 155-165 in W. J. Matthews and D. C Heins, eds. Communitiy and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Delisle, J.M. and W.H. Busby, Kansas Natural Heritage Program. 2004. Biological inventory for vertebrates at Fort Larned NHS of the Southern Plains Network.

Dugan, J. T., T. McGrath, and R. B. Zelt. 1994. Water-level changes in the High Plains aquifer predevelopment to 1992. U.S. Geological Survey Water-Resources Investigations Report 94-4027. 34 pp.

EPA 2002. Integrated Water Quality Monitoring and Assessment Report Guidance. http://www.epa.gov/owow/tmdl/2002wqma.html

EPA 2000. National Water Quality Inventory 2000. www.epa.gov/305b/2000report

Fort Larned National Historic Site, Midwest Regional Office. 1979. Assessment of alternative natural resources management for Fort Larned NHS.

Freitag, A.L. 1994. Cultural Landscape Study of Fort Union NM. University of Pennsylvania publishing.

Gionfriddo, J.P., D.R. Culver, and J. Stevens. 2002. Biological Survey of Bents Old Fort NHS, Otero County, CO.

Hanson, R.L. and S.W. Cates. 1994. Hydrogeology of the Chickasaw NRA, Murray County, OK. US Geological Survey Water-Resources Investigations Report 94-4102.

Huntzinger, T. L. 1996. Surface water: a critical Great Plains resource. In S. Johnson and A. Bouzaher, editors. Conservation of Great Plains ecosystems: current science, future options. Kluwer Academic Press, Dordrecht, The Netherlands.

Inglis, R. 2001. Trip report for travel to Washita Battlefield. July 16-19, 2001. Water Resources Division.

Johnson, K., G. Sadoti, G. Racs, J. Butler, and Y. Chauvin. Natural Heritage New Mexico. 2003. National Park Service Southern Plains Network: Final Inventory Report for New Mexico Parks.

Koplin, D. W., M. R. Burkart, and E. M. Thurman. 1994. Herbicides and nitrate in near-surface aquifers in the midcontinental United States, 1991. U.S. Geological Survey Water-Supply Paper 2413. 34 pp.

Kromm, D.E., and S.E. White. 1992. Groundwater Exploitation in the High Plains, Lawrence: University Press of Kansas.

Ladyman, J.A. 2003. Bent's Old Fort National Historic Site Vegetation Restoration Management Plan. Centennial, CO.
Longo, P. J., and D. W. Yoskowitz. 2002. Water on the Great Plains: issues and policies. Texas Tech U., Lubbock. 200pp.
Muldavin, E., Y. Chauvin, A. Browder, and T. Neville. 2004. A vegetation survey and map of Fort Union NM, NM.
National Park Service. 1995. Baseline water quality data inventory and analysis: Pecos National Historical Park. Water Resources Division, Technical Report NPS/NRWRD/NRTR-95/66, Washington, DC.
National Park Service. 1997. Baseline water quality data inventory and analysis: Chickasaw National Recreation Area. Water Resources Division, Technical Report NPS/NRWRD/NRTR-97/146. Washington, DC.
National Park Service. 1998a. Baseline water quality data inventory and analysis: Bent's Old Fort National Historic Site. Water Resources Division, Technical Report NPS/NRWRD/NRTR-98/165. Washington, DC.
National Park Service. 1998b. Baseline water quality data inventory and analysis: Fort Union National Monument. Water Resources Division, Technical Report NPS/NRWRD/NRTR-98/176, Washington, DC.
National Park Service. 1999. Baseline water quality data inventory and analysis: Capulin National Monument. Water Resources Division, Technical Report NPS/NRWRD/NRTR-99/207. Washington, DC.
National Park Service. 2000a. Baseline water quality data inventory and analysis: Lake Meredith National Recreation Area. Water Resources Division, Technical Report NPS/NRWRD/NRTR-99/245, Washington, DC.
National Park Service. 2000b. Baseline water quality data inventory and analysis: Fort Larned National Historic Site. Water Resources Division, Technical Report NPS/NRWRD/NRTR-98/229, Washington, DC.
National Park Service. 2001. Baseline water quality data inventory and analysis: Lyndon B. Johnson National Historical Park. Water Resources Division, Technical Report NPS/NRWRD/NRTR-2000/271, Washington, DC.
Reber, J., M. Flora, and J. Harte. 1999. Washita Battlefield NHS, OK, Water Resources Scoping Report: National Park Service, Technical Report NPS/NRWRS/NRTR-99/235.
Southwest Region. 1984. General management plan/environmental assessment, Fort Union National Monument, Mora county, New Mexico. Draft. National Park Service. Santa Fe, NM.
Washita Battlefield National Historic Site. 2001. Resource management plan – Washita Battlefield National Historic Site.
Wikle, T., M. Nicholl, T. Brown, J. Nord, R. Parker, and D. Weeks. 1998. Water resources management plan for Chickasaw NRA.

# AIR QUALITY AND AIR QUALITY RELATED VALUES MONITORING CONSIDERATIONS FOR THE SOUTHERN PLAINS NETWORK

**April 2005**

## Introduction

The Southern Plains Network (SOPN) of the National Park Service (NPS) Inventory and Monitoring Program includes Alibates Flint Quarries National Monument (NM), Bent's Old Fort National Historic Site (NHS), Capulin Volcano NM, Chickasaw National Recreation Area (NRA), Fort Larned NHS, Fort Union NM, Lake Meredith NRA, Lyndon B. Johnson NHP, Pecos NHP, Sand Creek Massacre NHS, and Washita Battlefield NHS. All of the network units are Class II air quality areas. Air quality and related information for the network is at http://www2.nature.nps.gov/air/Permits/ARIS/networks/index.htm.

Although most of the park units in the network are some distance from cities and pollution sources, many experience occasional poor air quality from pollutants such as ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxics. These air pollutants affect, or have the potential to affect, air quality and natural resources in SOPN, including vegetation, wildlife, soils, water quality, and visibility. High levels of ozone in the area, for example, may affect vegetation, as well as the health of park visitors and staff. Nitrogen compounds from the atmosphere have the potential to affect water quality and biota, soil nutrient cycling and plant species composition. Pollutant particles in the air reduce visibility in the region and affect how far and how well we can see. Atmospheric deposition of toxic organic compounds and metals, including mercury, may have a wide range of effects on fish and wildlife. The following sections describe air pollutant emissions, air quality monitoring, and air pollutant concerns for resources in the network.

## Air Pollutant Emissions

Air quality in the network is affected primarily by air pollution sources in Texas, Oklahoma, New Mexico, Colorado, and Kansas, although more distant sources can also affect the area's air quality. Air pollutant emissions come from a variety of sources, including mobile sources (e.g., cars, trucks, off-road vehicles), stationary sources (e.g., power plants and industry), and area sources (e.g., agriculture, fires, and road dust).

Some of the most common and abundant pollutant emissions include nitrogen oxides, ammonia, and sulfur dioxide. Figure 1 shows distribution maps for emissions of nitrogen oxides, ammonia, and sulfur dioxide in Texas, Oklahoma, New Mexico, Colorado, and Kansas. Major sources of nitrogen oxides include cars and other mobile sources, compressors, power plants and industry. Agricultural activities are the main sources of ammonia. The major sources of sulfur dioxide are coal-burning power plants, industry, and diesel engines. Additional information on pollutant sources can be found at http://www.epa.gov/air/data/index.html.

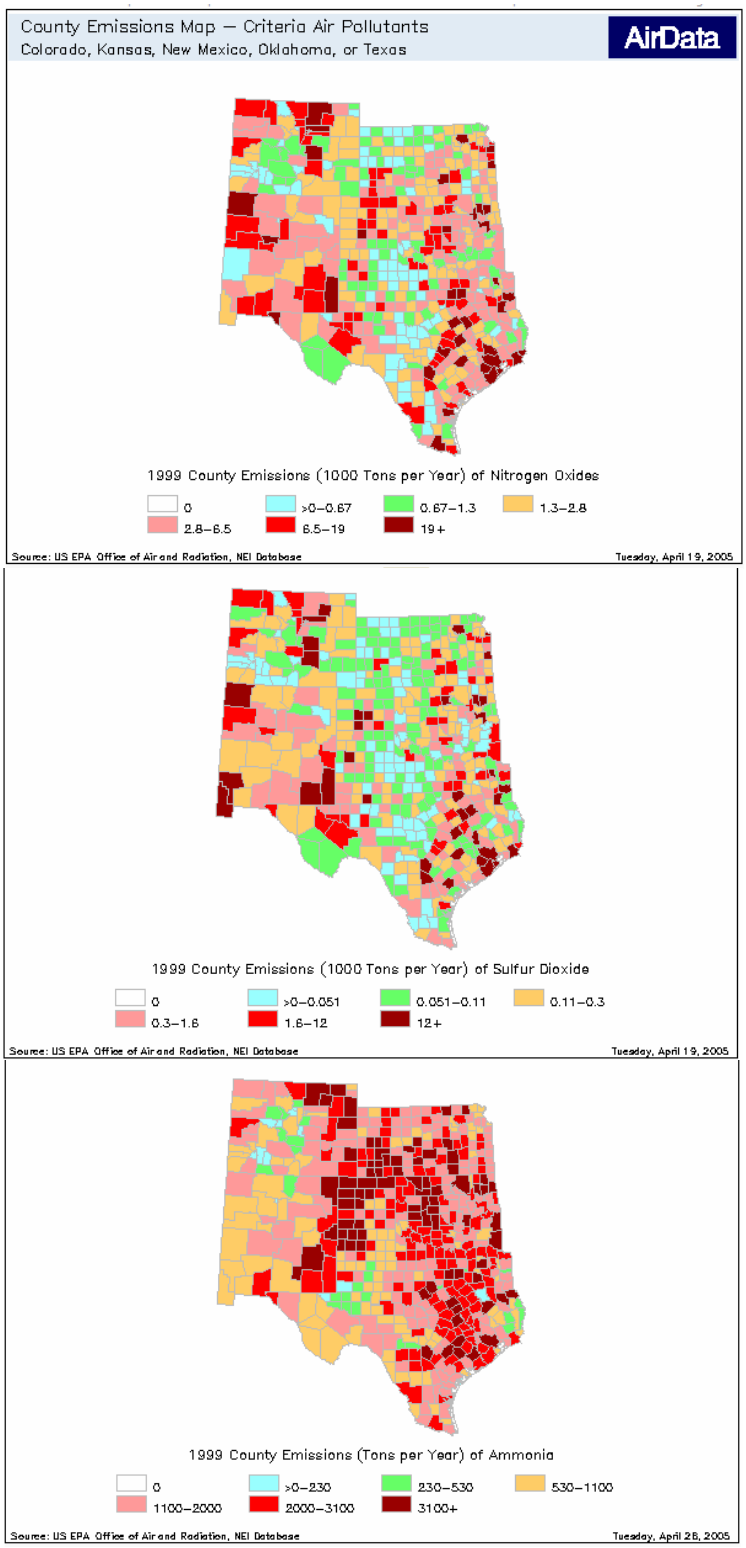



**Figure 1. Air pollutant emissions of nitrogen oxides, ammonia, and sulfur dioxide, by county, in Texas, Oklahoma, New Mexico, Colorado, and Kansas.** Emissions are given in thousands of tons per year for nitrogen oxides and sulfur dioxide and tons per year for ammonia (from EPA AirData at http://www.epa.gov/air/data/index.html).

## Air Quality Monitoring and Effects

Figure 2 shows current air quality monitoring near SOPN park units. Table 1 lists air quality monitoring site locations. There are no air quality monitors in the units, but nearby monitors may be representative of conditions in the network units. Types of monitoring include ozone monitoring by States (Ozone); wet deposition (rain, snow) monitoring of atmospheric pollutants by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN); wet deposition monitoring of mercury by the Mercury Deposition Network (MDN); dry deposition (dryfall) monitoring of atmospheric pollutants by the Clean Air Status and Trends Network (CASTNet); and visibility monitoring by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program.

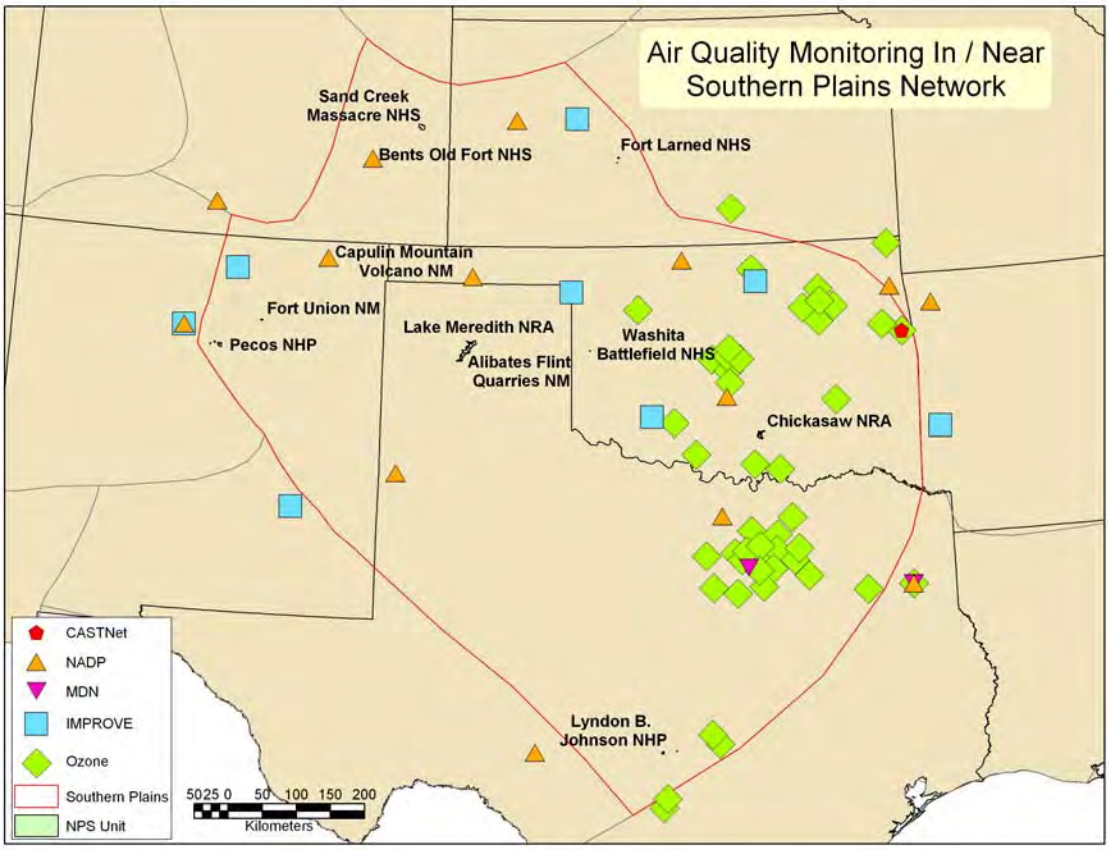



**Figure 2. Air quality monitoring in SOPN** (CASTNet= Clean Air Status and Trends Network; NADP= National Atmospheric Deposition Program; MDN=Mercury Deposition Network; IMPROVE=Interagency Monitoring of Protected Visual Environments; Ozone=ozone monitoring by States.

**Table 1. Current air quality monitoring sites near NPS units in SOPN.** Air quality data is available from the monitoring network websites listed below. Data from distant monitors are unlikely to be representative of conditions in a park unit; Air Atlas estimates should be used in these cases. Air quality estimates for SOPN park units are available from NPS Air Atlas at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm.

| MONITORING NETWORK | SITE I.D. | LOCATION |
|---|---|---|
| **CASTNet** | CHE185 (Cherokee Nation) | Adair County, OK |
| **NADP** | CO00 (Alamosa)<br>CO01 (Las Animas Fish Hatchery)<br>KS32 (Lake Scott State Park)<br>NM07 (Bandelier National Monument)<br>OK29 (Goodwell Research Station)<br>OK00 (Salt Plains National Wildlife Refuge)<br>OK17 (Great Plains Apiaries)<br>TX02 (Muleshoe National Wildlife Refuge)<br>TX56 (LBJ National Grasslands)<br>TX21 (Longview)<br>TX16 (Sonora)<br>AR27 (Fayetteville) | Alamosa, CO<br>Bent County, CO<br>Scott County, KS<br>Los Alamos County, NM<br>Texas County, OK<br>Alfalfa County, OK<br>McClain County, OK<br>Bailey County, TX<br>Wise County, TX<br>Gregg County, TX<br>Edwards County, TX<br>Washington County, AR |
| **MDN** | TX50 (Fort Worth)<br>TX21 (Longview)<br>OK15 (Newkirk) | Tarrant County, TX<br>Gregg County, TX<br>Kay County, OK |
| **IMPROVE** | CEBL1 (Cedar Bluff)<br>CHER1 (Cherokee Nation)<br>ELLI1 (Ellis)<br>WIMO1 (Wichita Mountains NWR)<br>SACR1 (Salt Creek NWR)<br>BAND1 (Bandelier National Monument)<br>WHPE1 (Wheeler Peak)<br>ELDO1 (El Dorado Springs) | Trego County, KS<br>Kay County, OK<br>Ellis County, OK<br>Comanche County, OK<br>Grant County, NM<br>Los Alamos County, NM<br>Taos County, NM<br>Cedar County, MO |
| **Ozone** | | There are a number of ozone monitors located near Oklahoma City (OK), Tulsa (OK), Dallas/Ft. Worth (TX), Austin (TX), and San Antonio (TX) |

NADP/NTN = National Atmospheric Deposition Program at http://nadp.sws.uiuc.edu/
MDN = Mercury Deposition Network at http://nadp.sws.uiuc.edu/mdn/
CASTNet = Clean Air Status and Trends Network at http://www.epa.gov/castnet/
IMPROVE = Interagency Monitoring of Protected Visual Environments at http://vista.cira.colostate.edu/views/
Ozone = EPA AirData at http://www.epa.gov/air/data/index.html or NPS AirWeb at http://www2.nature.nps.gov/air/data/index.htm

*Air Quality Estimates: Air Atlas*

NPS Air Resources Division has developed Air Atlas to provide estimates of air quality conditions for park units without on-site monitoring (http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm). Air Atlas serves as the air inventory for parks and is a mini-GIS tool that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. An update with 1999-2003 data will be available in summer 2005.

The estimated air quality values provided in Air Atlas are based on the center of the polygon defining the park or multiple units of the park. Data from all available monitors operated by NPS, States, EPA, and other programs are used for the interpolation of the air quality values.

Air Atlas contains a comprehensive set of air quality parameters. Table 2 summarizes selected air quality parameters for SOPN.

**Table 2. Estimates of selected air quality parameters for units of SOPN** (from Air Atlas at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm). Sand Creek Massacre NHS and Washita Battlefield NHS are not included in the currently available Air Atlas estimates because these units were not originally part of the SOPN.

| SOUTHERN PLAINS NETWORK | | Ozone ---------- | | | | | NADP (kg/ha/yr) ===: | | Visibility - IMPROVE | |
|---|---|---|---|---|---|---|---|---|---|---|
| PARK | CLASS | 2ndHi1hr | 4thHi8hr | #8hr>85 | #1hr>100 | Sum06_3Mo | Total S | Total N | $b_{ext}$Clear | $b_{ext}$Hazy |
| Alibates Flint Quarries NM | 2 | 104.4 | 77.9 | 3.5 | 7.1 | 21.9 | 1.44 | 2.51 | 8 | 34 |
| Bent's Old Fort NHS | 2 | 98.4 | 71.8 | 1.7 | 2.2 | 8.7 | 1.32 | 2.69 | 7 | 26 |
| Capulin Volcano NM | 2 | 92.6 | 68.8 | 0.7 | 0.9 | 10.7 | 1.18 | 2.14 | 7 | 26 |
| Chickasaw NRA | 2 | 122.4 | 90.0 | 9.3 | 23.0 | 24.2 | 2.56 | 3.05 | 18 | 97 |
| Fort Larned NHS | 2 | 106.6 | 78.9 | 3.4 | 5.3 | 21.2 | 2.12 | 3.75 | 9 | 44 |
| Fort Union NM | 2 | 88.6 | 68.0 | 0.2 | 0.3 | 16.3 | 1.14 | 1.81 | 8 | 27 |
| Lake Meredith NRA | 2 | 102.6 | 76.7 | 3.0 | 5.7 | 21.9 | 1.44 | 2.5 | 8 | 34 |
| Lyndon B. Johnson NHP | 2 | 126.8 | 89.2 | 8.9 | 24.9 | 17.4 | 2.02 | 2.12 | 13 | 60 |
| Pecos NHP | 2 | 89.4 | 68.2 | 0.2 | 0.2 | 15.8 | 1.13 | 1.71 | 8 | 27 |

Class: refers to an area's designation under the Clean Air Act
Ozone information represents 5-yr average of annual values from 1995-1999
2nd High 1 hr concentration (ppb): indicates peak values for ozone; old standard of 0.12 ppm (120 ppb) was based on 2nd hi,1-hr average
4th high 8 hr concentration (ppb): new ozone standard of 0.08 ppm (80 ppb) is based on 4th hi, 8-hr average
#8 hours>85 ppb: indicates how often the area would be in violation of the new 8-hr standard of 0.08 ppb
# hours> 100 ppb: high peaks in ozone concentration, as well as cumulative dose, contribute to vegetation injury
SUM06_3mon (ppm-hrs) - sum of hourly ozone conc.≥0.06 ppm (60 ppb) over 3 months (~ growing season), i.e., cumulative ozone dose
NADP information represents 6-yr average of annual values from 1995-2000
NADP deposition (kg/ha/yr): estimate of pollutants deposited to ecosystem by precipitation (NADP-National Atmospheric Deposition Program)
NADP Total S - sulfur from sulfate deposited by precipitation
NADP Total N - inorganic nitrogen (ammonium plus nitrate) deposited by precipitation
Visibility IMPROVE information represents 5-yr average of annual values from 1995-1999
bextClear - measure of light scattering and absorption, i.e., extinction, by particles in the air on an average clear day
bextHazy - measure of light scattering and absorption, i.e., extinction, by particles in the air on an average hazy day

*Wet Deposition Monitoring of Atmospheric Pollutants*

Estimates of wet deposition for park units is available from Air Atlas. Figure 2 shows locations of NADP/NTN wet deposition samplers near SOPN units. Table 1 lists the site identification codes and locations. NADP/NTN collects data on both pollutant deposition (in kilograms per hectare per year – kg per ha per yr) and pollutant concentration (in microequivalents per liter – µeq per L). Deposition measurements are useful because they give an indication of the total annual pollutant loading at the site. However, deposition varies with the amount

of annual precipitation. Concentration measurements are independent of precipitation amount; therefore, concentration provides a better indication of whether ambient pollutant levels are increasing or decreasing over time, despite rainfall fluctuations. In general, wet deposition and concentration of sulfate, nitrate, and ammonium are low in the western U.S. relative to the Midwest and East. Pollutant deposition in the SOPN is consistent with this pattern. A trend analysis of 1994-2003 data indicates that sulfate concentrations are decreasing at many sites in the West; however, nitrate and ammonium concentrations are increasing at many sites (Appendix A, figures A.1-A.3).

*Dry Deposition Monitoring of Atmospheric Pollutants*

Estimates of dry deposition for park units are available from Air Atlas. There is only one dry deposition CASTNet sampler near the SOPN (figure 2, table 1), and it is located close to the eastern border of Oklahoma and may not be representative of SOPN units.

*Total Atmospheric Deposition*

When assessing ecosystem impacts from atmospheric deposition it is desirable to have estimates of total deposition, that is, wet plus dry deposition plus cloud/fog deposition. Cloud and fog deposition are not likely to be significant in the SOPN; total deposition can be estimated from wet plus dry deposition. However, the dry deposition data record at CHE185 is incomplete. In the lack of dry deposition data, total deposition can be estimated by assuming that dry deposition rates are approximately equal to wet deposition rates and therefore,

**Total deposition = 2 (wet deposition)**

NADP/NTN estimates of wet inorganic nitrogen deposition (nitrate plus ammonium) for 2003 (http://nadp.sws.uiuc.edu/lib/data/2003as.pdf) range from approximately 1.5-3.5 kg per ha per year in the SOPN area, so that:

**Total inorganic N deposition = 3-7 kg per ha per year**

NADP/NTN estimates of wet sulfur deposition for 2003 range from approximately 0.3-0.5 kg per ha per year in the SOPN area, so that:

**Total inorganic N deposition = 0.6-1 kg per ha per year**

These estimates suggest that deposition of both nitrogen and sulfur are elevated above natural levels of deposition. Estimates of natural deposition for either sulfur or nitrogen in the West are approximately 0.2 kg per ha per yr.

*Atmospheric Deposition Effects to Ecosystems*

Atmospheric deposition of nitrogen and sulfur compounds can affect water quality, soils, and vegetation. Both nitrogen and sulfur emissions can form acidic compounds (e.g., nitric or sulfuric acid); when deposited into ecosystems with low buffering capacity, acidification of waters or soils can occur. Park units in the SOPN are unlikely to be sensitive to acidification because of high amounts of buffering cations, such as calcium and magnesium, in their soils and waters.

Deposition of nitrogen compounds can also have a fertilization effect on waters and soils. In some areas of the country, elevated nitrogen deposition has been shown to alter soil nutrient cycling and vegetation species composition. Arid ecosystems, typical of SOPN ecosystems, are often nitrogen-limited. Over time, excess nitrogen deposition may cause native plants that have adapted to nitrogen-poor conditions to be out-competed and replaced by nitrogen-loving nonnative grasses and other exotic species. In addition to changes in species composition, there may be increases in productivity, resulting in increased biomass (i.e., fuel loading) and fire frequency.

*Ground-level Ozone Monitoring*

Estimates of ozone peak concentrations and exposure metrics for SOPN park units can be obtained from AirAtlas. There are no ozone monitors in any of the units; however, State and local air quality agencies operate a number of ozone monitors near SOPN park units (figure 2). Most of these monitors are placed to characterize ozone concentrations in urban areas, including Tulsa, Oklahoma City, Dallas/Ft. Worth, Austin, and San Antonio.

Data from these monitors has been used by the States and EPA to determine compliance with the EPA ozone health standard (based on an 8-hr averaging period). Part or all of 474 counties nationwide are designated as nonattainment for either failing to meet the 8-hour ozone standard or for causing a downwind county to fail (Figure 4). Nonattainment areas include the Dallas/Ft. Worth metropolitan area and San Antonio. States are required to develop plans to bring these areas into compliance with the standard. A trends analysis for 1994-2003 indicates that ozone is increasing in many areas of the West (Appendix A, figure A.4).

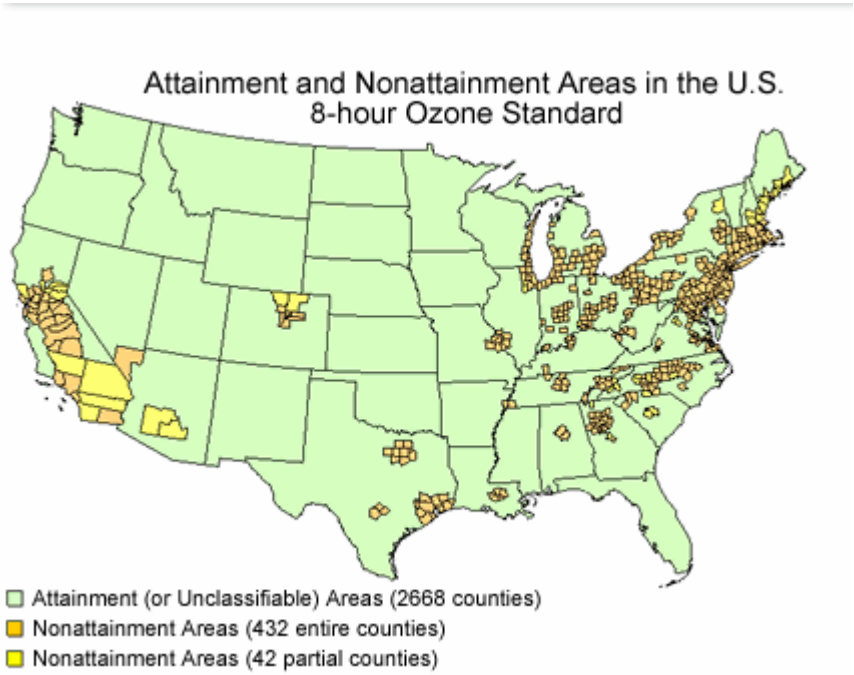



**Figure 5. Attainment and nonattainment areas in the U.S. for the 8-hr ozone standard** (from http://www.epa.gov/oar/oaqps/glo/designations/index.htm).

Ground-level ozone is produced by the reaction of nitrogen oxides ($NO_x$) and volatile organic compounds (VOCs) in the presence of sunlight. Ozone is a strong oxidant. Upper-atmospheric ozone (i.e., stratospheric ozone) acts as a protective shield against ultraviolet radiation; ground-level ozone (i.e., tropospheric ozone) is harmful to human health and vegetation. Although ground-level ozone is principally an urban problem, it and its precursor emissions can travel long distances, resulting in elevated ozone levels in national park units. Power plants, automobiles, and factories are the main anthropogenic emitters of nitrogen oxides. Vehicles and industries also emit VOCs. Natural biogenic VOC emissions are also significant in some geographic areas.

Ozone affects human health, causing acute respiratory problems, aggravation of asthma, temporary decreases in lung capacity in some adults, inflammation of lung tissue, and impairment of the body's immune system. Chamber studies have shown ozone effects to birds and other wildlife. However, these effects to birds and wildlife have not been demonstrated in the wild. Effects to vegetation have been widely documented and ozone is one of the most widespread pollutants affecting vegetation in the U.S. Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. Long-term exposures can result in shifts in species composition, with ozone tolerant species replacing intolerant species.

Research shows that some plants are more sensitive to ozone than humans, and effects to plants occur well below the EPA standard. Ozone causes considerable damage to vegetation throughout the world, including agricultural crops and native plants in natural ecosystems. Ozone effects on natural vegetation have been documented throughout the U.S., particularly in many areas of the East and in California. A relatively small number of national parks have been surveyed for ozone injury; injury has been documented in Great Smoky Mountains, Shenandoah, Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite National Parks.

Scientists use various metrics to describe ozone exposure to plants, in addition to the 1-hour or 8-hour average concentrations reported by EPA. These metrics, the Sum06 and the W126, are believed to be biologically relevant, as they take into account both peak ozone concentrations and cumulative exposure to ozone. Hourly concentrations from a continuous or portable continuous ozone analyzer are needed to calculate either metric.

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The Sum06 is expressed in cumulative ppm-hr. Several thresholds have been developed for Sum06:

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr. Several thresholds have been developed for W126:

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone sensitive and bioindicator plant species have been identified for all of the SOPN units except Sand Creek Massacre NHS (at the time of this report, NPSpecies does not have a plant list for the unit). Species were identified by cross-referencing NPSpecies with sensitive species identified in "Ozone Sensitive Plant Species on National Park Service and U.S. Fish and Wildlife Service Lands" (2003) at http://www2.nature.nps.gov/air/Pubs/BaltFinalReport1.pdf.

Sensitive species are those that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one observer. Bioindicator species for ozone injury meet all or most of the following criteria: 1) species exhibit foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject matter experts, 2) species ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers, 3) species are widely distributed regionally, and 4) species are easily identified in the field. Because of these attributes, bioindicator species are recommended for field surveys to assess ozone injury.

NPS completed a risk assessment for parks in 2004, based on the concept that foliar ozone injury on plants is the result of the interaction of the plant, ambient ozone, and the environment. That is, the risk for foliar injury is high if three factors are present: species of plants that are genetically predisposed to ozone, concentrations of ambient ozone that exceed a threshold required for injury, and environmental conditions, primarily soil moisture, that foster gas exchange and the uptake of ozone by the plant.

The assessment used ozone data from 1995-1999 to evaluate risk. Chickasaw NRA was determined to be at high risk from ozone injury; Lyndon B. Johnson was at moderate risk; the remaining units are thought to be at low risk (the assessment was not done for Sand Creek Massacre NHS or Washita Battlefield NHS, as these were not part of the network when the assessment was initiated. It is likely that the risk at these units is low). The assessments should be re-evaluated if ozone increases in the area.

*Visibility Monitoring*

Estimates of visibility conditions for the SOPN units can be obtained from AirAtlas. Visibility-impairing particles and gases are monitored nationwide through the IMPROVE program. Most IMPROVE monitors are located in or near Class I air quality areas in order to characterize visibility conditions and assess progress

towards visibility improvement under the Regional Haze Program (http://www.epa.gov/air/visibility/program.html). Tribes and other agencies have also placed IMPROVE monitors at certain locations (table 1, figure 2). Each IMPROVE site has a fine particle sampler that measures the types and amounts of particles that obscure visibility. Data are available from the Visibility Information Exchange Web System (VIEWS) at http://vista.cira.colostate.edu/views/.

Visibility is not monitored in any of the SOPN park units. However, visibility impairment is regional in nature and nearby IMPROVE samplers indicate that visibility is degraded to some extent throughout the SOPN area. Trend analysis indicates that visibility is improving slightly on the clearest days and worsening on the haziest days in many areas of the West (Appendix A, figures A.5-A.6). States are required to develop plans to make progress towards the national goal of "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution." Regional planning organizations are currently discussing these plans. The regional planning group for the western U.S., including Colorado and New Mexico, is the Western Regional Air Partnership (WRAP), with information at www.wrapair.org. The regional planning group for the central U.S., including Kansas, Oklahoma, and Texas, is the Central States Regional Air Partnership (CENRAP), with information at http://cenrap.org/.

*Toxic Air Pollutant Monitoring (Mercury Deposition Monitoring)*

Monitoring of toxic air pollutants, including organic chemicals (e.g., pesticides, herbicides, PCBs, dioxin) and heavy metals, has been done in some areas of the country on an ad hoc basis, but has not been done as part of a long-term nationwide network. An exception is the Mercury Deposition Network, which collects rainfall for mercury analysis at over 60 sites nationwide (http://nadp.sws.uiuc.edu/mdn/). MDN monitors near SOPN units are listed in table 1. Sources of mercury include atmospheric deposition, mining activities, and natural sources. Coal contains mercury and large coal-burning power plants are major sources of mercury to the atmosphere and, eventually, terrestrial and aquatic ecosystems. Bioaccumulation of mercury in fish and wildlife has resulted in fish consumption advisories, and neurological and reproductive effects to wildlife and humans.

*Initial Recommendations*

- Obtain air quality data summaries and annual reports from NPS Air Resources Division (http://www2.nature.nps.gov/air/index.htm).

- Consider a scouting survey to examine vegetation for ozone injury at Chickasaw NRA.

- Periodically update ozone risk assessments for SOPN park units, which were based on 1995-1999 ozone data. Increasing ozone concentrations in the region may result in higher risk categories for some parks.

*Relevant Websites*

ARIS at http://www2.nature.nps.gov/air/
NPS AirWeb at http://www2.nature.nps.gov/air/
Air Atlas at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm
NADP at http://nadp.sws.uiuc.edu/
MDN at http://nadp.sws.uiuc.edu/mdn/

CASTNet at http://www.epa.gov/castnet/
EPA Ozone (AirData) at http://www.epa.gov/air/data/index.html
NPS Ozone Data at http://www2.nature.nps.gov/air/data/index.htm
IMPROVE at http://vista.cira.colostate.edu/views/
Pollution sources and air quality data at http://www.epa.gov/air/data/index.html
VIEWS at http://vista.cira.colostate.edu/views/

# Appendix A: Trends in Ozone, Visibility, and Wet Deposition

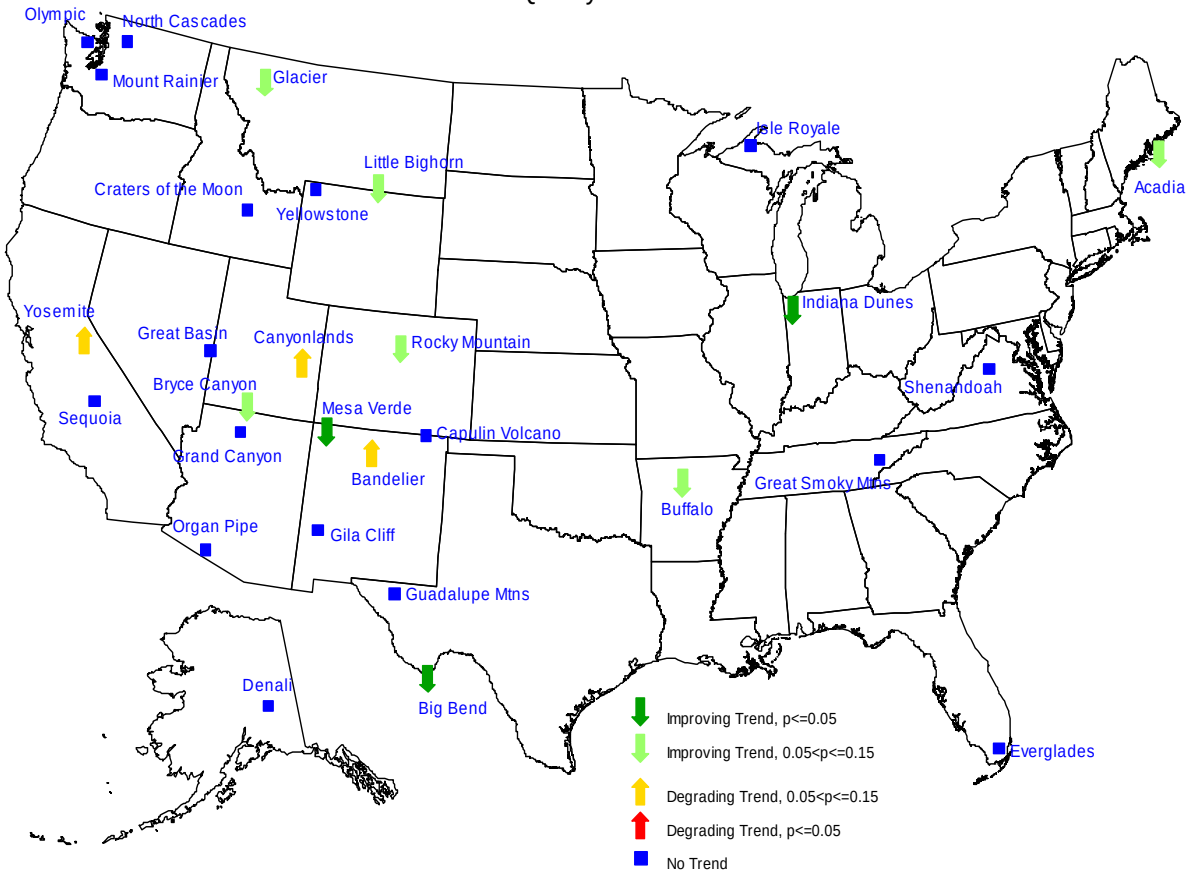
## 1994-2003

(Source: FY 2004 Annual Performance Report: Government Performance and Results Act, Air Resources Division)

Figure A.1

# Trends in SO4 Concentrations in Precipitation, 1994-2003

FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)
Air Quality Goal Ia3



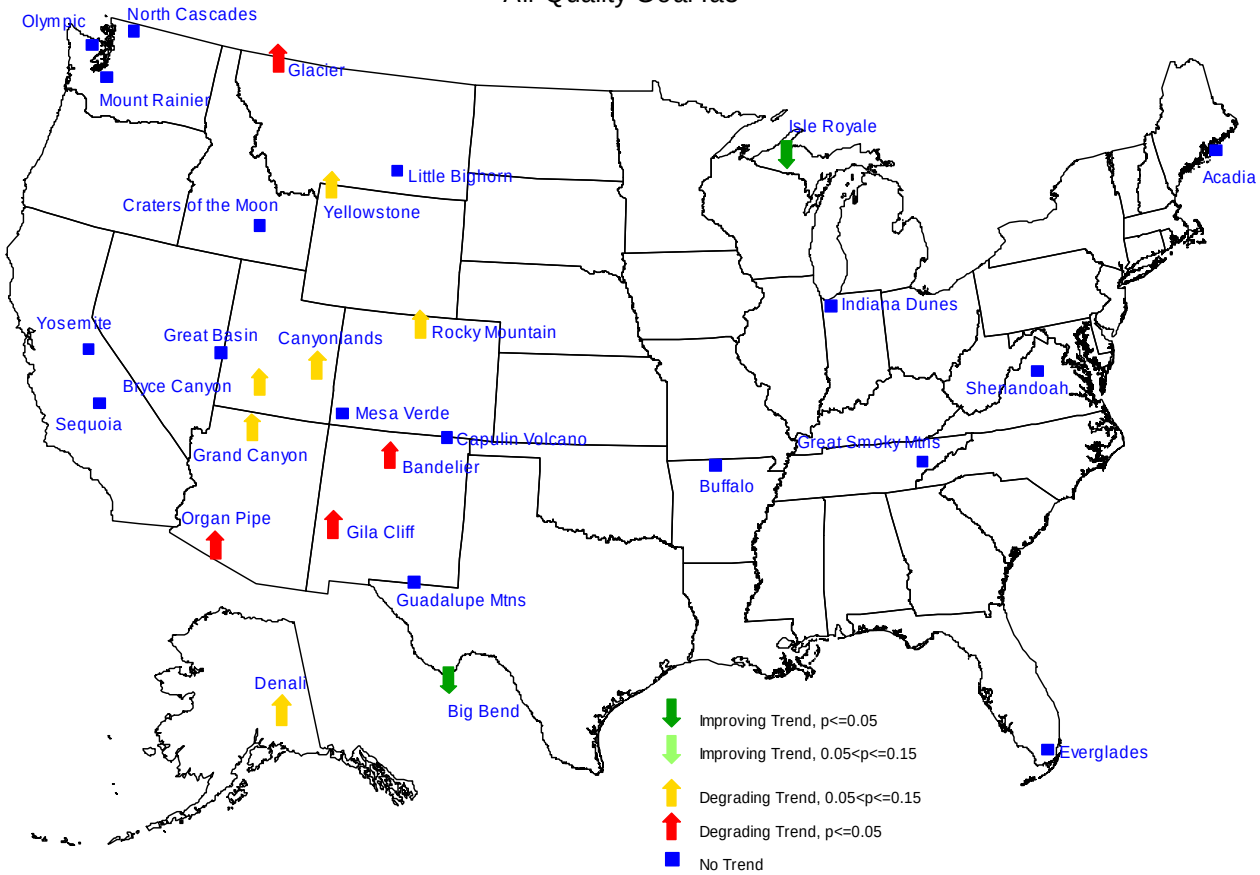

02/03/2005

Figure A.2

# Trends in NO3 Concentrations in Precipitation, 1994-2003

FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)

Air Quality Goal Ia3

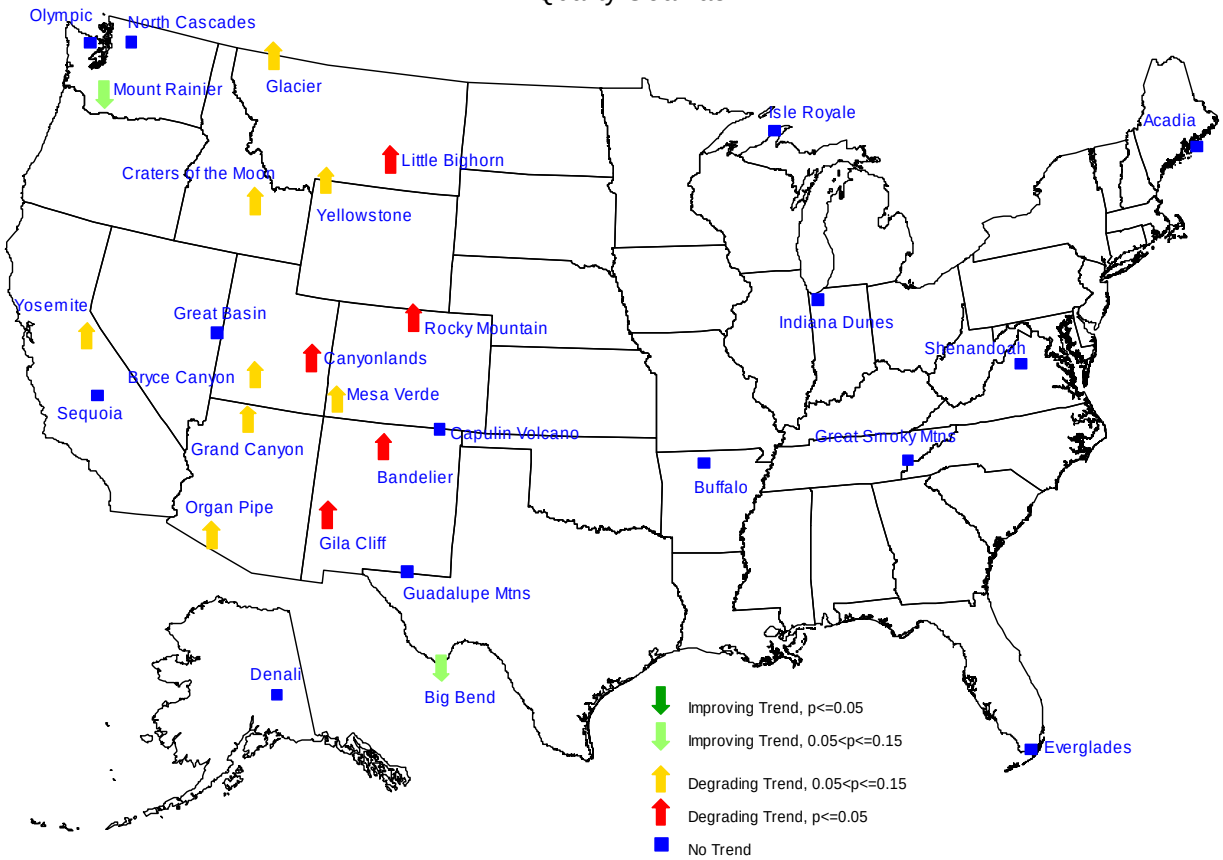



02/03/2005

Figure A.3

# Trends in NH4 Concentrations in Precipitation, 1994-2003

FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)
Air Quality Goal Ia3




02/03/2005

Figure A.4

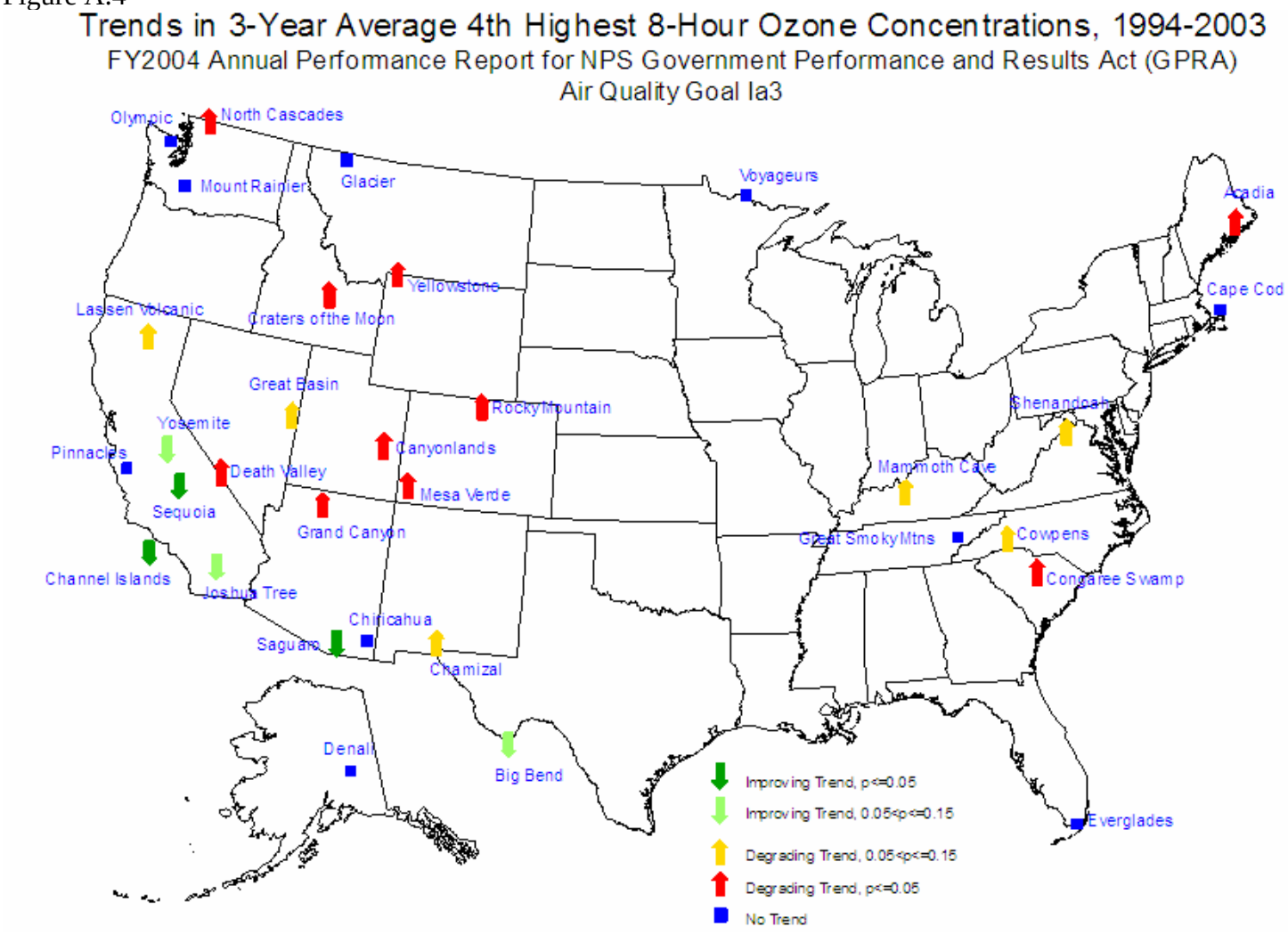

Trends in 3-Year Average 4th Highest 8-Hour Ozone Concentrations, 1994-2003
FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)
Air Quality Goal Ia3
Olympic
North Cascades
Mount Rainier
Glacier
Voyageurs
Acadia
Cape Cod
Yellowstone
Craters of the Moon
Lassen Volcanic
Great Basin
Rocky Mountain
Shenandoah
Yosemite
Pinnacles
Canyonlands
Death Valley
Mammoth Cave
Mesa Verde
Sequoia
Grand Canyon
Great Smoky Mtns
Cowpens
Channel Islands
Congaree Swamp
Joshua Tree
Chiricahua
Saguaro
Chamizal
Denali
Big Bend
Everglades
Improving Trend, p<=0.05
Improving Trend, 0.05<p<=0.15
Degrading Trend, 0.05<p<=0.15
Degrading Trend, p<=0.05
No Trend

Figure A.5

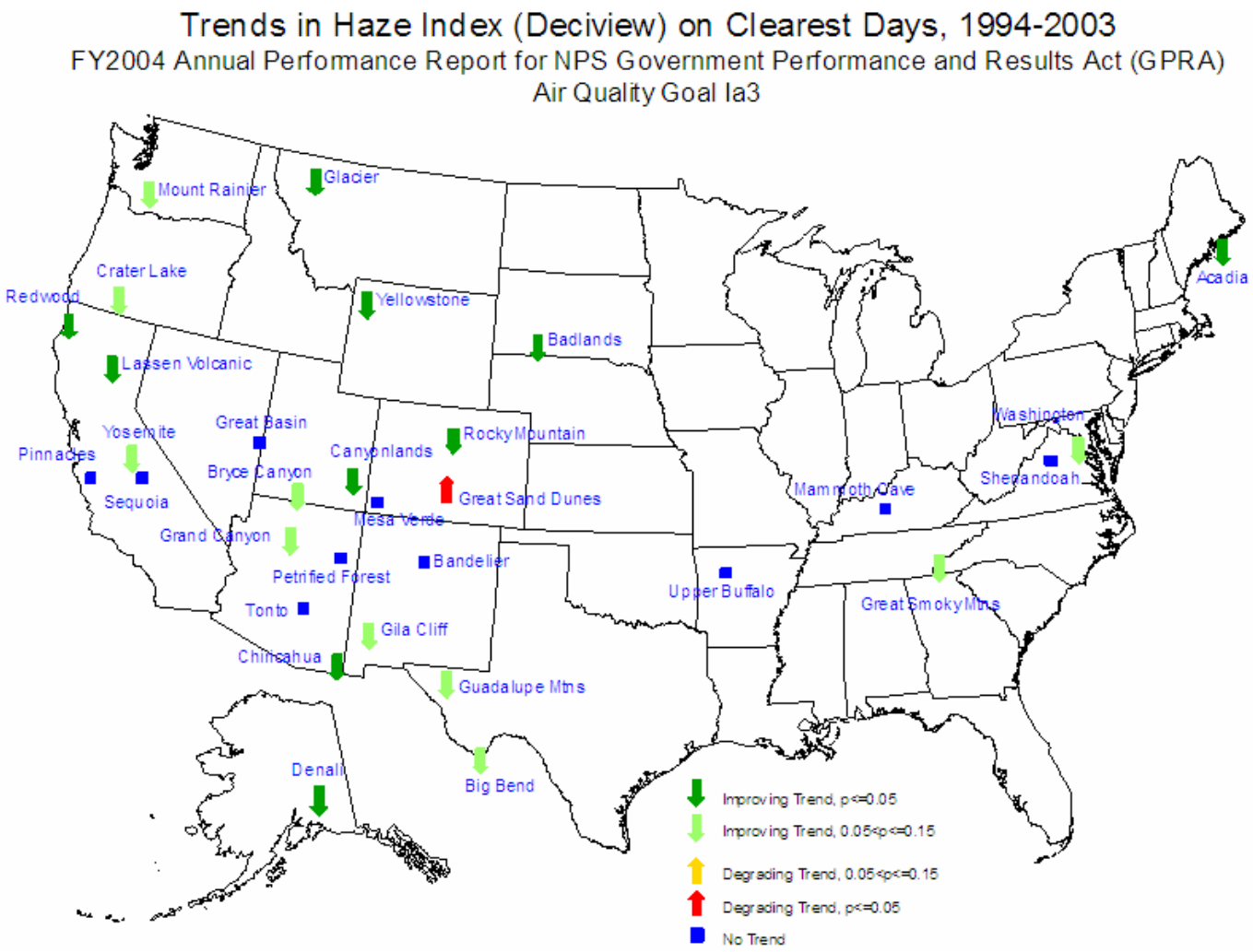
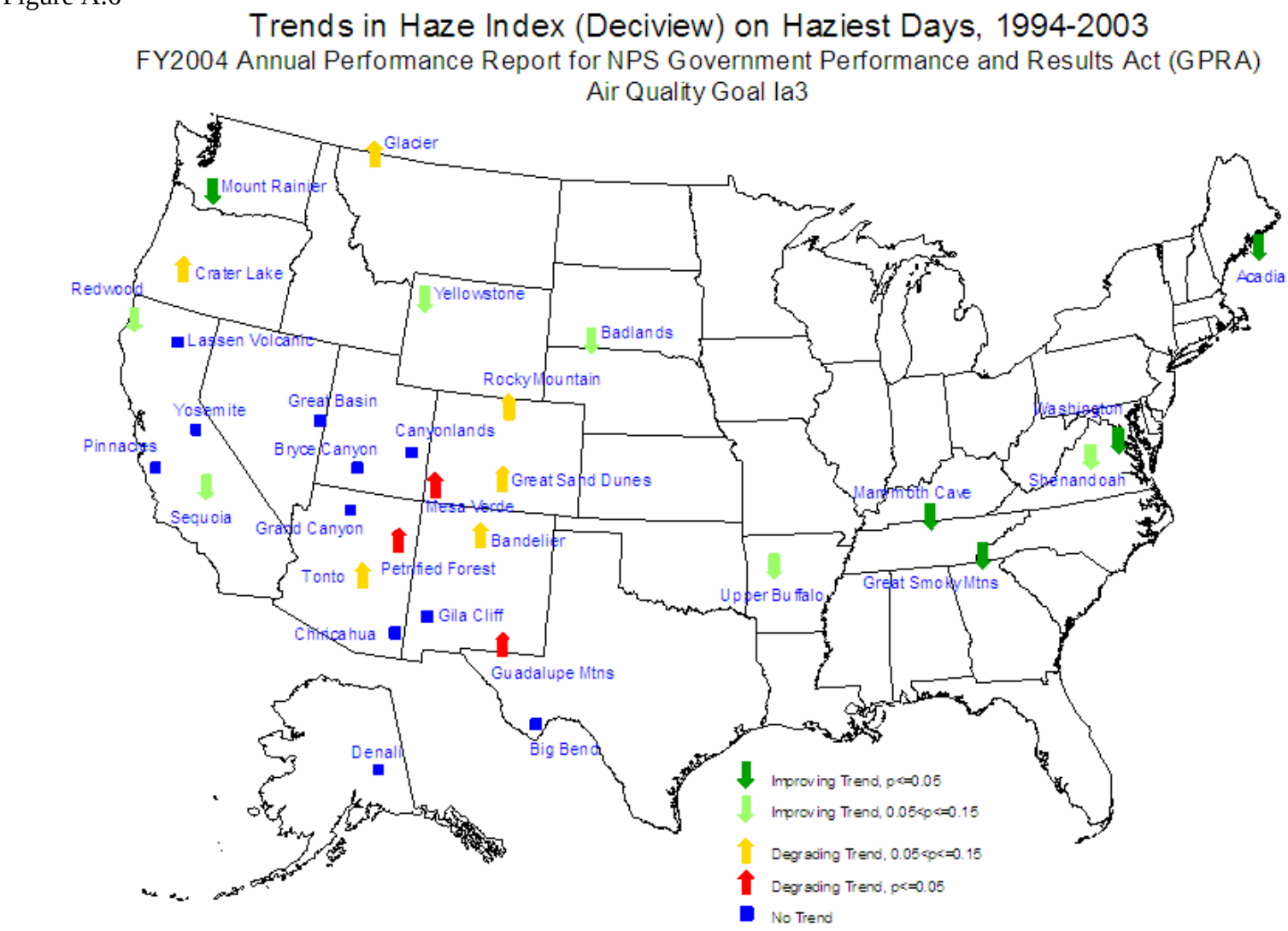

Trends in Haze Index (Deciview) on Clearest Days, 1994-2003
FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)
Air Quality Goal Ia3
Mount Rainier
Glacier
Crater Lake
Redwood
Yellowstone
Badlands
Lassen Volcanic
Acadia
Great Basin
Yosemite
Pinnacles
Canyonlands
Rocky Mountain
Bryce Canyon
Sequoia
Great Sand Dunes
Mesa Verde
Grand Canyon
Bandelier
Petrified Forest
Tonto
Gila Cliff
Chiricahua
Guadalupe Mtns
Big Bend
Denali
Washington
Shenandoah
Mammoth Cave
Upper Buffalo
Great Smoky Mtns
Improving Trend, p<=0.05
Improving Trend, 0.05<p<=0.15
Degrading Trend, 0.05<p<=0.15
Degrading Trend, p<=0.05
No Trend

Figure A.6


Trends in Haze Index (Deciview) on Haziest Days, 1994-2003
FY2004 Annual Performance Report for NPS Government Performance and Results Act (GPRA)
Air Quality Goal Ia3
Glacier
Mount Rainier
Crater Lake
Redwood
Yellowstone
Badlands
Lassen Volcanic
Rocky Mountain
Yosemite
Great Basin
Canyonlands
Pinnacles
Bryce Canyon
Great Sand Dunes
Mesa Verde
Sequoia
Grand Canyon
Bandelier
Tonto
Petrified Forest
Gila Cliff
Chiricahua
Guadalupe Mtns
Big Bend
Denali
Acadia
Washington
Shenandoah
Mammoth Cave
Great Smoky Mtns
Upper Buffalo
Improving Trend, p<=0.05
Improving Trend, 0.05<p<=0.15
Degrading Trend, 0.05<p<=0.15
Degrading Trend, p<=0.05
No Trend

# SOUTHERN PLAINS NETWORK

## ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHERN PLAINS NETWORK

**October 2004**

### Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

### Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

### Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

**Levels of Ozone Exposure**

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

**Soil Moisture Status**

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

**Site-Specific Assessment**

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

**Literature Cited**

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

**SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHERN PLAINS NETWORK**

| Park | Code | State | Risk | O3 Data |
|---|---|---|---|---|
| Alibates Flint Quarries NM | ALFL | TX | low | kriged |
| Bent's Old Fort NHS | BEOL | CO | low | kriged |
| Capulin Volcano NM | CAVO | NM | low | kriged |
| Chickasaw NRA | CHIC | OK | high | kriged |
| Fort Larned NHS | FOLS | KS | low | kriged |
| Fort Union NM | FOUN | NM | low | kriged |
| Lake Meredith NRA | LAMR | TX | low | kriged |
| Lyndon B. Johnson NHP | LYJO | TX | moderate | kriged |
| Pecos NHP | PECO | NM | low | kriged |

## ALIBATES FLINT QUARRIES NATIONAL MONUMENT (ALFL)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Parthenocissus quinquefolia | Virginia creeper | Vitaceae |
| Platanus occidentalis | American sycamore | Platanaceae |
| Robinia pseudoacacia | Black locust | Fabaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for ALFL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 14 | 11 | 10 | 20 | 18 |
| W126 | 25.1 | 22.9 | 24.1 | 39.5 | 30.4 |
| N60 | 420 | 402 | 397 | 730 | 516 |
| N80 | 56 | 28 | 33 | 81 | 62 |
| N100 | 6 | 2 | 2 | 6 | 2 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at ALFL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.34 | -3.45 | 2.27 | -0.30 | -0.52 |
| Month 2 | -0.66 | -0.70 | -0.38 | -3.69 | -0.04 |
| Month 3 | -1.52 | 2.86 | -0.72 | 3.65 | -1.65 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at ALFL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | -0.84 | -2.43 | 8.34 | -0.13 | 3.65 |
| May | 2.24 | -3.45 | 1.20 | -2.94 | 2.90 |
| June | 0.34 | -0.70 | 2.45 | -3.77 | 3.48 |
| July | -0.66 | 2.86 | 1.83 | -1.70 | 1.08 |
| August | -1.52 | 3.55 | 2.27 | -0.30 | -0.52 |
| September | 2.86 | 1.46 | -0.38 | -3.69 | -0.04 |
| October | -1.33 | -1.45 | -0.72 | 3.65 | -1.65 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, but none of them are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- No consistent relationship is apparent between 90-day Sum06 accumulation period indices of ozone and soil moisture. This is largely a consequence of similar levels of exposure and scattered months of drought. There was one month of mild or severe drought in four of the five years. There does not appear to be any association between the W126 level of ozone exposure and soil moisture status. The highest and lowest ozone years, 1998 and 1996, experienced four and three months, respectively, of mild to severe drought. The second highest ozone

year 1999 had one month of mild drought, the mid-exposure year 1995 had two months of mild drought and the second lowest ozone year 1997 had normal soil moisture. There were no associations between ozone and soil moisture for either the Sum06 or the W126 indices of exposure.

The low level of ozone exposure at Alibates Flint Quarries National Monument makes the risk of foliar ozone injury to plants low. While the Sum06 threshold is satisfied, the W126 criteria generally are not. The N100 counts are low with only two years having six hours of ozone greater than 100 ppb. Although there is no apparent association between ozone exposure and soil moisture, several years had three or four months of mild to severe drought that constrain the uptake of ozone and reduce the likelihood of foliar injury development.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

## BENT'S OLD FORT NATIONAL HISTORIC SITE (BEOL)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Fraxinus pennsylvanica | Green ash | Oleaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for BEOL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 8 | 12 | 8 | 12 | 10 |
| W126 | 14.8 | 19.5 | 17.5 | 25.3 | 23.6 |
| N60 | 203 | 313 | 261 | 426 | 378 |
| N80 | 13 | 15 | 10 | 27 | 21 |
| N100 | 1 | 1 | 0 | 2 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at BEOL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 6.75 | 2.21 | -2.10 | -2.20 | 7.76 |
| Month 2 | 2.82 | 1.77 | 1.63 | -0.29 | 3.50 |
| Month 3 | 0.61 | 2.06 | -0.15 | 7.21 | 2.70 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at BEOL | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 3.18 | -1.39 | 3.26 | 1.36 | 7.76 |
| May | 6.11 | -0.89 | -2.10 | -2.20 | 3.50 |
| June | 6.75 | -0.24 | 1.63 | -0.29 | 2.70 |
| July | 2.82 | 2.21 | -0.15 | 7.21 | 3.84 |
| August | 0.61 | 1.77 | 5.87 | 2.44 | 5.00 |
| September | 1.33 | 2.06 | 0.25 | -1.14 | 0.77 |
| October | -1.26 | -0.42 | 5.01 | 2.82 | 0.40 |

**Risk Analysis**

- There is one ozone-sensitive species at the site, but it is not a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation, but the values are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Only two months of drought occurred in the five-year period for the Sum06 index; one in one of the highest ozone years, 1998, and one in the lowest, 1997. For the W126 index, there were two months of drought in the highest ozone year, 1998, and none in the second highest year, 1999. One month of drought occurred in each of the remaining three years. No association with the level of ozone is evident from

this distribution of drought.

The risk of foliar ozone injury to plants at Bent's Old Fort National Historic Site is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Only a few hours of exposure to ozone concentrations greater than 80 ppb occur each year, while exposures to 100 ppb are rare.

If the level of risk increases in the future and an injury assessment becomes desirable, bioindicator species will have to be identified at the site.

## CAPULIN VOLCANO NATIONAL MONUMENT (CAVO)

### Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAVO

| | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|
| Sum06 | 8 | 12 | 8 | 12 | 10 |
| W126 | 14.8 | 19.5 | 17.5 | 25.3 | 23.6 |
| N60 | 203 | 313 | 261 | 426 | 378 |
| N80 | 13 | 15 | 10 | 27 | 21 |
| N100 | 1 | 1 | 0 | 2 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at CAVO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 3.60 | -4.72 | 0.50 | -2.65 | 4.42 |
| Month 2 | 0.31 | 0.53 | 1.76 | -2.14 | 2.21 |
| Month 3 | -0.31 | 0.20 | 0.40 | 2.93 | 2.20 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at CAVO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.14 | -2.33 | 2.69 | 0.46 | 4.42 |
| May | 4.26 | -4.72 | 0.50 | -2.65 | 2.21 |
| June | 3.60 | 0.53 | 1.76 | -2.14 | 2.20 |
| July | 0.31 | 0.20 | 0.40 | 2.93 | 3.52 |
| August | -0.31 | 0.58 | 0.93 | -0.04 | 3.56 |
| September | 1.51 | 0.13 | 2.02 | -1.77 | 0.24 |
| October | -2.28 | 1.55 | -0.22 | 5.19 | -1.25 |

**Risk Analysis**

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation, although the levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The 90-day Sum06 accumulation period levels of ozone were relatively consistent over the five-year period making it difficult to assess relationships with soil moisture. There is some indication, however, that soil moisture levels during the 90-day periods may be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the same high ozone exposure value, 1996 and 1998, experienced one and two months of moderate or severe drought, respectively. The remaining three years had favorable soil moisture conditions. However, the limited occurrence of drought makes the inverse nature of the association uncertain. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. The highest ozone year, 1998, had three months of mild and moderate, while the second highest year, 1999, had one month of mild drought. There were two months of moderate and severe drought in the mid-level ozone year 1996. The lowest ozone year had one month of drought, and the second lowest year had normal conditions.

The risk of foliar ozone injury to plants at Capulin Volcano National Monument is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Exposure

to 80 ppb ozone is infrequent, and exposure to 100 ppb rare. Soil moisture is inversely related to ozone exposure and serves to constrain the uptake of ozone at higher exposure levels. This effect further reduces the likelihood of foliar injury development.

No ozone-sensitive or bioindicator species have been identified at the site.

## CHICKASAW NATIONAL RECREATION AREA (CHIC)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Fraxinus americana | White ash | Oleaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Parthenocissus quinquefolia | Virginia creeper | Vitaceae |
| Platanus occidentalis | American sycamore | Platanaceae |
| Rhus copallina | Flameleaf sumac | Anacardiaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae. |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for CHIC | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 11 | 7 | 7 | 15 | 27 |
| W126 | 40.4 | 30.3 | 31.8 | 50.8 | 40.1 |
| N60 | 674 | 511 | 534 | 920 | 682 |
| N80 | 155 | 84 | 93 | 168 | 131 |
| N100 | 30 | 14 | 16 | 20 | 14 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at CHIC | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 1.07 | 0.32 | 0.04 | -4.42 | 0.58 |
| Month 2 | 1.56 | -0.26 | -2.42 | -2.15 | -0.67 |
| Month 3 | -0.09 | -4.17 | 0.31 | -2.25 | -2.28 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at CHIC | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.46 | -0.26 | 2.42 | -0.71 | 1.06 |
| May | 2.84 | -4.17 | 0.04 | -3.75 | 0.08 |
| June | 1.07 | -0.94 | 0.27 | -2.54 | 1.27 |
| July | 1.56 | 1.68 | -1.16 | -4.42 | -0.63 |
| August | -0.09 | 5.11 | 0.04 | -2.15 | -1.35 |
| September | 1.83 | 2.62 | -2.42 | -2.25 | 0.58 |
| October | -1.74 | -0.18 | 0.31 | 0.72 | -0.67 |

**Risk Analysis**

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In the highest ozone year, 1999, there was one month of moderate drought, while in each of the two years with the lowest ozone, 1996 and 1997, there was one month of severe or moderate drought. Soil moisture levels associated with the seasonal W126 index give some indication of being inversely related to ozone concentrations: when ozone is high, soil moisture is low, however the inconsistencies in the pattern are significant. The year with the highest ozone level, 1998, had five months of moderate and severe drought. The remaining four years each had one or two months of mild to severe drought.

The risk of foliar ozone injury to plants at Chickasaw National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in some years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years such as 1995 and 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, American sycamore, and skunkbush.

## FORT LARNED NATIONAL HISTORIC SITE (FOLS)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Asclepias syriaca | Common milkweed | Asclepiadaceae |
| Cercis canadensis | Redbud | Fabaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for FOLS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 21 | 15 | 15 | 28 | 20 |
| W126 | 23.2 | 12.8 | 22.9 | 41.5 | 27.6 |
| N60 | 438 | 278 | 378 | 788 | 478 |
| N80 | 67 | 15 | 13 | 88 | 54 |
| N100 | 8 | 1 | 0 | 6 | 2 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at FOLS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 2.56 | -1.44 | 2.31 | 1.59 | 2.55 |
| Month 2 | 1.40 | 1.49 | 1.97 | -1.77 | -0.01 |
| Month 3 | 1.79 | 4.09 | 4.00 | -2.38 | 1.69 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at FOLS | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 1.34 | -1.40 | 2.10 | -0.17 | 3.60 |
| May | 5.10 | -1.53 | 0.14 | -1.79 | 0.04 |
| June | 2.56 | -1.44 | 2.31 | -2.40 | 2.24 |
| July | 1.40 | 1.49 | 1.97 | 1.59 | 2.55 |
| August | 1.79 | 4.09 | 4.00 | -1.77 | -0.01 |
| September | 0.26 | 3.58 | 1.63 | -2.38 | 1.69 |
| October | -1.83 | 0.38 | 1.93 | 3.56 | -1.67 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. The highest exposures may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure year, 1998, had two months of mild and moderate drought, while one of the lowest, 1996, had one month of mild drought. Soil moisture in the other three years was normal. The year with the highest W126 exposure index, 1998, had four months of mild and moderate drought, and the year with the lowest, 1996, had three months of mild drought. There were only two months of mild drought in the remaining three years.

The low levels of ozone exposure at Fort Larned National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 threshold criteria are satisfied, while the W126 criteria are generally not fulfilled. While there are some years with a significant number of hours of ozone above 80 ppb, hours of exposure to concentrations above100 ppb are generally low. Levels of ozone and soil moisture conditions are unrelated, and the number of months of drought varies widely among years. In some years, such as 1995, exposures reach injury thresholds while soil moisture conditions foster the uptake of ozone. The opportunity for foliar injury to occur is greatest when these conditions coincide.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use common milkweed or redbud.

## FORT UNION NATIONAL MONUMENT (FOUN)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Amelanchier alnifolia | Saskatoon serviceberry | Rosaceae |
| Fraxinus pennsylvanica | Green ash | Oleaceae |
| Robinia pseudoacacia | Black locust | Fabaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for FOUN | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 9 | 17 | 11 | 16 | 14 |
| W126 | 16.5 | 23.1 | 18.7 | 25.6 | 25.8 |
| N60 | 219 | 376 | 282 | 448 | 420 |
| N80 | 13 | 12 | 9 | 13 | 20 |
| N100 | 1 | 0 | 0 | 0 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at FOUN | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 3.60 | -4.72 | 0.50 | -0.04 | 2.21 |
| Month 2 | 0.31 | 0.53 | 1.76 | -1.77 | 2.20 |
| Month 3 | -0.31 | 0.20 | 0.40 | 5.19 | 3.52 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at FOUN | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.14 | -2.33 | 2.69 | 0.46 | 4.42 |
| May | 4.26 | -4.72 | 0.50 | -2.65 | 2.21 |
| June | 3.60 | 0.53 | 1.76 | -2.14 | 2.20 |
| July | 0.31 | 0.20 | 0.40 | 2.93 | 3.52 |
| August | -0.31 | 0.58 | 0.93 | -0.04 | 3.56 |
| September | 1.51 | 0.13 | 2.02 | -1.77 | 0.24 |
| October | -2.28 | 1.55 | -0.22 | 5.19 | -1.25 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, none of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. However, the two months occurred in the years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a conclusion. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe

drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Fort Union National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb during the assessment period. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

There are no ozone bioindicator species at the site.

## LAKE MEREDITH NATIONAL RECREATION AREA (LAMR)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Parthenocissus quinquefolia | Virginia creeper | Vitaceae |
| Platanus occidentalis | American sycamore | Platanaceae |
| Robinia pseudoacacia | Black locust | Fabaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for LAMR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 14 | 11 | 10 | 19 | 17 |
| W126 | 24.5 | 22.3 | 23.9 | 39.3 | 30.2 |
| N60 | 412 | 393 | 393 | 726 | 511 |
| N80 | 54 | 26 | 32 | 80 | 60 |
| N100 | 5 | 2 | 2 | 6 | 2 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at LAMR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 0.34 | -3.45 | 2.27 | -0.30 | -0.52 |
| Month 2 | -0.66 | -0.70 | -0.38 | -3.69 | -0.04 |
| Month 3 | -1.52 | 2.86 | -0.72 | 3.65 | -1.65 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at LAMR | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | -0.84 | -2.43 | 8.34 | -0.13 | 3.65 |
| May | 2.24 | -3.45 | 1.20 | -2.94 | 2.90 |
| June | 0.34 | -0.70 | 2.45 | -3.77 | 3.48 |
| July | -0.66 | 2.86 | 1.83 | -1.70 | 1.08 |
| August | -1.52 | 3.55 | 2.27 | -0.30 | -0.52 |
| September | 2.86 | 1.46 | -0.38 | -3.69 | -0.04 |
| October | -1.33 | -1.45 | -0.72 | 3.65 | -1.65 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 index, there was one month of mild or severe drought in four of the five years. With the W126 index, there were three months of moderate and severe drought in the highest ozone year, 1998, and three months of mild to severe drought in the lowest year, 1996. Distribution of months of drought in the intermediate years shows no association with exposure.

The low level of ozone exposure at Lake Meredith National Recreation Area makes the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a few hours of exposure above 80 ppb, but exposures above 100 ppb are generally rare. One year, 1998, had exposures that satisfied the Sum06 and W126 criteria, but dry soil conditions during several months that year would significantly constrain the uptake of ozone and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

## LYNDON B. JOHNSON NATIONAL HISTORIC PARK (LYJO)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Cercis canadensis | Redbud | Fabaceae |
| Parthenocissus quinquefolia | Virginia creeper | Vitaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for LYJO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 13 | 4 | 10 | 15 | 20 |
| W126 | 36.4 | 13.4 | 22.1 | 25.7 | 32.0 |
| N60 | 594 | 205 | 372 | 443 | 539 |
| N80 | 161 | 41 | 74 | 79 | 128 |
| N100 | 26 | 7 | 8 | 12 | 18 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at LYJO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | -1.28 | -0.94 | 5.60 | 6.87 | -2.41 |
| Month 2 | -0.98 | -1.15 | 1.64 | -1.81 | -2.94 |
| Month 3 | 0.39 | -3.47 | -1.51 | 0.45 | -1.22 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at LYJO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 0.27 | -1.15 | 2.93 | -1.77 | -0.71 |
| May | 1.74 | -3.47 | 0.74 | -3.70 | -1.45 |
| June | 0.33 | -2.73 | 5.60 | -2.31 | 0.28 |
| July | -1.28 | -2.09 | 1.64 | -2.72 | -0.80 |
| August | -0.98 | 2.96 | -1.51 | 6.87 | -2.41 |
| September | 0.39 | 1.06 | -2.24 | -1.81 | -2.94 |
| October | -1.98 | 0.14 | -0.54 | 0.45 | -1.22 |

**Risk Analysis**

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure was in 1999 when there were three months of mild and moderate drought, while the lowest exposure was in 1996 when there were two months of mild and severe drought. The remaining intermediate ozone years each had one month of drought. With the W126 index, the highest ozone year, 1995, had two months of mild drought. The second highest year, 1999, had four months of mild and moderate drought while the two intermediate years had five and two months of drought. The lowest year, 1996, four months of mild to severe drought. Overall, no association between ozone exposure and drought is apparent for either

index.

The risk of foliar ozone injury to plants at Lyndon B. Johnson National Historic Park is moderate. While the levels of ozone exposure consistently create the potential for injury, periods of low soil moisture may reduce the likelihood of injury developing in particular years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use redbud.

## PECOS NATIONAL HISTORIC PARK (PECO)

### Plant Species Sensitive to Ozone

| *Latin Name* | *Common Name* | *Family* |
|---|---|---|
| Pinus ponderosa | Ponderosa pine | Pinaceae |
| Rhus trilobata | Skunkbush | Anacardiaceae |
| Salix gooddingii | Gooding's willow | Salicaceae |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

| | | |
|---|---|---|
| Natural Ecosystems | 8 - 12 ppm-hr | (foliar injury) |
| Tree Seedlings | 10 - 16 ppm-hr | (1-2% reduction in growth) |
| Crops | 15 - 20 ppm-hr | (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

| | W126 | N100 |
|---|---|---|
| Highly Sensitive Species | 5.9 ppm-hr | 6 |
| Moderately Sensitive Species | 23.8 ppm-hr | 51 |
| Low Sensitivity | 66.6 ppm-hr | 135 |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for PECO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06 | 9 | 17 | 11 | 16 | 14 |
| W126 | 17.2 | 23.8 | 19.0 | 25.9 | 26.4 |
| N60 | 229 | 391 | 288 | 453 | 432 |
| N80 | 15 | 12 | 10 | 14 | 21 |
| N100 | 1 | 0 | 0 | 0 | 0 |

**Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at PECO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Month 1 | 3.60 | -4.72 | 0.50 | -0.04 | 2.21 |
| Month 2 | 0.31 | 0.53 | 1.76 | -1.77 | 2.20 |
| Month 3 | -0.31 | 0.20 | 0.40 | 5.19 | 3.52 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at PECO | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| April | 2.14 | -2.33 | 2.69 | 0.46 | 4.42 |
| May | 4.26 | -4.72 | 0.50 | -2.65 | 2.21 |
| June | 3.60 | 0.53 | 1.76 | -2.14 | 2.20 |
| July | 0.31 | 0.20 | 0.40 | 2.93 | 3.52 |
| August | -0.31 | 0.58 | 0.93 | -0.04 | 3.56 |
| September | 1.51 | 0.13 | 2.02 | -1.77 | 0.24 |
| October | -2.28 | 1.55 | -0.22 | 5.19 | -1.25 |

**Risk Analysis**

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had one hour in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. One month of drought occurred in each of the two years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a relationship. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the

effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Pecos National Historic Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.

# AirAtlas Summary Tables for I&M Parks

The Air Atlas is a mini-GIS tool available on the Internet that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. Air Atlas was produced by the National Park Service Air Resources Division (ARD) in association with the University of Denver. Air Atlas will serve as the Air Inventory for the parks and is available on the Internet at http://www2.nature.nps.gov/ard/gas/ (see section called *Air Atlas*).

The estimated air quality values provided in the look-up table are based on the center of the polygon defining the park or multiple units of the park. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations throughout the park. Greater variability may exist for other parameters, such as deposition and visibility. In the future, the full Air Atlas dataset will be available on the internet, and users of ArcView and ArcGIS will be able to obtain air quality values for multiple points in a park by entering the latitude and longitude coordinates.

Air Atlas contains a comprehensive set of air quality parameters for all I&M parks. In addition, ARD has prepared a summary table that includes a select group of air quality parameters for each I&M network. The summary version is intended to provide parks with a synopsis useful for characterizing air quality conditions. Air quality parameters selected for the summary version are described below.

## Ozone Parameters

Ozone can be expressed as concentration or cumulative dose. Relevant concentration and dose parameters include:

2nd Hi 1-hr: expressed in parts per billion (ppb), this value is the 2nd highest hourly value in a year and can be compared to the former Environmental Protection Agency (EPA) human health-based standard for ozone of 125 ppb (0.12 ppm).

4th Hi 8-hr: expressed in parts per billion (ppb), this value is the average hourly value in the 4th highest 8 hour period and can be compared to the present EPA human health-based standard for ozone of 85 ppb (0.08 ppm).

# 8 hrs > 85 ppb: indicates how often the site would exceed the present ozone standard.

# 1 hr > 100 ppb: indicates how often the site experiences high ozone concentrations; high concentrations contribute to vegetation (foliar) injury in sensitive plant species.

SUM06_3Mo: The running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 ppm; represents cumulative exposure dose of ozone to plants.

Ozone is one of the most widespread air pollutants. Ozone is not emitted directly from smokestacks or vehicles, but is formed when other pollutants, primarily nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight, usually during the warm summer months. In addition to harming human health, ozone is phytotoxic, and causes considerable damage to vegetation throughout the world, including agricultural crops and native plants in natural ecosystems. The Environmental Protection Agency has established an ozone standard to protect human health; however, EPA has not set a standard to protect vegetation and there is much evidence to suggest that the human health-based standard is not protective of sensitive vegetation.

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone injury can be induced by a sufficiently high seasonal dose of ozone (expressed as SUM06, in ppm-hrs), high peak concentrations of ozone (expressed in ppb), or a combination of both. Ozone effects to natural vegetation have been documented throughout the country, particularly in many areas of the East and in California. For sensitive natural vegetation in the East, researchers have recommended SUM06 effects endpoints of 8-12 ppm-hrs for foliar injury and 10-15 ppm-hrs for growth effects on tree seedlings in natural forest stands. In the West (Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs), researchers have found that foliar injury on ponderosa and Jeffrey pines ranges from about 15-50 percent at ozone values between 25-30 ppm-hrs. Sites with values above these endpoints may be at risk for vegetation injury if sensitive species are present. However, to adequately assess risk, other factors, including temperature and soil moisture, must be considered. In conditions of low moisture, for example, stomates may close, preventing ozone uptake. Ozone peak concentrations exceeding 100 ppb are also considered to be important in inducing injury and the number of hours in a year above 100 ppb may be significant for evaluating risk.

**Atmospheric Deposition Parameters**

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. (at over 200 sites), as part of the National Atmospheric Deposition Program (NADP). Dry deposition is monitored at about 70 sites as part of the Clean Air Status and Trends Network (CASTNet). Clouds and fog may contribute significantly to total deposition at certain locations (e.g., high

elevation areas and areas that experience a high frequency of clouds and fog), but monitoring cloud and fog deposition is difficult and is done at only a couple of locations in the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Deposition can be expressed as concentration (e.g., micrograms per cubic meter or milligrams per liter) or deposition rates (e.g., kilograms per hectare per year – kg/ha/yr). Deposition rates are included in Air Atlas summaries, as these rates best characterize the amount of deposition an ecosystem experiences.

NADP dep (kg/ha/yr): pollutant ions in wet deposition from rain or snow are measured by the National Atmospheric Deposition Program (NADP) and expressed as kg/ha/yr. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

NADP Total S (kg/ha/yr): total sulfur from sulfate ions in wet deposition.

NADP Total N (kg/ha/yr): total inorganic nitrogen from ammonium and nitrate ions in wet deposition.

Atmospheric deposition affects ecosystems in a variety of ways, including acidification, fertilization or eutrophication, and accumulation of toxics. Acid deposition from sulfur and nitrogen compounds affects freshwater lakes, streams, and watersheds. Acid deposition effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. Deposition can also cause changes in soil that affect soil microorganisms, understory plants, and trees. Excess nitrogen deposition can cause unwanted fertilization effects, leading to changes in plant community structure and diversity. In estuaries and coastal waters, nitrogen can cause algae blooms, decreases in dissolved oxygen, and loss of seagrasses (i.e., eutrophication).

All areas of the country are experiencing levels of atmospheric deposition above natural levels. The ability of ecosystems to deal with increased levels of deposition varies widely. High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition. Other sensitive areas include the upper Midwest, New England, and Florida, including the shallow bays and estuaries along the Atlantic and Gulf Coasts. Streams in both Shenandoah and Great Smoky Mountains NPs are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain NP is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition. In some areas, excess nitrogen deposition has caused shifts in plant species composition, with native species being replaced by invasive and exotic species that are better able to utilize nitrogen.

**Visibility Parameters**

A number of visibility indices, or measurements, can be used to express visibility conditions. The measurement used in Air Atlas summaries is light extinction.

bextClear: annual average light extinction, expressed in inverse megameters, on the 20 percent clearest days

bextHazy: annual average light extinction, expressed in inverse megameters, on the 20 percent haziest days

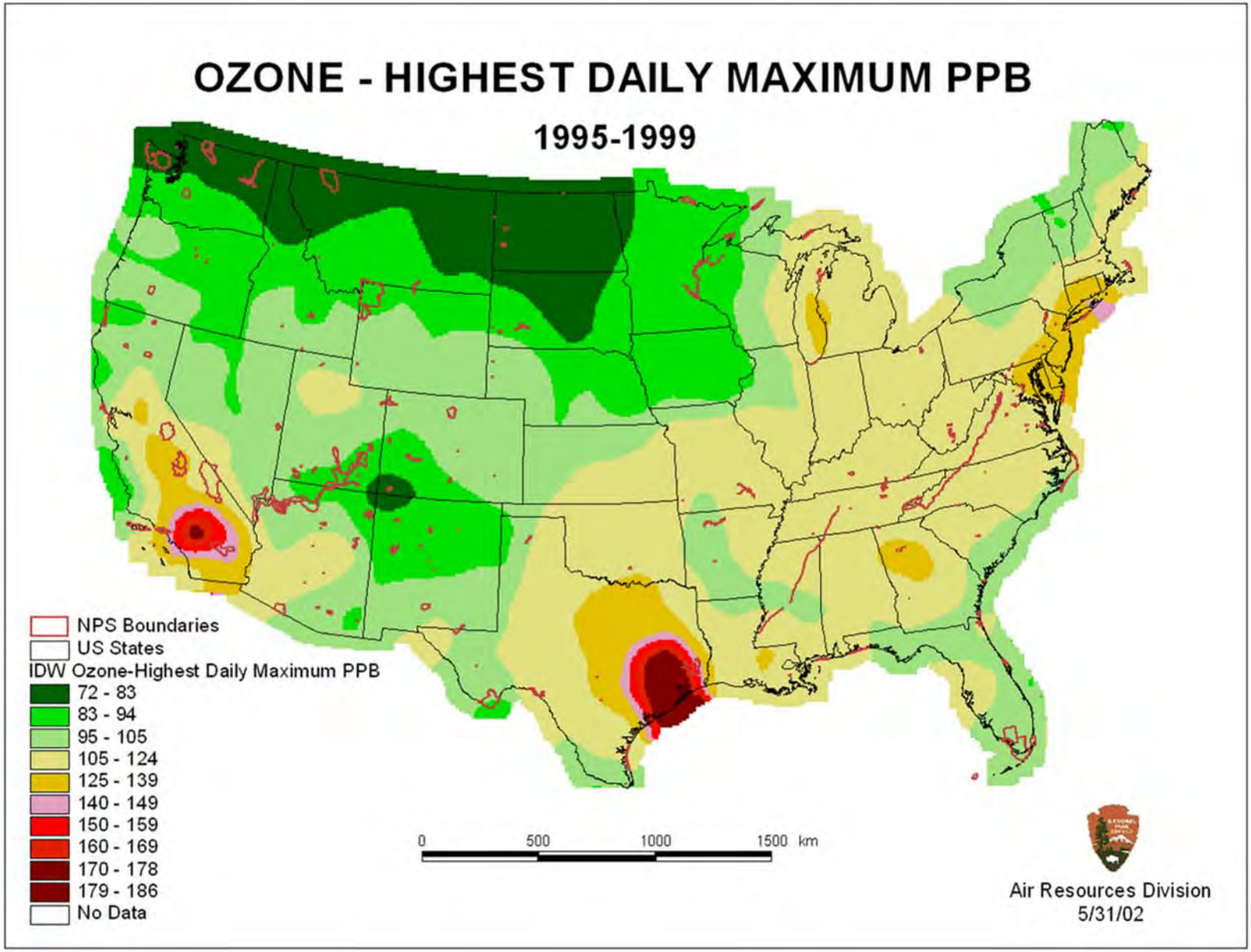
Light extinction, expressed in the form of inverse megameters ($Mm^{-1}$), is proportional to the amount of light lost because of scattering or absorption by particles in the air as the light travels over a million meters (one million meters = one megameter). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase.

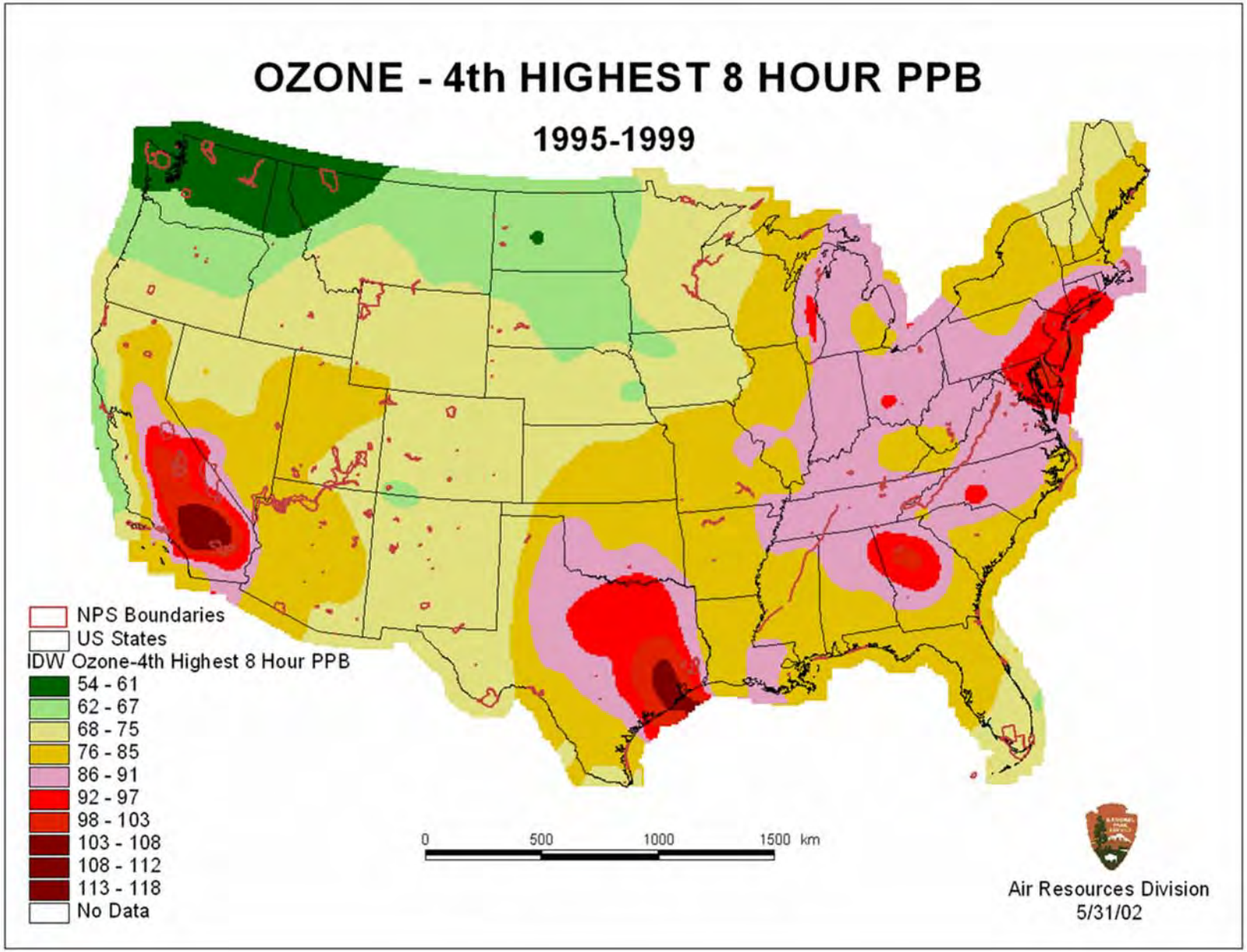
Extinction can be measured directly, with a transmissometer and nephelometer, or it can be calculated from representative aerosol measurements. Air Atlas extinction estimates, so-called "reconstructed" estimates, are calculated from aerosol measurements. Total extinction is the sum of the individual extinctions caused by gases, particles, and air molecules in the atmosphere. Relative humidity, as well as particle concentrations, is considered in the equation, as relative humidity increases the extinction efficiency of certain particles.

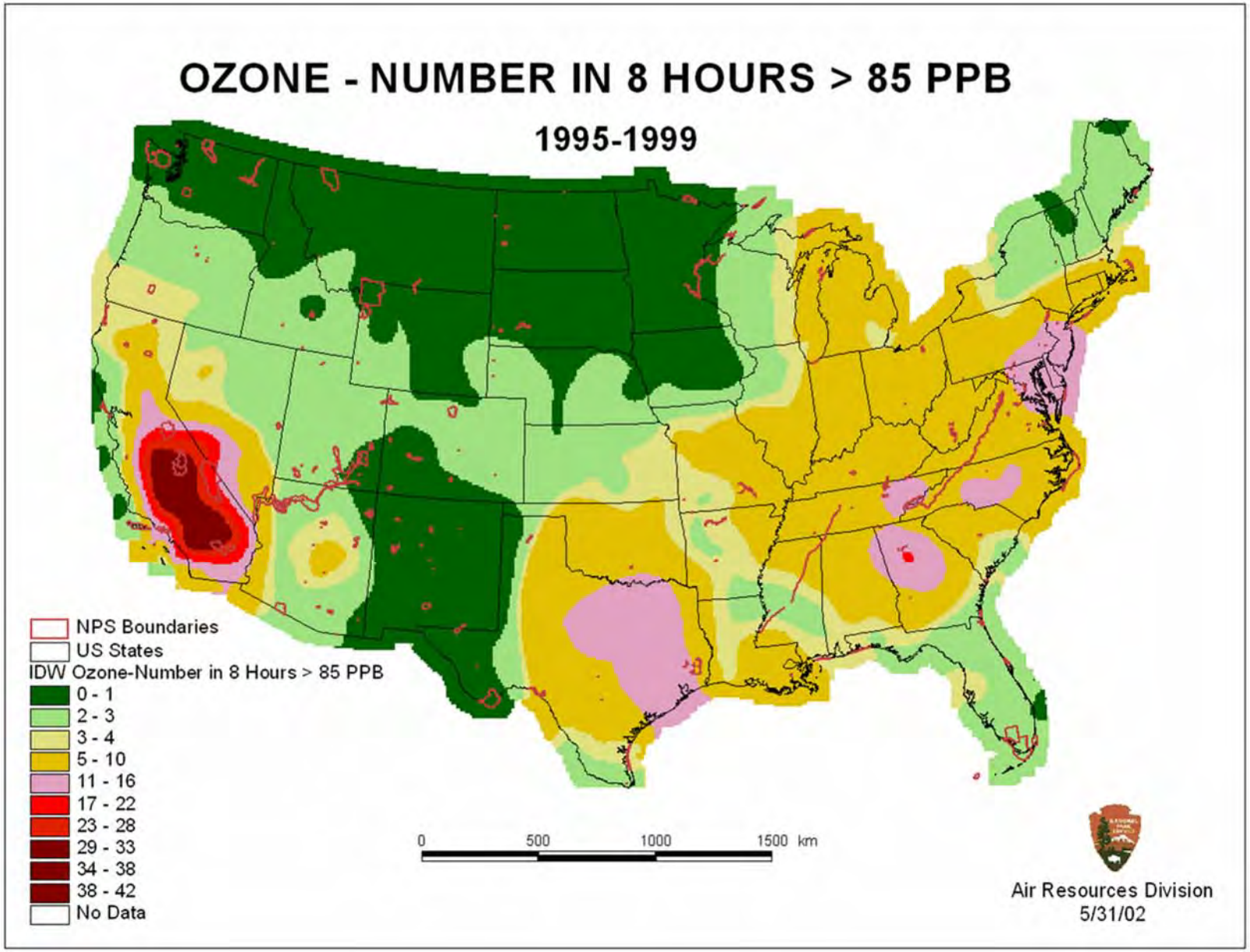
Light extinction is averaged for the 20 percent clearest and the 20 percent haziest days in an area. The Environmental Protection Agency's 1999 Regional Haze Regulations require that reasonable progress be made to restore visibility to natural background conditions within 60 years. States are to establish goals for each Class I area to improve visibility on the haziest days (defined as the 20 percent haziest day) and ensure no degradation occurs on the clearest days (defined as the 20 percent clearest days). Emissions reductions that benefit visibility in Class I areas are also expected to benefit visibility in all other areas.

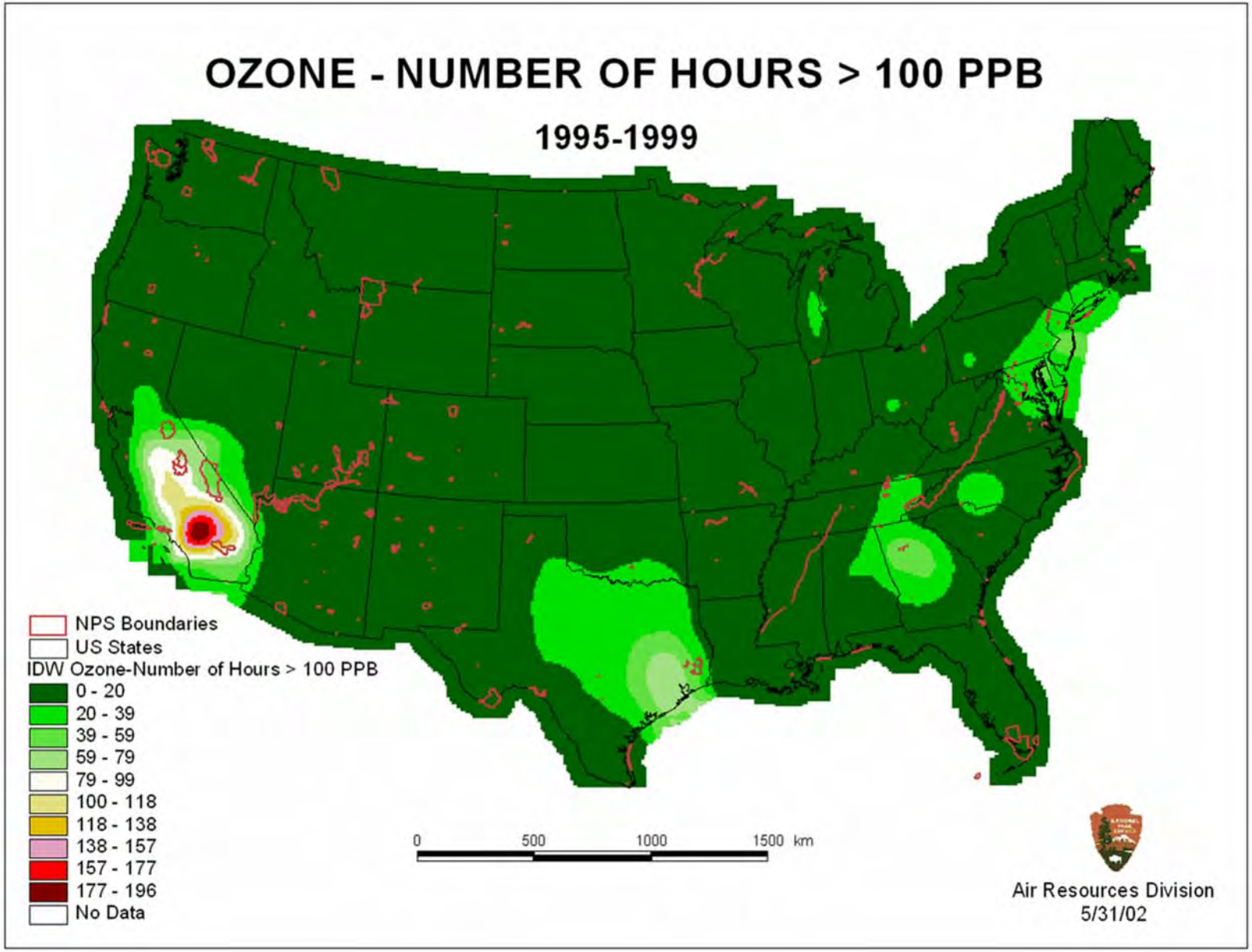
Visual range (VR) is another index used to describe visibility. Because VR is not particularly useful for assessing the quality of scenic vistas (clarity, color), light extinction is used in Air Atlas. However, VR is sometimes useful for describing visibility to the general public. VR is expressed as length; extinction is expressed as 1/length. The relationship between VR and extinction is:

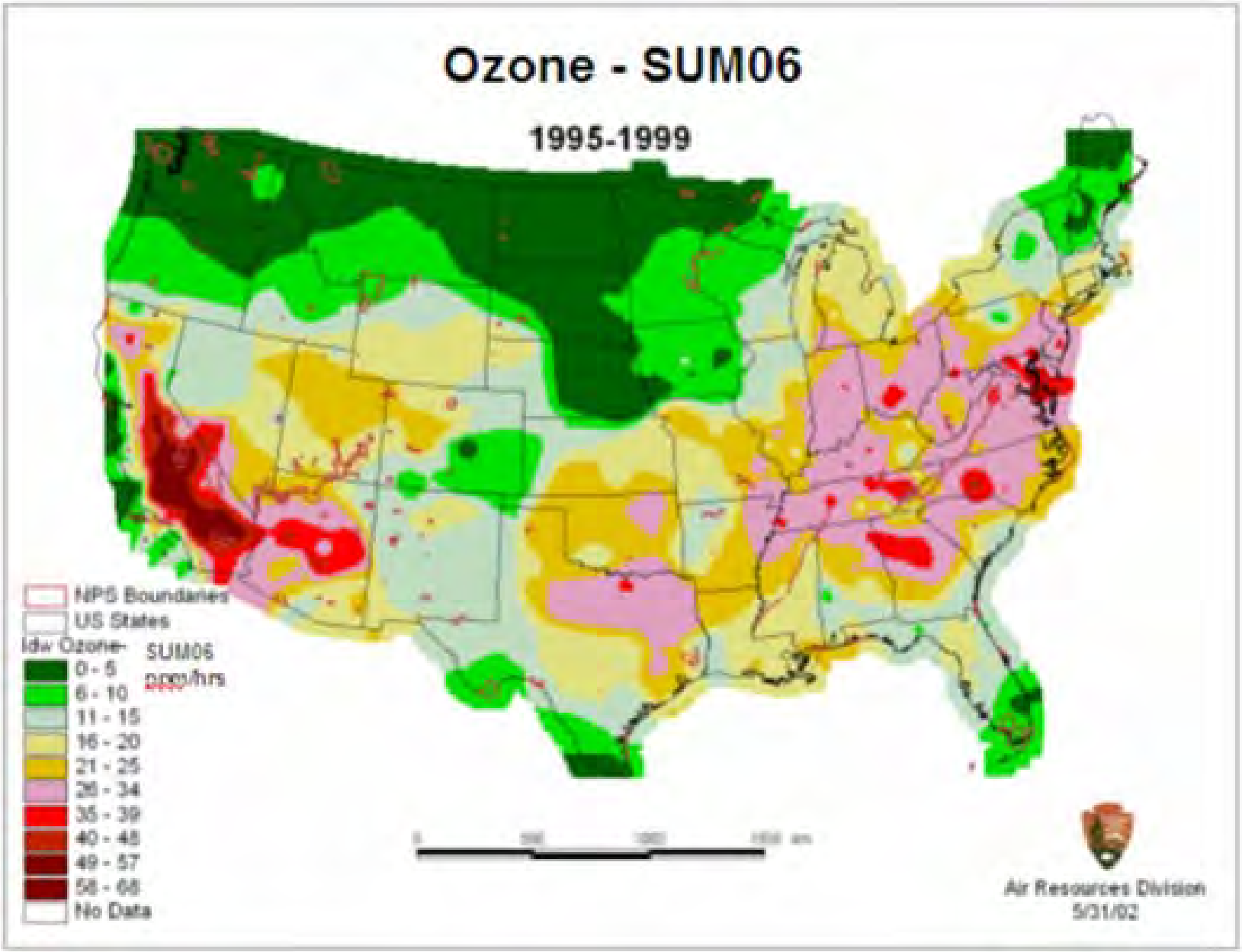
$$VR = \frac{3.912}{\text{bext}(\text{km}^{-1})} = \frac{3912}{\text{bext}(\text{Mm}^{-1})}$$

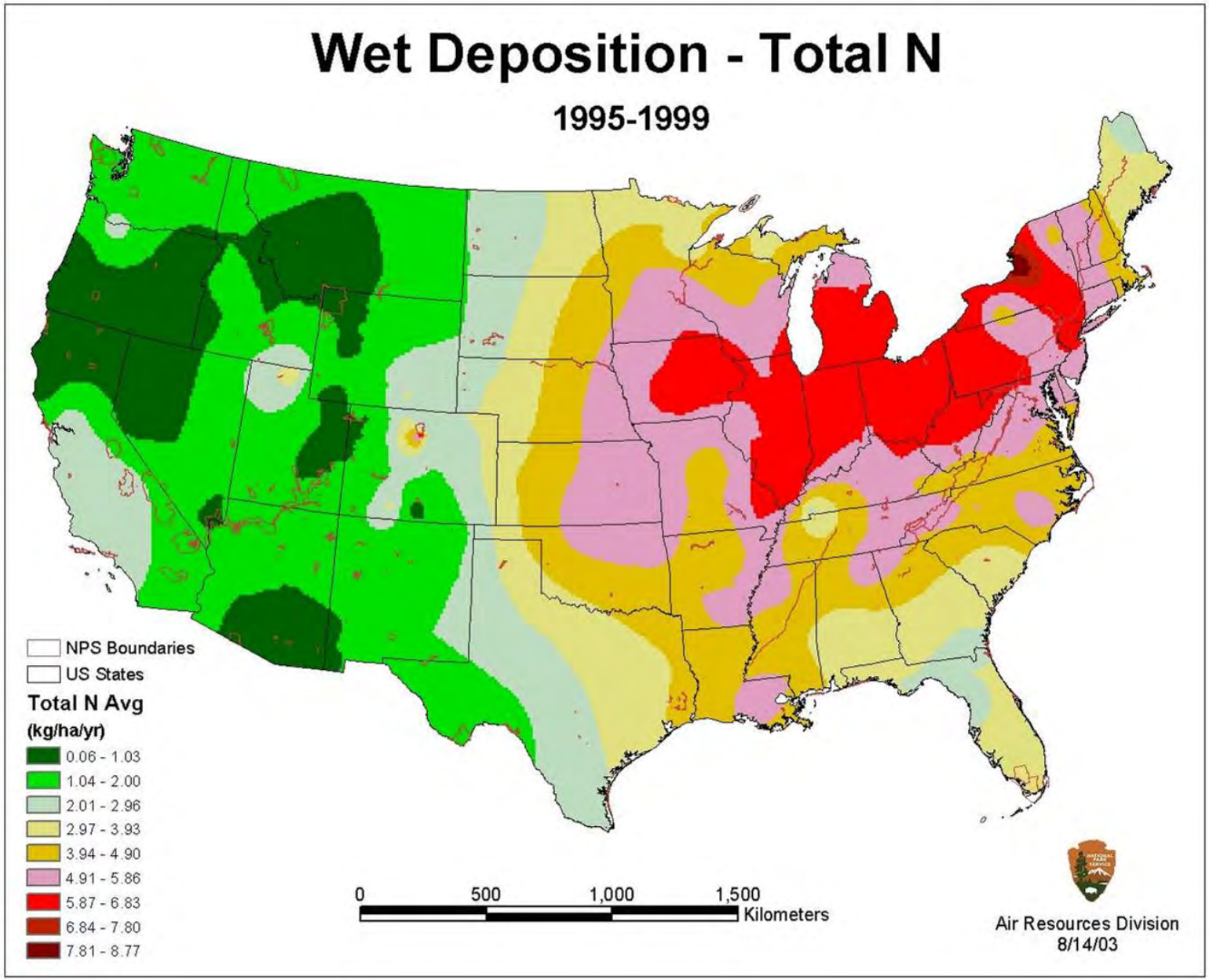

OZONE - HIGHEST DAILY MAXIMUM PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-Highest Daily Maximum PPB
72 - 83
83 - 94
95 - 105
105 - 124
125 - 139
140 - 149
150 - 159
160 - 169
170 - 178
179 - 186
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02

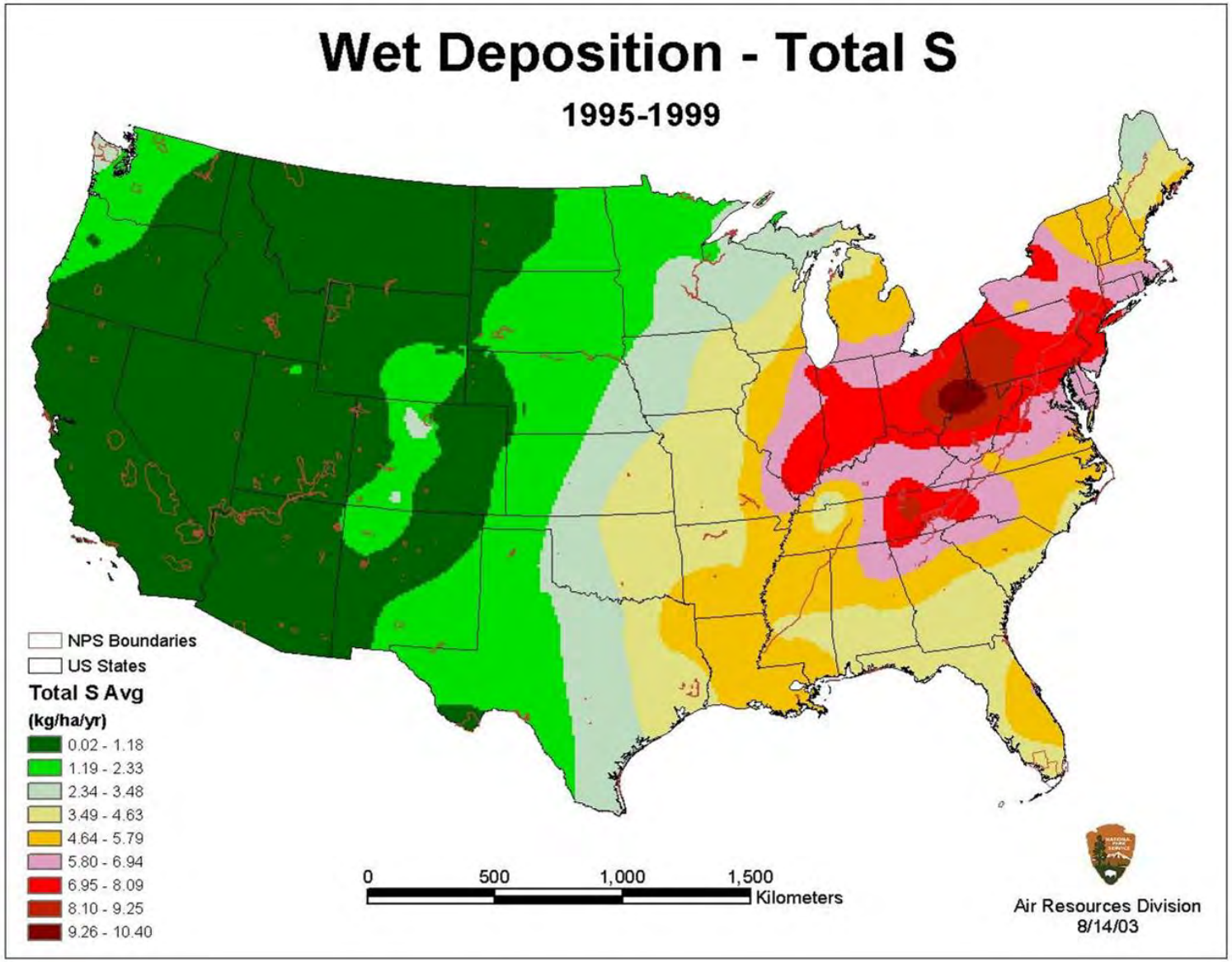

OZONE - 4th HIGHEST 8 HOUR PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-4th Highest 8 Hour PPB
54 - 61
62 - 67
68 - 75
76 - 85
86 - 91
92 - 97
98 - 103
103 - 108
108 - 112
113 - 118
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02

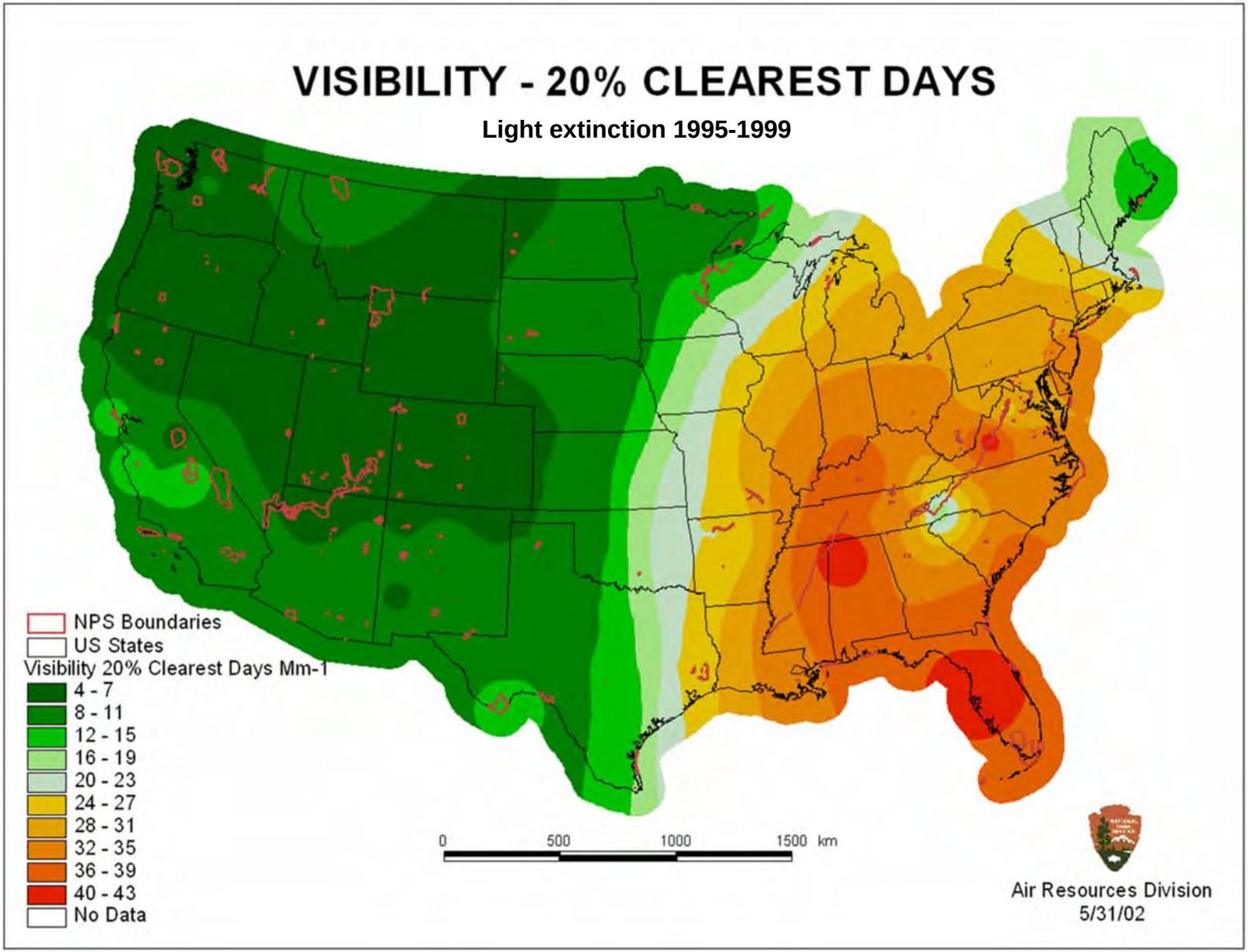

OZONE - NUMBER IN 8 HOURS > 85 PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-Number in 8 Hours > 85 PPB
0 - 1
2 - 3
3 - 4
5 - 10
11 - 16
17 - 22
23 - 28
29 - 33
34 - 38
38 - 42
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02

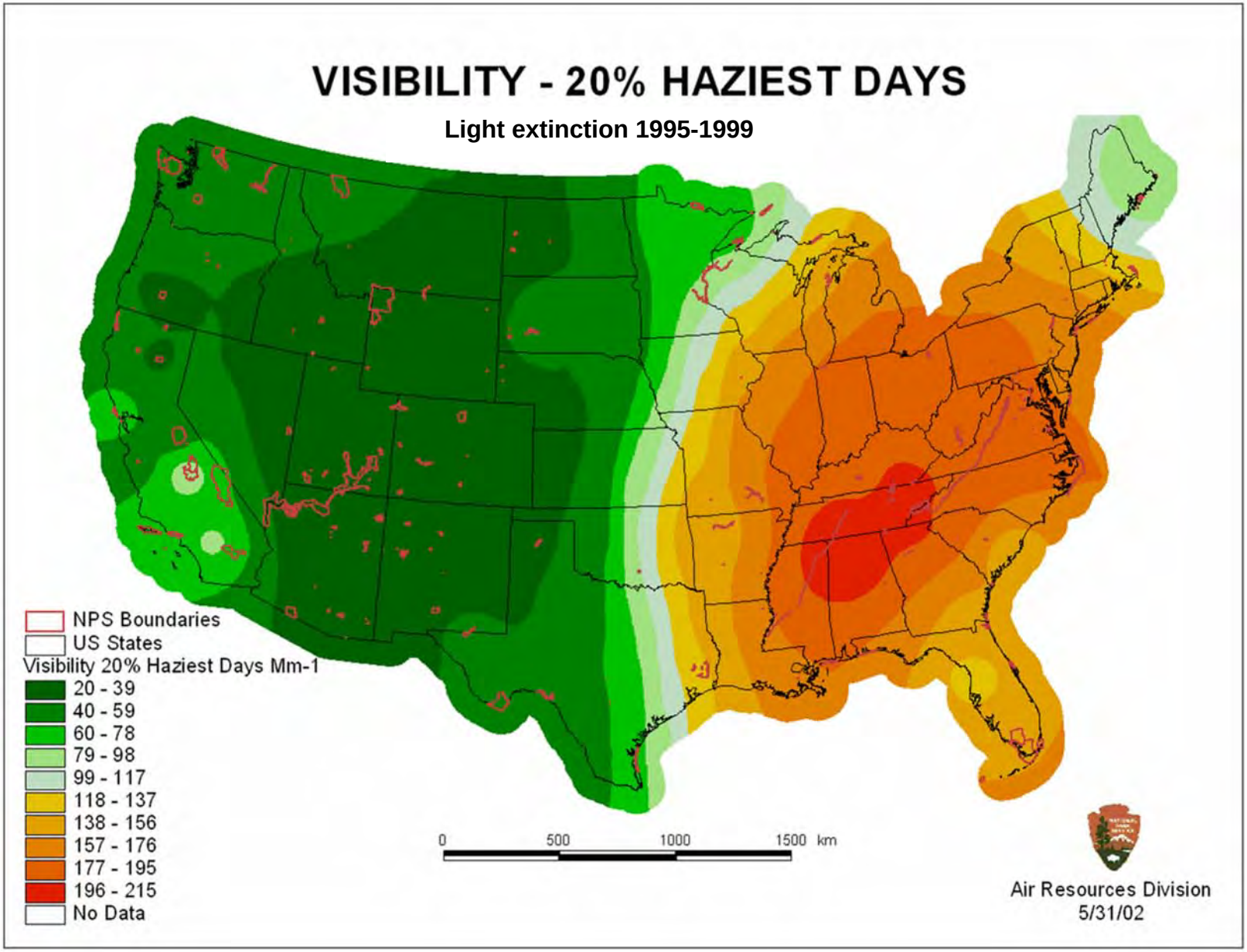

OZONE - NUMBER OF HOURS > 100 PPB
1995-1999
NPS Boundaries
US States
IDW Ozone-Number of Hours > 100 PPB
0 - 20
20 - 39
39 - 59
59 - 79
79 - 99
100 - 118
118 - 138
138 - 157
157 - 177
177 - 196
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02


Ozone - SUM06
1995-1999
NPS Boundaries
US States
Idw Ozone
SUM06
ppm/hrs
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 34
35 - 39
40 - 48
49 - 57
58 - 68
No Data
Air Resources Division
5/31/02


Wet Deposition - Total N
1995-1999
NPS Boundaries
US States
Total N Avg
(kg/ha/yr)
0.06 - 1.03
1.04 - 2.00
2.01 - 2.96
2.97 - 3.93
3.94 - 4.90
4.91 - 5.86
5.87 - 6.83
6.84 - 7.80
7.81 - 8.77
0
500
1,000
1,500
Kilometers
Air Resources Division
8/14/03


Wet Deposition - Total S
1995-1999
NPS Boundaries
US States
Total S Avg
(kg/ha/yr)
0.02 - 1.18
1.19 - 2.33
2.34 - 3.48
3.49 - 4.63
4.64 - 5.79
5.80 - 6.94
6.95 - 8.09
8.10 - 9.25
9.26 - 10.40
0
500
1,000
1,500
Kilometers
Air Resources Division
8/14/03


VISIBILITY - 20% CLEAREST DAYS
Light extinction 1995-1999
NPS Boundaries
US States
Visibility 20% Clearest Days Mm-1
4 - 7
8 - 11
12 - 15
16 - 19
20 - 23
24 - 27
28 - 31
32 - 35
36 - 39
40 - 43
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02


VISIBILITY - 20% HAZIEST DAYS
Light extinction 1995-1999
NPS Boundaries
US States
Visibility 20% Haziest Days Mm-1
20 - 39
40 - 59
60 - 78
79 - 98
99 - 117
118 - 137
138 - 156
157 - 176
177 - 195
196 - 215
No Data
0
500
1000
1500 km
Air Resources Division
5/31/02

## APPENDIX M SCOPING SUMMARIES. INTEREVIEWS WITH EACH SOPN PARK

TABLE OF CONTENTS

Table of Contents ..... A-235
M.1. Alibates Flint Quarries National Monument ..... A-236
M.2. Bent's Old Fort National Historic Site ..... A-239
M.3. Capulin Volcano National Monument ..... A-243
M.4. Chickasaw National Recreation Area ..... A-248
M.5. Fort Larned National Historic Site ..... A-252
M.6. Fort Union National Monument ..... A-256
M.7. Lake Meredith National Recreation Area ..... A-259
M.8. Lyndon B. Johnson National Historical Park ..... A-263
M.9. Pecos National Historical Park ..... A-266
M.10. Sand Creek Massacre National Historic Site ..... A-271
M.11. Washita Battlefield National Historic Site ..... A-275

**1) What are the park's most significant natural resources and issues?**
-cultural/geologic resource protection

**-Other important natural resources and issues?**
-Soils and erosion, slopes (>12%)
-exotic species
-native invasive species - mesquite
-funding slated originally for 4 million, never got any
-oil and gas – not a big deal in current form – no new surface drilling
-Air quality – attempted to monitor, TPW would give equipment if LAMR could give personnel. There is a copper refinery in the area, Class II park

**2) What are the greatest current threats to significant park natural resources?**
-funding
-exotics – tumbleweed, kochia
-erosion of dolomite
-air pollution – rock art is disappearing

**-Other current threats?**
-native invasives/fire - mesquite
-people servicing oil and gas

**3) What are the greatest potential threats to significant park natural resources?**
-excavation of quarry pits
-still have 270 acres not acquired but within boundary, would like to acquire

**-Other potential threats?**

**4) What are the park's most significant natural resource needs?**
-funding
-invasive exotics

**-Other natural resource needs?**
-lack of trail maintenance, interpretation of natural resources

**5) What are the park's most valuable/important/significant species?**
-Texas horned lizard
-big game
-Mississippi kites

**-Other important species?**

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**
-Texas horned lizard
-swift fox – possible. LAMR was looked at as a possible place for re-introduction, but not selected
-lesser prairie chicken - possible

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Effects of large wildfire – 1998-2003 - stopped | | | |
| -West Texas A+M – may continue herp study started by The Nature Conservancy | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| -Breeding bird surveys | | | |
| -Study of paleontological erosion areas | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Geological tour of the area produced by a student – filled chimneys are under-developed resource | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

-TPW, Texas Tech, TNRCC, NRCS, CRWMA, WRD, GRD, Black Kettle National grasslands, Panhandle Plains Historical Muesuem (where collections are held)

**11) What monitoring projects do you think the park needs the most and why?**

-Post-fire vegetation monitoring. Fires burned 5,200 acres, denuded vegetation and affected cultural resources. Hot fire due to dry weather,high temperatures, fuel buildup, burned entire park

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

TPW- Charlie Monger (fish), Gene Miller (ecologist), Bill Johnson (waterfowl), Robert Perez (quail), Dave Cook (deer)
Alvin Linn - erosion
J. R. bell – vegetation
Wes Phillips – retired
John Hughes - USFWS
Ed Day - springs

**13) What are the land uses on land adjacent to the park?**

Palo Duro ranch – grazing, and LAMR

**14) What is the next closest public conservation area?**

Palo Duro Canyon (TPW), Cross bar (BLM), Wildcat Bluff (private nature center), Playa Lakes WMA, Gene Howe WMA

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Annual report
-Summary reports of researcher's work
-Webpage

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

-In kind agreements with private landowners for fire, CRWMA, BLM

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

Ducks Unlimited, Quail Unlimited, TPW, USFS, West Texas A+M, Canadian River Water management authority, Texas Tech (Gene Wilde), Amarillo College, Botanical Research Institute of Texas, The Nature Conservancy, NRCS (rehabilitation)

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**a) Major habitat types at the park**

High plains, canyons, breaks

**b) Major processes**

Fire, grazing

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

Wes Phillips

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

**21) After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Karren Brown, cc Paul Eubank, Mike Davin

**22) Who should be the main SOPN contact in your park?**

Paul Eubank

**23) Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

**24) Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

Park is lacking GIS data

**Most Pressing Inventory Needs:**

Air Inventory, Migratory Birds, Swift Fox, big game species, Amphibians

**1) What are the park's most significant natural resources and issues?**
-death of Cottonwoods from fire, regeneration issues, future fire management
-value/function of arch wetland

**-Other important natural resources and issues?**
-short-grass prairie ecosystem around the park
-Prairie restoration – from old rowcrops on south side of river
-exotic control (thistle, kochia)
-historic viewshed
-water drainage
-fire management
-water drainage/hydrology/effects on adobe fort, upstream dams
-flooding

**2) What are the greatest current threats to significant park natural resources?**
-wild fire

**-Other current threats?**
-exotics (Tamarisk, whitetop- Cardaria, Lepidium, Russian knapweed, Canada thistle)
-wildlife diseases (west Nile, hantavirus – effects on cultural)
-flooding/hydrology

**3) What are the greatest potential threats to significant park natural resources?**
**-Other potential threats?**
-zebra mussels
-hazardous spill on railway or highway
-poor management adjacent to park
-wildlife diseases
-don't own mineral rights on south side of river, gravel pits in area

**4) What are the park's most significant natural resource needs?**
-wetland inventory (Arch wetland) – some debate about whether this was here at time of Fort, important biological feature regardless
-regeneration of cottonwoods – what to do? (hides highway/railway, buffers sound)
- weed control, pest control

**-Other natural resource needs?**
-Arkansas darter and Arkansas river shiner presence/absence
-disturbed land/prairie restoration
-weed control
-boundary survey
-park is almost 800 acres, very little open to public, only public access to river in the area
-encouraging other agencies / adjacent landowners to control tamarisk/other exotics
-removal of tamarisk was to lessen threat to cottonwoods

**5) What are the park's most valuable/important/significant species?**
-cottonwoods
**-Other important species?**
-native grasses (buffalo, blue gramma)
-prairie dogs
-oxen/peacocks

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-prairie dogs
-cottonwood/willow riparian ecosystem globally rare
-presence/absence of Arkansas darter, Arkansas river shiner?

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Vegetation transects (transects in excel) | since 1993 | Throughout | BEOL |
| Prairie dogs | last 4-5 years | Dog town | BEOL |
| Visitor use | | | BEOL |
| Exotics (tamarisk/exotics GPSed w/metadata) | last 4 years | Throughout | BEOL |
| Water table | last 3 years | River | BEOL |
| Mouse population | | Fort | ???? |
| Fire Plots | 2002 | | |
| West Nile Virus | 2003 | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| Breeding Birds Survey – Route 327 Crowley County | | | |
| Christmas Bird counts – one in Rocky Ford and one at John Martin Dam. | | | |
| USGS – River flow | | | |
| Colorado DOW – flights for deer, does by reach, 2 include BEOL | | | |
| Federal Highways are doing new aerial photographs | | | |
| Weather station | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Tamarisk research (1968), South side of river, at the time the location said ¼ mile east of Fort, this area is now owned by BEOL | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

-Weed control – adjacent landowners, CO DOW, Colorado Corrections, CO State Forest Service, private adjacent landowners, CO Boys Ranch, La Junta City Golf Course, Fort Lyon Canal
-Otero Junior College (Greenhouse proposal for restoration)
-NRCS

**11) What monitoring projects do you think the park needs the most and why?**

-Arch wetland and other wetlands/river
-water quality/quantity
-IPM

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

-Ben Berlinger (NRCS).

From Fran: Now these are not people that this park has worked with. They are just knowledgeable people that I know of: Is this supposed to be someone who has worked with the park?

Ivo Lindauer, Tamarisk/riparian plant communities. Currently on the board of the Colorado Native Plant Society. 970-255-1112. I don't know any more about him than that except that he did his master's thesis on the Arkansas river and you have copies of his publications.

Wendell Hassell - worked for NRCS most of his career, transferred to NPS as regional vegetation specialist. They will know him in region, I think. Right now he is chairman of the High Altitude Revegetation Committee. Excellent resource. Really nice man.

Ken Lair - USDI, BOR ,National Restoration Ecologist, working on tamarisk in southern NM. Knows our project. Very knowledgeable. Also nice person.

Someone I don't know that Kathy Tonnessen might is D. Terrance Booth, Rangeland Scientist, High Plains Grasslands Research Station, USDA, Cheyenne, Wyoming.

**13) What are the land uses on land adjacent to the park?**

-East CODOW 400 acres (hunting, low intensity rowcrops)
-farming (rowcrops)
-abandoned rowcrops
-highway, railway

**14) What is the next closest public conservation area?**

-CO DOW Oxbow Unit
-Comanche National Grasslands
-Southern Plains Land Trust – Fresh Tracks
- Ryan's Ponds in Rocky Ford, DOW land.

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Web page link from BEOL to SOPN – Greg Holt is contact
-brochure

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

-SEPAS, CCI, Rocky Mountain CESU

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-Dexter Hess, retired Otero Junior College Botany Professor

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

-Kathy Tonnesson

**a) Major habitat types at the park**

-Short-grass prairie, wetlands, riparian cottonwood ecosystem

**b) Major processes**

-Floods, fire, grazing

**19) Are there any natural resource park "experts" that you think we should conduct this interview with? No**

20) **In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

Dexter Hess, OJC

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Fran, Karl

22) **Who should be the main SOPN contact in your park?**

Fran

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

24) **Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

**Crucial Inventory Needs:**

Wetland/river inventories

**1) What are the park's most significant natural resources and issues?**

-Capulin is a classic cinder cone volcano – protection of volcanic features and geologic processes is most significant.
-Eerosion caused by the road (2.5 miles, built in 1920's, paved 1988) and effects on volcano is the most serious issue; 27 culverts have little protection for slowing water down resulting in large gulleys below the road.

**-Other important natural resources?**

-GPRA Goals established performance measures and targets for restoration of disturbed lands and control of exotic species.
-scenic quality and air quality are also significant; the views from Capulin Volcano are one of the most important features and resources
-adjacent land uses; in respect to impacts on scenic and air quality, visual impairments, effects on wildlife and spread of exotic plants
-Pinion-juniper encroachment, hillside use to be almost all grassland, effects on butterfly?
-lack of consistent long-term management; need for general management plan
-unauthorized trails/human use
-weedy invasions, no state listed noxious weeds (tumbleweed, mullein, cheatgrass, thistle, clover, horehound (mint), and houndstongue (borage) are present )
-fire suppression for 80 years
-effects of no grazing since 1970's
-exotics - going from park to adjacent lands, and possibly brought into park from vehicles, roads, use of hay in erosion control projects (difficult to impossible to find "weed free" hay, but have screened local hay sources for presence of noxious weeds.)
-porcupine – population cycles, effect of eating bark causes management and visitor concern when the number of scarred trees seems to increase
-what is CAVO providing for wildlife? – no water, is it lack of grazing, protection?

**2) What are the greatest current threats to significant park natural resources?**

-erosion
-exotics
-pinion juniper encroachment

**-Other current threats?**

-drought interaction with exotic plant encroachment
-lack of long-term management
-impacts to butterfly
-development impacts on viewshed, haze and air quality, night skies

**3) What are the greatest potential threats to significant park natural resources?**

Erosion accelerated by human disturbance, such as the Volcano Road and trails.
Uncontrolled wildland fire
Unmanaged disease and pests (to plants and wildlife)
Invasive species

**-Other potential threats?**

-drought
Human Encroachment and disturbance, including -subdivision of ranches; adjacent land uses and developments such as potentially two new coal fired power plants
-Regional haze and diminished air quality
-Folsom has contaminated water
-Undeclared Raton Basin acquafer – water rights, unknown status

**4) What are the park's most significant natural resource needs?**

-lack of long-term management plan; need for general management plan; revision of resource management plan in alignment with GMP and Strategic Plan
-Staffing and funding for a full-time position in resource management.

**-Other natural resource needs?**

-water – lack of a source for wildlife, should park provide?
-erosion mitigation plan for Volcano Road
-fire plan

**5) What are the park's most valuable/important/significant species?**

-butterfly – dependent on grassland, don't know host species, not found at CAVO last year, but weather may have affected surveys, found at Dale Mt. last year
-easternmost locations of aspen, and ponderosa pine, other than Sierra Grande
-Pinion pine; Fringed sagewort;
-Mule deer; Gray fox
-Eastern fence lizard, Western prairie rattlesnake
-Common Raven, Rufous sided Towhee
-ungrazed short-grass prairie, some tallgrass species, some lava flows may hold water allowing tall grass species

**-Other important species?**

-diversity of species, combination of Montane, prairie, desert ecosystem in small area
-Townsend's big-eared bat
-Bear, mountain lion, Elk
-other endemic arthropods; ladybugs from cultural perspective, swarm at high elevations
-horned lizard
-just outside park, playas major migratory bird stopover point

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-butterfly
Townsend's big-eared bat

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Visitor use, visitor survey University of Idaho | | | |
| -Gypsy moth, 2 traps per year, CAVO | | | |
| -Fire effects- CAVO | | | |
| -Butterfly project, surveys again this year | | | |
| -Weed mapping GIS, Great Plains CESU | | | |
| -Air Quality - Acid rain – 20 years of precipitation, pH, part of national program - CAVO | | | |
| -Armillaria – every five years, started either 5 or 10 years ago -CAVO | | | |
| -Night sky monitoring unsuccessful attempts 2 times last year | | | |
| -2003 grasslands - Pam Benjamin | | | |
| -Tree coring – Peter Brown, Colorado Alpine Research Center | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| -Widening highway, may be useful information | | | |
| -Vegetation at time of Santa Fe Trail – Raymond Owensby at local high school | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Breeding bird survey, | 1993, 1994, 1996 | | |
| -Gennarro veg map – | 1970's | | |
| -Air Quality - visibility | | | |
| -Mosquitoes - did not catch any | | | |
| -Pellet counts mule deer | | | |
| -Erosion plots photographs, CAVO | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

-FHA restoration eroded areas
-Butterfly – NM Natural Heritage
-Weed Mapping –Great Plains CESU UNebraska

**11) What monitoring projects do you think the park needs the most and why?**

-montane grasslands
-restoration of disturbances
-road effects
-air quality
-movement of big game through park
-special habitats as they are identified

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

- Dr. Kris Johnson Natural Heritage New Mexico,
- Dr. Parmenter, completed T&E survey, UNM,
- Dr. Larry Crumpler, Geologist, New Mexico Natural History Museum in Albuquerque
-Dr. Bill Sayre, geologist, thunderstorms, College of Santa Fe
-Dr. Lee, weed survey,
-Rinkin, professor at Trinidad Jr. College, Pondersosa Pine
-Pam Benjamin, plant ecologist with NPS-IMR-Denver
-Dave Steenson, Geomorphology, NPS-WASO Geologic Resources Division
-Dr. Peter Brown, long term drought study/tree coring, Alpine Research Center
– All of these were suggestions for committee

**13) What are the land uses on land adjacent to the park?**

-West and North state land leased for grazing, some also on East.
-South, east, and Southeast ranching on private land,
-East some surface mining

**14) What is the next closest public conservation area?**

-Maxwell NMW, Las Vegas NWR
-Kiowa National Grasslands, USFS, in Union County near Clayton
-Sugarite State Park

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Site Bulletin, traveling exhibit for visitor center, permanent exhibit at CAVO visitor center would be welcome, student volunteers, link from CAVO to SOPN, yearly newsletter

16) **What funding sources have you applied to when seeking to increase natural resource funds?**

-Western National Park Association, cooperating association research fund.
-Federal Lands Highway Program, transportation (Roads) funds for road and road associated erosion work.
-Small Park NRPP
-Disturbed Lands – NRPP
-Fee Demo Program – both 20% and 80% funds; a lot of restoration work was accomplished over the past 5 years with 20% fee demo funding of the Public Land Corp crew.

17) **Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-Boy Scouts, YCC, 20% fee demo (Public land Corps, Erosion, Exotic plant reductions), Raton Youth Organization

18) **Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

-NRCS has some ecosystem models
-Other NPS park with volcanoes El Malpais – S. Colorado Plateau
-grassland, Pinyon/Juniper/Montane

**c) Major habitat types at the park**

-lava flows (grasslands), boca (Montane w/pondersosa and aspen), cone (Pinyon/Juniper)

**d) Major processes**

-fire, grazing, woody encroachment

19) **Are there any natural resource park "experts" that you think we should conduct this interview with?**

-Steve Cinnamon - Natural Resources, Midwest Region (former CAVO employee)
-Dennis Carruth – Superintendent Aztec Ruins NM (former CAVO Chief Ranger)

20) **In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

Dave Cleary (birds, volunteer w/FWS), Pam Benjamin- NPS-IMR plant ecologist, Steve Carey (butterfly, NM State Parks); Bob Dyes, manager and Sarah Wood, interpreter at Sugarite State Park.

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

-Brian, Maggie

22) **Who should be the main SOPN contact in your park?**

-Chief Ranger: Brian Quigley, 505/278-2201x230

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions,**

**information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

24) **Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

-think about future staffing needs for SOPN
-make sure parks are buying in, keep in contact with parks through visits, inform neighbors, maybe an evening presentation at CAVO, tribal consultations

Most Pressing Inventory Needs:
-Non-vascular plants – lichens
-Cryptobiotic soils
-herps
-Soils inventories
-invertebrates, potential for other endemics

**1) What are the park's most significant natural resources and issues?**

-Water quality and quantity – lentic, lotic, groundwater, artesian wells, springs, seeps, lakes, public water supply, recreational issues, habitat issues. Corps of Engineers monitors lake level and flow, Bureau of Reclamation relases water

-Vegetation management – Invasive plants (eastern red cedar, Johnson grass). Fire suppression leads to cedar invasion. Cedar issues is related to water due to consumption by cedar. Much of area historically a savannah.

**-Other important natural resources and issues?**

-soundscape – degradation of from urban development
-exotic animals – hogs, dogs, cats, fallow deer
-importance of riparian areas – near western most distribution of this forest type
-hunting – big game animals deer and turkey
-reptile population
-Fishing – effects on fishery, different genetics from historical due to introduction of Florida strain, hybrid stripers
-fossil resources
-wetlands/ ponds – largely unknown
-much of Platt District – artificial forest/landscape
-low numbers of quail due to cedar invasion and high number of raccoons

**2) What are the greatest current threats to significant park natural resources?**

-Water quality and quantity
-Red cedar invasion
-lack of funding

**-Other current threats?**

-chicken farming
-water mining
-exotic plant invasion through horse feces and vehicles
-erosion along lake
-hunting
-poaching – Echinacea, reptiles
-surrounding landscape's effect on aquifer
-urban interface – development, viewsheds, boats, pollutants, boundary encroachments
-effects of visitors on natural resources – 1.5 million visitors
-sewer system goes through park
-raccoons in campgrounds
-IPM issues
-E. coli bacteria

**3) What are the greatest potential threats to significant park natural resources?**

-water mining
-exotics

**-Other potential threats?**

-Zebra mussels
-nitrates in water
-water mining

**4) What are the park's most significant natural resource needs?**

-lack of natural resource staff
-water quality/quantity information
-prairie restoration/removal of cedar

**-Other natural resource needs?**

5) **What are the park's most valuable/important/significant species?**

No specific one

**-Other important species?**

-deer/turkey/waterfowl/fisheries
-echinacea
-fossils
-native grasses/associated species
-birds (for birdwatchers)
-bald eagles
-red cedar
-raccons

6) **What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-Bald eagle (winter resident), whooping crane (migrant), interior least tern (migrant)
-alligator snapping turtle, Texas horned lizard, marsh rice rat, black-capped vireo????

7) **Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Deer – spotlight surveys | 1999-present | All over | CHIC |
| E. coli | 2000-present | Swimming areas (weekly) | CHIC |
| Water flow | 2004-present | Tributaries | CHIC |
| Fish surveys | ??-Present | Lakes | OK Dept. of Fish and Game |
| Aquatic invertebrates | | Water bodies | East Central University |
| Rainfall/temperature | 1978-present | CHIC | CHIC |
| -Rainfall back to 1900's | | | |
| Water quality (ph, dissolved oxygen, conductivity, turbidity) | ??-Present | | CHIC |
| Lake level, spring levels, Flow | ??-Present- USGS | | |

8) **Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| Deer, birds | Noble Foundation, Wildlife Research Unit | Ardmore County, 2800 acres | |
| Weather station – NOAA in Murray County | | | |
| Breeding bird survey, Christmas Bird Counts in area | | | |

9) **Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Additional weather variables | | | |
| Spring monitoring ceased in 1994, Tom Taylor | | | |

10) **Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

OK Dept. of Fish and Game – Fish survey, presence/absence, density, electrofishing/gillnetting
USGS – water quality/quantity, bacteria levels
East Central University – Aquatic invertebrates

11) **What monitoring projects do you think the park needs the most and why?**

-springs
-deer
-fisheries – genetics/abundance
-reptiles
-grassland indicator

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

-Jennifer Buck, John Beck – NPS, WRD Fort Collins
-John Reber – Physical Scientist, NPS
-R.V. Ward, Grand Canyon NP

**13) What are the land uses on land adjacent to the park?**

-urban residential, agriculture (chicken farm, feedlots, grazing, rowcrops), resort, youth camp

**14) What is the next closest public conservation area?**

-Tishomingo NWR, Pontohoc Ridge (TNC)

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-webpage

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

-National Wild Turkey Federation, Noble Foundation, Fire money, fee Demo, Private donations

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-USGS, Noble Foundation, Lifestyle Center of America, Goddard youth Camp, OK Dept. of Wildlife, East Central University, NRCS – RC+D, OK Coop. Extension, Arbuckle Master Conservancy, Sulphur Schools, Murray County, City of Sulphur, Boy Scouts, Oklahoma State University

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**a) Major habitat types at the park**

-Upland prairie, lake, riparian hardwoods

**b) Major processes**

-Fire, woody encroachment

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

No

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

-Jennifer Buck, John Beck – NPS, WRD Fort Collins

-John Reber – Physical Scientist, NPS
-R.V. Ward, Grand Canyon NP

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Steve Burrough

22) **Who should be the main SOPN contact in your park?**

Steve Burrough

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

24) **Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

Truly fulfilling mandate, restoring habitat and then species, i.e. black-tailed prairie dogs

**Most Pressing Inventory Needs:**
Mapping of exotic plants

**1) What are the park's most significant natural resources and issues?**

-Prairie restoration – remove exotics (smooth brome, fire weed, poison hemlock), very few forbs, need more diversity
-prairie dogs at trail ruts site (33 acre town), need to continue to monitor extent, evaluate effect on ruts, population control methods, problem with adjacent landowners, occasional burrowing owl, study soil erosion deposition rates of prairie dog town interaction with trial ruts – clipped vegetation may reduce deposition from adjacent land uses?

**-Other important natural resources?**

-Fire management – prescribed fire began in 1999 – evidence that seed production and seed vigor of smooth brome went down after fire, effects of timing of fire on prairie restoration
-completing inventories, getting to 90% (coverboards are still out)
-get established on the Kansas Birding Trail, increase visitation based on natural resources
-Pawnee River – was clean clear flowing, perennial river, now dry due to adjacent land uses – irrigation and dams above FOLS. Not sure what FOLS staff can do. Water may still be flowing underneath the surface (Hyporheic zone). A large increase in sedimentation at FOLS

**2) What are the greatest current threats to significant park natural resources?**

-exotic vegetation
-prairie dog/trail rut issue

**-Other current threats?**

-Irrigation/dam/sedimentation on Pawnee
-viewshed issues, currently have 300 acres under easement, but not complete only 30-40 feet around ownership
-air quality

**3) What are the greatest potential threats to significant park natural resources?**

**-Other potential threats?**

-viewsheds – wind farms
-water use issue, FOLS has continued to fight to maintain the water use right to replenish water to the Pawnee River
-Feedlots that could be adjacent to FOLS, or upstream on the Pawnee

**4) What are the park's most significant natural resource needs?**

-prairie restoration (see above)
-prairie dogs (see above)

**-Other natural resource needs?**

-inventories, get to 90%
-new resource management plan

**5) What are the park's most valuable/important/significant species?**

-prairie dogs

**-Other important species?**

-mule deer / white-tailed deer
-coyote
-bobcat – recently reduced in the area due to trapping at a nearby farm
-small mammals
-turkey

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-prairie dogs
-bald eagle – observed, but no known nesting activity
-burrowing owl

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| KBS – Inventories | | | |
| Kansas Geological Survey | | | |
| Kansas Water Resources Division | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| NWS stream monitoring stations | | | |
| Ground water (Earl Grove) | | | |
| Breeding Bird Survey in Pawnee County, Routes 314, 9 | | | |
| Christmas Bird Counts – Quivira NWR, Dodge City | | | |
| Konza – Breeding Biology and Research and Monitoring Database and other prairie info | | | |
| Kansas Breeding Atlas – Pawnee County | | | |
| Precipitation Record – Larned | | | |
| Nearest Official weather station, Great Bend, 43 mile east | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible For project? |
|---|---|---|---|
| Historical resource accounts at time of Fort | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

None at this time

**11) What monitoring projects do you think the park needs the most and why?**

-prairie restoration
-prairie dog monitoring/sedimentation/deposition

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

-NRCS field agent – Toni Farebacker
-Scott Gibben – birds (Kansas Ornithological Society)

**13) What are the land uses on land adjacent to the park?**

-row crop agriculture
-highway 156
-some oil/gas within 2 miles of park boundary
-stock yard to the north

**14) What is the next closest public conservation area?**

-Cheyenne Bottoms WMA, Quivira NWR, Konza, Cheyenne Bottoms Preserve (The Nature Conservancy), Smokey Valley Ranch (The Nature Conservancy)

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-webpage, link from FOLS to SOPN
-potential to communicate with Arkansas River Coalition, NRCS, FWS, Kansas State Wildlife Agency, Sierra Club
-electronic newsletter

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

-SEPAS

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-NRCS, Fort Hays State University, Kansas State University, Kansas Ornithological Society, Audubon Christmas Bird Count

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**c) Major habitat types at the park**
Grasslands, Pawnee River/Riparian/Oxbow

**d) Major processes**
Fire , grazing –investigate as alternative to fire

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

Tony Ferenbacher – NRCS, Choate – Fort Hays, people from Cheyenne Bottoms

**21) After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Felix, Steve

**22) Who should be the main SOPN contact in your park?**

Felix

**23) Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

October good time for meeting

**24) Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

-Finding staff to do natural resources is a major issue at FOLS

**Inventory Crucial Needs Question**

-All inventories lacking, no need greater than another at this time

**1) What are the park's most significant natural resources and issues?**

Most significant natural resource at Fort Union is the native prairie grass. Issues associated with natural resources within the fort are:

Burrowing rodents and their effects on the cultural resource and vegetation encroachment on the ruins.

-gopher and rabbit effects on the ruins
-vegetation encroachment on the ruins

**-Other important natural resources?**

-effects on the lack of grazing for over 50 years – comparisons with surrounding ranch?
-using vegetation to control effects of erosion on Santa Fe Trail ruts (run approximately from NE corner to SW corner
The use of fire as a means of revitalize vegetation?
-managing for 1862 conditions, except for what was most likely very heavily grazed lands around the fort?
-maintain vegetation within ruins
-approximately 80 acres at 3rd fort site ruins, and 10 of 80 acres at first fort site are ruins
-viewshed- (Cultural Landscape)

**2) What are the greatest current threats to significant park natural resources?**

Existing drought

**-Other current threats?**

Exotic plants – mapping study underway

**3) What are the greatest potential threats to significant park natural resources?**

**-Other potential threats?**

-exotic plants

**4) What are the park's most significant natural resource needs?**

-A study on impacts of natural resources (mammals, vegetation) on ruins

**-Other natural resource needs?**

**5) What are the park's most valuable/important/significant species?**

-shortgrass prairie community

-gophers and rabbits

Snakes and coyotes keep rodents in check

**-Other important species?**

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-burrowing owls in area, none documented on site
-mountain plovers possibly in the area
-opportunity for peregrine falcons

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Weed mapping | – Gary Willson, Great Plains CESU | | |

Fire weather data
Visitor use

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Vegetation survey of historic conditions | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

New Mexico Natural Heritage Program, Great Plains CESU, EA for fire with USFWS, Soil Conservation Service (brief overview of exotic plants – Las Vegas Mr. Lucerro)

**11) What monitoring projects do you think the park needs the most and why?**

-Effects of weeds/mammals on ruins, can draw on eradication programs at PECO

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

-For cultural issues – Bob Hartzler

**13) What are the land uses on land adjacent to the park?**

Fort Union Cattle Ranch - grazing

**14) What is the next closest public conservation area?**

-Area in Wagon Mound
-Las Vegas NWR
-Maxwell NWR

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Site bulletins, 1 page specific to FOUN
-Link from FOUN to SOPN

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-Highlands University
-Weed Management organizations

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**e) Major habitat types at the park**

Short grass prairie

**f) Major processes**

Fire, grazing

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

Soil Conservation Service, Ag. Extension

**21) After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Mitzi

**22) Who should be the main SOPN contact in your park?**

Ruben and Mitzi

**23) Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

**24) Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

**Most Pressing Inventory Needs:**

FOUN Bird checklist
Vegetation Map

M.7. LAKE MEREDITH NATIONAL RECREATION AREA, MARCH 24, 2004

---

**1) What are the park's most significant natural resources and issues?**

-water quantity and quality (ground and surface water) – sources of pollution in river and lake. Canadian River is dammed twice above LAMR. Lake level never came up as high as predicted. Current lake level is 59', intake is at 49'

**-Other important natural resources and issues?**

-Soils and erosion, slopes (>12%), unstable soils, sedimentation, turbidity
-exotic species – tamarisk
-off-road vehicle use – supposed to stay in flats, but much illegal use
-native invasive species - mesquite
-funding
-hunting (need assistance, only getting voluntary information from hunters) and fishing (getting help from TPW), there is a fish advisory eating warning (mercury) for walleye
-oil and gas – not a big deal in current form
-reclamation of roads
-Air quality – attempted to monitor, TPW would give equipment if LAMR could give personnel. There is a copper refinery in the area, Class II park
-state owns river bed and flood plain, but park has responsibilities for management

**2) What are the greatest current threats to significant park natural resources?**
-funding
-exotics
-pollution to lake and river – lake is water supply for 11 communities. Water is currently 500 ppm saline, have to add well water

**-Other current threats?**
-native invasives/fire - mesquite
-erosion
-off-road vehicle use
-impacts of man on ecosystem
-7 known springs that are drying up
-gray water from subdivisions enters lake

**3) What are the greatest potential threats to significant park natural resources?**
-funding – use to have 30 positions, now only 24. Not complying with mandates, policies.

**-Other potential threats?**
-hog farms
-oil and gas – if it changes from current management
-geologic hazards

**4) What are the park's most significant natural resource needs?**
-boundary marked and fenced (12 miles unfenced) – for hunting, grazing, orv. Cattle grazing pretty much stopped in 1980's, but in areas that are not fenced cattle wander on and graze
-funding – specifically for protection and enforcement

**-Other natural resource needs?**
-public education and interpretation – about water issues, declining water table

**5) What are the park's most valuable/important/significant species?**
-Texas horned lizard
-cottonwood/tallgrass gallery
-river corridor
-salt cedar

**-Other important species?**
-deer, turkey, ducks geese, mountain lion
-fishery - southern most location for walleye
-Mississippi kites
-Rolling Plains / high plains ecotone

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**
-Texas horned lizard, bald eagle,
-Arkansas river shiner – State is against listing the shiner. If lake ever achieved its conservation pool, shiner habitat would be wiped out. Critical habitat at LAMR was recently removed. Tamarisk makes for silty bottoms, shiner needs sandy bottoms
-black-tailed prairie dogs – former colony at picnic area, 2001 plague wiped them out, likely to come back in the future
-swift fox – possible. LAMR was looked at as a possible place for re-introduction, but not selected
-lesser prairie chicken - possible

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Christmas bird count, >10 years | | | |
| -Winter eagle count with local Audubon group, >10 years | | | |
| -Deer count by state | | | |
| -Fire fuel plots – 1999-present | | | |
| -Stillings basin – water quality, fecal coliform | | | |
| -EPA/Univerisity of New Mexico – point source water quality | | | |
| -Canadian River Authority – monthly water quality | | | |
| -State inventories of game fish >10 year data set | | | |
| -Salt cedar – photo points | | | |
| -BOR – will be releasing salt cedar leaf beetle – first will be put in sealed tents. LAMR needs help monitoring. Texas tech involved (birds eating the beetle). | | | |
| -West Texas A+M – may continue herp study started by The Nature Conservancy | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| -Breeding bird surveys | | | |
| -Study of paleontological erosion areas | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -4 historic wells | | | |
| -Geological tour of the area produced by a student – filled chimneys are under-developed resource | | | |
| -Erosion at LAMR | | | |
| -Monitoring for loss of fuel at underground storage tanks | | | |
| -Geologic hazards – above Blue Creek, Spring Canyon, North Canyon | | | |
| -Arkansas river shiner work – Texas Tech | | | |
| -Blue Creek – elevated pesticide levels | | | |
| - Gas leak – 400-700 gallons, monitored | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

-TPW, Texas Tech, TNRCC, NRCS, CRWMA, WRD, GRD, Black Kettle National grasslands, Panhandle Plains Historical Muesuem (where collections are held)

**11) What monitoring projects do you think the park needs the most and why?**

-salt cedar / bug project
-Big game, quail
-Central flyway
-mussels inventory
-water quality – heavy metals
-ORV use – erosion, last 10 years has gotten worse
-amphibians
-invasives

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

TPW- Charlie Monger (fish), Gene Miller (ecologist), Bill Johnson (waterfowl), Robert Perez (quail), Dave Cook (deer)
Alvin Linn - erosion

J. R. bell – vegetation
Wes Phillips – retired
John Hughes - USFWS
Ed Day - springs

**13) What are the land uses on land adjacent to the park?**

Urban, private ranchland, residential, sewage treatement, gravel, oil and gas, agriculture (corn wheat, milo, cotton sorghum)

**14) What is the next closest public conservation area?**

Palo Duro Canyon (TPW), Cross bar (BLM), Wildcat Bluff (private nature center), Playa Lakes WMA, Gene Howe WMA

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Annual report
-Summary reports of researcher's work
-Webpage
-add exhibit to the kiosk")

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

-National Wild Turkey Foundation – tamarisk removal
-In kind agreements with private landowners for fire, CRWMA, BLM

**17) Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

Ducks Unlimited, Quail Unlimited, TPW, USFS, West Texas A+M, Canadian River Water management authority, Texas Tech (Gene Wilde), Amarillo College, Botanical Research Institute of Texas, The Nature Conservancy, NRCS (rehabilitation), BLM)

**18) Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**g) Major habitat types at the park**

High plains/rolling plains, springs, lake, river, cottonwood galleries, breaks (areas that were cut and carved by river)

**h) Major processes**

Salt cedar, hunting, ORV, fluctuating water levels, wave action, salt cedar, salinity, fire, grazing

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

Wes Phillips

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Karren Brown, cc Paul Eubank, Mike Davin

22) **Who should be the main SOPN contact in your park?**

Paul Eubank

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

24) **Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

Park is lacking GIS data

**Most Pressing Inventory Needs:**

Air Inventory
Migratory Birds
Swift Fox
Big game species
Amphibians

**1) What are the park's most significant natural resource management issues?**

-Bank stabilization and erosion issues on the Pedernales River

**-Other important natural resources issues?**

-Water quality and water quantity of the Pedernales River
-Effects of dams? – are they to blame for erosion? Drought? Adjacent land uses?
-3 dams near the park, 2 are within park boundaries
-1952 Flood, 500 year event, changed the whole area
-Native grasses
-Night sky – lighting of sky from increasing development
-Overpopulation of white-tailed deer
-Exotic animals, nutria, grass carp, blackbuck antelope
-Attempts to control erosion by revegetating banks and excluding the cattle do not appear to be working
-cedar invasion, not a problem in the park, but is on adjacent lands
-Oak wilt
-air quality from distant factories, urban areas in Texas, South America
-distemper
-silver leaf nightshade, thistle, and other native species that are dealt with as pests at the ranch due to hay production

**2) What are the greatest current threats to significant park natural resources?**

-None specified

**-Other current threats?**

-Deer, antelope, squirrels, raccoons overpopulation
-Possibly more coyotes, foxes, bobcats
-urban sprawl, light pollution
-ranch mangt, exotic grasses
-ranch mngt, adjacent lands, 7-foot fences
-Air quality from far-off factories
-dams – not sure what effect they have
-river pollution from agriculture

**3) What are the greatest potential threats to significant park natural resources?**

-none specified

**-Other potential threats?**

-Axis deer
-africanized honeybee
-Night sky, lessening from adjacent dvlpt.
-Feral cats
-HW 290 could have accidents with hazardous material that spill into Pedernales, Rocky Creek
-Fredericksburg sewer treatment – potential to contaminate Pedernales
-adjacent agriculture (Hog Farms)
-decreasing quail numbers

**4) What are the park's most significant natural resource needs?**

-Deer/game management

**-Other natural resource needs?**

-King ranch bluestem – how to control
-assistance with long-term natural resource planning

-bank/erosion problem on Pedernales
-low small mammal numbers, why? Possibly linked to KR bluestem
-information on invertebrates

**5) What are the park's most valuable/important/significant species?**

-Most important – Herefords bred to appear as they did when LBJ lived at the ranch

**-Other important species?**

-Live oaks, American elms (Trees in general)
-Native grasses at Johnson settlement
-King Ranch bluestem (negative)
-Pecans (most at settlement will be removed except near creek where they are in their natural habitat, the orchard is managed at ranch)
-Wildflowers
-Guadalupe bass, Texas Map turtle
-fish, ducks
-Freshwater mussels (lack thereof, did not come back after 1952 flood)
-Zebra mussel (exotic)
-Texas horned toad

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-Bald eagle – only species on the park's official list
-Texas horned toad – state listed as threatened, may be at LYJO
-Texas map turtle – Edwards plateau endemic
-Guadalupe bass – Edwards plateau endemic
-Golden-cheeked warbler, black-capped vireo – federally endangered species in the area, not known to occur at LYJO and don't really have right habitat

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Water quality | 1996-Present | 2 locations on Ped. (1 in park) | CRWA |
| Inverts | 2004-Present | 2 locations on Ped. (1 in park) | LYJO |
| Oak wilt | 2002-Present | Drive around LYJO | Texas Forest Serv/LYJO |
| Meterology | ?Longest fire weather station in area, | Ranch, | LYJO w/Texas Forest Serv |
| Precip/Rain | ?-Present | Ranch | National Weather Service |
| Vistor Use | ?-Present | | LYJO |
| Water quality | ? | Spring-fed pond, JC | LYJO |
| Well water monitoring | ? | Several locations | LYJO |

-opportunistically trap/eliminate armadillos and other pests, may be records of #s

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location ? | Who is responsible for project? |
|---|---|---|---|
| Breeding birds | ? | One in Gillespie | BBS |
| | | Several more in surrounding counties | |
| Winter Birds | ? | several in area | Xmas Bird Count |
| Birds | ? | Bamberger | Bamberger |
| Oak wilt | ? | area | TX Forest Serv. |
| Groundwater | | | Groundwater Cons. Dist |

Others who may monitor – West Cave (LCRA), NRCS, CCRA (cedar), Texas Center for Policy Data

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Grassland restoration | Varies | Settlement | Smiens |
| Insects of Pecan nuts | ???? | Ranch Orchard | NPS |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

**11) What monitoring projects do you think the park needs the most and why?**

Fire vegetation monitoring – planned to be done
Canadian elm beetle – historic elms
Fire ants
Invasive plants
Oak wilt
Small mammals
Birds
Landscape around park
Insects - Inventory

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

Dr. Fred Smiens – Texas A+M
Sanders – Botantical Research Institute of Texas
Mark Simmons – National Wildflower Research Center
??NRCS Rep in Kerrville/Llano – Game management
Bill Botard – Ag Extension, Fredericksburg

**13) What are the land uses on land adjacent to the park?**

Ranch - Ranching, low density residential, state park, tourism, highways, farming
Johnson City – Commercial, residential, highways, ranching

**14) What is the next closest public conservation area?**

State Parks - Pedernales Falls, Enchanted Rock State Park, Blanco River, LBJ, Guadalupe River, Honey Creek State Natural Area, Colorado Bend State Park, Longhorn Cavern, Inks Lake State Park, James River Bat Cave
US Fish and Wildlife Service - Balcones Canyonlands NWR
Private Land - Barton Creek Habitat Preserve (The Nature Conservancy), Storm Ranch (Hill Country Conservancy)
West Cave Preserve (LCRA?)

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

Website, email briefing staff, guest lecture, newsletter, link from LYJO webpage to SOPN webpage, LCRS (Ralph), Farm Bureau (Potential partner) – Tab Duncan

**16) What funding sources have you applied to when seeking to increase natural resource funds?**

LCRA – River watch, SEPAS, National Wildflower Research Center, Small Park Natural Resource Block Grants

17) **Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

Texas Parks and Wildlife, LCRA, NRCS, Texas A+M, Bamberger Ranch, Texas Forest Service, Local Audubon Chapters (Highland Lakes), King Ranch

18) **Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

i) **Major habitat types at the park**
Oak Savanna, Pedernales River

j) **Major processes**
Fire, Precipitation highly variable

19) **Are there any natural resource park "experts" that you think we should conduct this interview with?**

20) **In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

Fred Smiens, Mark Simmons, Wendy Conley (Texas Parks and Wildlife), Andy Hubbard (Desert Southwest I+M Coordinator)

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Brian Carey who will then forward to appropriate people.

22) **Who should be the main SOPN contact in your park?**

Brian Carey

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

LYJO Will send representative to annual meetings, scoping (particularly if travel is paid for). Also suggested that someone from maintenance should attend these meetings.

24) **Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

**1) What are the park's most significant natural resources and issues?**
-exotic plants
-fire management

**-Other important natural resources?**
-feral dogs
-historic pastures
-water quality and water quantity
-impacts from external resources – viewsheds, water, air, noise, subdivision/suburban development
-fire and forestry management – exotics, fire plan, drought, beetle infestation, loss of Pinion Pines, historic pastures

**2) What are the greatest current threats to significant park natural resources?**
-feral dogs
-exotic plants

**-Other current threats?**
-erosion potential

**3) What are the greatest potential threats to significant park natural resources?**
-drought/ips beetle/pinion pines
-impacts from external resources

**-Other potential threats?**
-contaminants, hazardous waste spill (low priority)
-housing, dams upstream of park
impacts of timber stacked along Glorietta, chemicals in wood – not likely due to this just being a holding and transporting location, not turing trees into lumber here
-city sewage upstream not always functioning
-Gold and Silver mining upstream – Terrero mine, 13 miles upstream, cleanup site

**4) What are the park's most significant natural resource needs?**
-Fire management plant
-exotic plants and animals

**-Other natural resource needs?**
-dynamic between natural resources and cultural resources
-plant and mammal impacts to ruins
-need for Natural Resources Program, training, getting expertise, no EPMT
-contaminants in fishery – partnering with New Mexico Fish and Game, project underway
-see what happens with riparian restoration, monitor groundwater levels

**5) What are the park's most valuable/important/significant species?**
-Riparian Environment of Pecos and Glorietta

**-Other important species?**

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**
-dwarf milkweed – still present?
-SW willow flycatcher – not documented at park, one biologist may have heard flycatcher, although unkown if it was SW willow flycatcher

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| -Water Quality, heavy metals in fish, population, whirling disease – New Mexico Fish and Game, 3 miles of Pecos River November 2003-2004 | | | |
| -Visitor use | | | |
| -Termperature and precipitation since 1989 | | | |
| -Christmas Bird Count Route | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| -Spotted Owl – Rowe Forest Service in Santa Fe National Forest, 8 miles north of PECO | | | |
| -Neotropical migrants in 5 parks, PECO, FOUN, CAVO, Bandelier | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Lots of old inventory products | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**

-GIS data with neighboring 3 private ranches, several miles along Pecos – slope, topography, aspect – potential for examining bark beetle

**11) What monitoring projects do you think the park needs the most and why?**

-baseline information for Pigeon (85% owned, 350 acres) and Canoncita (25% owned, 350 acres) units
-river fishery – project under way with NM Game and Fish
-Encroachment of pinion-juniper into pastures
-depeding on results of NM Game and Fish fish study – then possibly monitoring project of toxicity, fishery has to be self-sustaining

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

Kris Johnson

**13) What are the land uses on land adjacent to the park?**

Grazing (South, east), residential (some with horses), National Forest (east), interstate
Pigeon and Canoncita: National Forest and private land grazing

**14) What is the next closest public conservation area?**

Santa Fe National Forest

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**

-Clear executive summary of network activities and inventories
-Talk to Christine and Lorenzo

16) **What funding sources have you applied to when seeking to increase natural resource funds?**

-NM Game and Fish – cooperative agreement
-Restoration project – Tierra Montes Soil and Conservation District (20K), EPA (20K), USGS (20K), WRD (20K)

17) **Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-NM Game and Fish
-Santa Fe National Forest

18) **Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

**e) Major habitat types at the park**

Pasture, PJ, riparian, mixed grass

**f) Major processes**

Beetle, erosion, flooding, drought, grazing, fire, I25 Corridor (put in 1960's) and associated culverts

19) **Are there any natural resource park "experts" that you think we should conduct this interview with?**

-National Wildland Fire and Associates – John Lithaway EA for fire management plan
-Bill deBuys- Conservation fund – moving force for Forked Lightning donation, philcophical approach
- have general conversation with both

20) **In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

-NM Game and Fish
-Santa Fe National Forest

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

-Marten and chief ranger when hired

22) **Who should be the main SOPN contact in your park?**

-Marten

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

**24) Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

**Most Pressing Inventory Needs:**
Baseline information at Canoncita and Pigeon Units

**1) What are the park's most significant natural resources and issues?**
-lack of planning and baseline data

**-Other important natural resources?**
-fire prevention (part of Front Range fire management group, MOA w/Kiowa Co Fire Dept.) – issues with habitat in creek and cultural significance of wood to Native Americans
-erosion control – sandy soils, vehicle use issues (currently no usage rules in place)
-2500 acres, grazing has suddenly stopped, need to restore grazing? Fire? Supposed to manage for 1864 conditions – study currently under way
-potential for long-tern study on what happens when you stop grazing
-species of management concern (prairie dogs, burrowing owls, swift foxes, lesser prairie chickens, mountain plovers, black-footed ferret, Colorado bursage)
-potential for pig expansion study
-location for cemetery of Sand Creek Massacre remains

**2) What are the greatest current threats to significant park natural resources?**
-lack of data and planning

**-Other current threats?**
-erosion
-effects of lack of grazing – Will not grazing increase the number if not the diversity of exotics?
-fuel load / fire
-exotics

**3) What are the greatest potential threats to significant park natural resources?**
-fire

**-Other potential threats?**

**4) What are the park's most significant natural resource needs?**
-planning and baseline data, plant inventories most important

**-Other natural resource needs?**
-listed species locations

**5) What are the park's most valuable/important/significant species?**
-lesser prairie chicken, documented within authorized boundary, no known locations within current boundary

**-Other important species?**
-prairie dogs, burrowing owls, swift foxes, mountain plovers, black-footed ferret, Colorado bursage, ferruginous hawks - all unknown except prairie dogs

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**
-prairie dogs, burrowing owls, swift foxes, lesser prairie chickens, mountain plovers, black-footed ferret, Colorado bursage

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Plant inventory – Don Troyer seasonal BEOL | | | |
| Western Environmental and Ecology – historic survey, what was present in 1864 | | | |

Water Resources Division report
Special Resources study
Exotic recon visit with EPMT
Ruth Carol Cushman and Steven Jones – writing about prairies, want to mention SAND when it is open

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

| What monitored? | Duration history? | Location? | Who is responsible for project? |
|---|---|---|---|
| -Listed in SAND environmental scoping summary | | | |
| -Water Flow monitoring, Eads public works | | | |

**9) Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| NRCS | | | |
| BLM-did survey of all federal lands, has 1880 survey notes | | | |
| Farm Service Administration | | | |
| Town of Eads | | | |
| USDA – Digital orthoquads | | | |
| Breeding Bird Survey – 3 routes in Kiowa County | | | |
| Big Sandy Creek Flow Monitoring – closest location is 30 miles downstream near entrance to Arkansas River, 1968 to present | | | |

**10) Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**
NRCS, CODOW, Town of Eads, see environmental scoping report, Rocky Mountain Bird Observatory, Colorado Native Plant Society, Volunteers for Outdoor Colorado

**11) What monitoring projects do you think the park needs the most and why?**
-inventory and planning in general
-erosion
-lack of grazing effects on prairie
-T+E species
-plant inventory

**12) Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**

**13) What are the land uses on land adjacent to the park?**
-grazing, Conservation Reserve program, corn/milo ( dry land farming)

**14) What is the next closest public conservation area?**
-The Great Plains Reservoirs – (Neenoche, Nee Gronda, Upper and Lower Queens Lakes and Blue Lake) 12 miles south of Eads, bottom owned by BLM, surrounding land by CODOW – big duck hunting area (23 sq miles of water surface)
-Bohart Ranch (The Nature Conservancy)

**15) We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**
-link from SAND to SOPN webpage
-blurb in newsletter

16) **What funding sources have you applied to when seeking to increase natural resource funds?**

-CESU (tree dating)
-USGS – planning
-SEPAS cultural plant use
-CCI – veg related, still pending

17) **Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**

-see question 10

18) **Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

-see Environmental scoping report

g) **Major habitat types at the park**

-Riparian cottonwood
-north of Sand Creek – short-grass prairie
-south of Sand Creek – sand sage community

h) **Major processes**

-fire, hydrology, grazing

19) **Are there any natural resource park "experts" that you think we should conduct this interview with?**

-Dawson, former land owner, Rod Johnson (Farm Service), Marvin Watson (NRCS), Brian Will/Travis Block (CODOW)
-hold second interview with these participants and several of the people who attended environmental scoping meeting
Burl Sherler

20) **In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

-see question 19

21) **After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Alexa, Fran, Karl

22) **Who should be the main SOPN contact in your park?**

Fran

23) **Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

**24) Are there other issues you would like considered or other topics about which you think we need more information to help us identify important monitoring needs?**

-cultural aspects will affect everything, NPS will be able to make very few, if any, fast unilateral decisions

**Most Pressing Inventory Needs:**

1) Plant inventory
2) Listed species (but way lower priority than plants)

**1) What are the park's most significant natural resources and issues?**

**-Other important natural resources and issues?**

-diversifying visitor impacts, both within the site and across the region. Within the site, impact of social trails on park resources.
-Cultural landscape - viewsheds
-Invasives – Kochia, cheatgrass, scotch thistle, western red cedar (native)
-prairie restoration
-monitoring effects of prescribed burns (on biannual cycle, after couple rotations, then once every 4 years)
-Water resources study – Oklahoma State, Marston

**2) What are the greatest current threats to significant park natural resources?**

**-Other current threats?**

-upstream dams – silt buildup, decrease flows
-invasives – Kochia, cheatgrass, thistle

**3) What are the greatest potential threats to significant park natural resources?**

-tamarisk
-viewshed – subdivision of land around park, mud plant

**-Other potential threats?**

-Oil and gas
-tribal disagreement of location of battle site

**4) What are the park's most significant natural resource needs?**

**-Other natural resource needs?**

-water resources study (Marston- OSU)
-tree invasion, plant structure in historic/cultural context
-exotic species invasions

**5) What are the park's most valuable/important/significant species?**

-Shortgrass/mixed grass prairie ecosystem

**-Other important species?**

**6) What are the park's species of concern (endemic, rare, threatened, and endangered)?**

-Texas horned lizard, longnose snake, northern earless lizard

**7) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the park?**

| What monitored? | Duration history? | Location in park? | Who is responsible for project? |
|---|---|---|---|
| Visitor use | | | |
| Historic vegetation study | | | |
| Water resources study | | | |
| Effects of roundup on thistle – does this have the same effect as USFS pesticide (rungestar) on thistle? | | | |

**8) Are there any current research, inventory, or monitoring projects on natural resources being conducted in the vicinity of the park?**

**Who is responsible**

**What monitored? Duration history? Location? for project?**
Cheatgrass – new herbicide may have good results
Weather station on USFS land

9) **Are there any historic research, inventory, or monitoring projects (conducted within or in the vicinity of the park) that you think are valuable in understanding the park's natural systems?**

**What monitored? Duration history? Location in park? Who is responsible for project?**
Surface survey for artifacts
Survey for phosphorous in an effort to detect horse kill site
Soil survey

10) **Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects that involve natural resources?**
USFWS – Washita NWR, USFS Black Kettle Grasslands

11) **What monitoring projects do you think the park needs the most and why?**
Air quality/noise – establish baseline
Visitor impact on and along trails

12) **Are there any scientists or "park experts" who you would like to recommend for the Science Advisory Committee?**
Mary Jane Ward – Cultural Oklahoma Historical society
Tim Burchett and Judy Reed (Pecos)
Alden Miller OKCI, cultural, native American liason

13) **What are the land uses on land adjacent to the park?**
Winter wheat (grazing), grasslands (grazing)

14) **What is the next closest public conservation area?**
Washita NWR, Black Kettle National Grasslands, Foss State Park – primarily recreational, adjacent to Washita NWR

15) **We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretative staff and the public?**
Layperson summary of reports, meeting with tribes

16) **What funding sources have you applied to when seeking to increase natural resource funds?**
No, but has Federal Grants Mngt. handbook

17) **Are there any potential partners that you are aware of that would be particularly helpful to the Inventory and Monitoring Program?**
USFS, USFWS, LAMR, Washita Battlefield National Historical Society, Cheyenne/Arapahoe, NRCS, Oklahoma Wildlife Prairie Alliance, Blue Thumb (Water quality)

18) **Over the next two years we will be developing conceptual models for the SOPN. These will be models that show the strength and directions of natural and anthropogenic processes and stressors on natural resources. Do you have any suggestions on types of models and experts that we should consult with?**

i) **Major habitat types at the park**

Develop a small park model first, rather then spend time on a overall mixed-grass prairie model. Shortgrass/mixed grass and riparian

**j) Major processes**

Fire

**19) Are there any natural resource park "experts" that you think we should conduct this interview with?**

Reggie Blackwell, Chuck Miller (USFS-Black Kettle)

**20) In the next 6-12 months we will be holding a second round of larger scoping meetings that brings in outside experts where we can review and discuss the information gathered during these meetings. These meetings may be based on ecosystem type or by geographic area. Do you have anyone you would like to suggest for this second round of scoping meetings?**

No suggestions

**21) After the conclusion of these scoping visits to each park, SOPN staff will prepare a comprehensive list of natural resource issues for SOPN parks. SOPN staff will be conducting a survey to rank natural resource issues within individual parks and as whole network. Which person(s) at your park should this survey be sent?**

Alden Miller

**22) Who should be the main SOPN contact in your park?**

Alden Miller

**23) Discussion of parks and network participation for the next 2 years. SOPN will briefly outline what SOPN will be doing (annual meetings, Scoping sessions, information gathering). How many of these activities do you anticipate your park participating in? How would you like to be informed of SOPN activities?**

**24) Are there other issues you would like considered, or other topics about which you think we need more information to help us identify important monitoring needs?**

Night sky and cell towers are other important issues.

**Most Pressing Inventory Needs:**

Baseline Air Quality

## APPENDIX N SOPN GIS DATASETS

Heidi Sosinski

### INTRODUCTION

Since September 2003, SOPN has been collecting GIS datasets relevant to the parks within the network. This task has been approached at two levels: 1) locating and documenting spatial data relating to the twelve basic I&M Natural Resource Inventories(Table 1) and 2.) collecting park data that currently exists and identifying gaps within the datasets. To date, all currently available park-related datasets have been collected, coming from either the NPS GIS and Metadata store or directly from the respective park's resource management division. SOPN will continue to develop the datasets necessary for developing a long-term monitoring program (Table 2). Several parks currently have some of these files available. Gaps in these categories can be filled by targeting them as priorities for completion through assistance from the IMR GIS program (e.g., GPS 'swat teams'), Special Emphasis Project Allocation System (SEPAS) funding, direct assistance or coordination with parks, or other means.

**Table 1: Twelve Basic Natural Resource Inventory Datasets Being Developed by the National Park Service.**

| | |
|---|---|
| Natural Resource Bibliography | Location of Air Quality Monitoring |
| Base Cartographic Data | Water Body Location & Classification |
| Geology Map | Water Quality Data |
| Soils Map | Vegetation Map |
| Weather Data | Vertebrate/Vascular Plant Species List |
| Air Quality | Species Distribution and Abundance |

**Table 2: General GIS Datasets Identified by Southern Plains Network as Essential to the Monitoring Program**

| | |
|---|---|
| **Base Cartographic Layers** | **Management** |
| Adjacent Land Ownership | Grazing Allotments |
| Special Designations (RNAs, Wilderness) | |
| Private In-holdings | **Park Infrastructure** |
| Trails - Established | Roads – Paved |
| Roads – (Paved and Unpaved) | Roads - Unpaved |
| | Roads - 4WD |
| **Natural Resources** | Campgrounds (and backcountry sites) |
| Hydrology – Rivers and Streams | Fences |
| Hydrology - Seeps/Springs | Utilities (pipelines, power lines, etc.) |
| Hydrology – Misc. (ponds, tanks, etc.) | |
| Fire Occurrence and History | **Resource or Stressor Monitoring** |
| Plants – Threatened and Endangered | Biological Resource Monitoring Locations |
| Plants - Exotic/Invasive | Physical Resource Monitoring Locations |
| Animals – Threatened and Endangered | |
| Animals – Exotic/Invasive | |

GIS DATA INDEX

The following tables provides a summary of geospatial data that has been catalogued by the Southern Plains Network. The information is organized by spatial extent and includes data related to each park unit within the network, data that covers a network-wide extent, and data covering a national extent. Records are further organized by broad category. This table does not include many statewide, regional, or national base cartographic data sets that are not specific to the network. The network's geospatial data is far from complete, and because of lack of documentation, some of the data sets catalogued here may not be usable. The process of obtaining, verifying, and documenting network geospatial will be an ongoing process.

*Explanation of Columns*

"Spatial Extent" indicates the geographic area the dataset encompasses. "Category" groups data based on broad subject (Note: wqgis refers to data produced by the Water Resources Division used to produce the Baseline Water Quality Data Inventory and Analysis Reports, given the general nature of this data, there are no plans to split the dataset into it's component categories). "Layer Type" indicates the file format (point, line or polygon shapefile, ArcInfo coverage, or geodatabase). "Description" provides a brief indication of the dataset content.

| Spatial Extent | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Bent's Old Fort NHS** | | | | |
| BEOL | Boundary | BEOL_2000boundary.shp | Line | BEOL boundary file |
| BEOL | Boundary | beol_bound.shp | Polygon | BEOL boundary file |
| BEOL | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| BEOL | Elevation | hillshade | raster | hillshade model produced from DEM's |
| BEOL | Geology | beolglg | Coverage | Geological Resources Division – Digital Geology Map |
| BEOL | Geology | BEOLGLG.shp | Polygon | Geological Resources Division – Digital Geology Map |
| BEOL | Geology | BEOLGLGA.shp | Line | Geological Resources Division – Digital Geology Map |
| BEOL | Geology | beolmin | Coverage | Geological Resources Division – Digital Geology Map |
| BEOL | Geology | BEOLMIN.shp | Point | Geological Resources Division – Digital Geology Map |
| BEOL | Hydrology | MAJORHYD.shp | Line | Water Resources Division – Small-Scale Base GIS Data |
| BEOL | Hydrology | NHDH1102.mdb | Geodatabase | National Hydrography Dataset – high resolution |
| BEOL | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| BEOL | Imagery | DRG | raster | USGS digital topographic maps |
| BEOL | Imagery | ortho_e1-1_s_co089.sid | raster | USDA-FSA-APFO Digital Ortho Mosaic of Otero County |
| BEOL | Transportation | MAJORRDS.shp | Line | Water Resources Division – Small-Scale Base GIS Data |
| BEOL | Wqgis | airport.shp | polygon | local area airports |
| BEOL | Wqgis | catalog_unit.shp | polygon | USGS catalog units |
| BEOL | Wqgis | dirt_road.shp | Line | dirt roads |
| BEOL | Wqgis | highway.shp | Line | highways |
| BEOL | Wqgis | hydro_main.shp | Line | major hydrography |
| BEOL | Wqgis | idg_station.shp | point | USGS monitoring station |
| BEOL | Wqgis | mine.shp | point | mine locations |

| Spatial Extent | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| BEOL | Wqgis | park_polygon.shp | polygon | park boundary |
| BEOL | Wqgis | place.shp | polygon | town locations |
| BEOL | Wqgis | railroad.shp | Line | railroads |
| BEOL | Wqgis | rf3_hydro.shp | Line | River Reach File (RF3) Hydrography |
| BEOL | Wqgis | road.shp | Line | area roads |
| BEOL | Wqgis | Santa_Fe_trail.shp | Line | Santa Fe Trail |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Capulin Volcano NM** | | | | |
| CAVO | Boundary | CAVO_bound.shp | polygon | CAVO boundary file |
| CAVO | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| CAVO | Elevation | hillshade | raster | hillshade model produced from DEM's |
| CAVO | Hydrology | MAJORHYD.shp | line | Water Resources Division – Small-Scale Base GIS Data |
| CAVO | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| CAVO | Imagery | DRG | raster | USGS digital topographic maps |
| CAVO | Imagery | DRG | raster | USGS digital topographic maps |
| CAVO | Imagery | DRG | raster | USGS digital topographic maps |
| CAVO | Transportation | CAVO_roadstrails.shp | line | roads and trails at CAVO |
| CAVO | Transportation | MAJORRDS.shp | line | major area roads |
| CAVO | Vegetation | CAVO_Brome_Boundaries.shp | polygon | areas containing brome around CAVO |
| CAVO | Vegetation | CAVO_fuelveg77.shp | polygon | standing fuels community and composition (living and dead) |
| CAVO | Wqgis | catalog_unit.shp | polygon | USGS Catalog Units |
| CAVO | Wqgis | dirt_road.shp | line | dirt roads |
| CAVO | Wqgis | highway.shp | line | highways |
| CAVO | Wqgis | mine.shp | point | mine locations |
| CAVO | Wqgis | park_polygon.shp | polygon | CAVO boundary |
| CAVO | Wqgis | parkhead.shp | point | park headquarters location |
| CAVO | Wqgis | place.shp | polygon | city limits boundaries |
| CAVO | Wqgis | railroad.shp | line | railroads |
| CAVO | Wqgis | rf3_hydro.shp | line | River Reach File (RF3) Hydrography |
| CAVO | Wqgis | road.shp | line | area roads |
| CAVO | Wqgis | spring.shp | point | springs |
| CAVO | Wqgis | town.shp | point | town locations |
| CAVO | Wqgis | wq_station.shp | point | water quality monitoring stations |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Chickasaw NRA** | | | | |
| CHIC | Boundary | CHIC_bound.shp | polygon | CHIC park boundary |
| CHIC | Boundary | CHIC_bound_line.shp | line | CHIC park boundary |
| CHIC | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| CHIC | Elevation | hillshade | raster | hillshade model produced from DEM's |
| CHIC | Elevation | NED | raster | National Elevation Dataset – CHIC area |
| CHIC | Facilities | boat_launch_adjusted.shp | point | boat launch ramp locations |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| CHIC | Facilities | buildings | coverage | building footprints at CHIC |
| CHIC | Facilities | camping | coverage | campsite locations |
| CHIC | Facilities | historical_features.shp | point | historical feature locations |
| CHIC | Facilities | manholes | coverage | manhole locations |
| CHIC | Facilities | power | coverage | electrical utility points |
| CHIC | Hydrology | hydro | coverage | Platt area rivers and lakes |
| CHIC | Hydrology | hydro_detail.shp | line | area rivers and streams |
| CHIC | Hydrology | lake.shp | polygon | lakes |
| CHIC | Hydrology | springs | coverage | area springs |
| CHIC | Hydrology | springs.shp | point | area springs |
| CHIC | Hydrology | water_NAD83.shp | polygon | Platt area rivers and lakes |
| CHIC | Imagery | DOQQ | | USGS digital ortho quarter quads |
| CHIC | Imagery | DRG | | USGS digital topographic maps |
| CHIC | Imagery | naip1-1_ok099_2003.sid | raster | USDA-FSA-APFO Digital Ortho Mosaic - Murray County |
| CHIC | Imagery | ortho.bil | raster | aerial photograph mosaic – CHIC area |
| CHIC | Imagery | platt.bil | raster | aerial photograph mosaic – Platt area |
| CHIC | Soils | base3114.shp | shapefile | soil survey of old Platt National Park area |
| CHIC | Soils | soils.mdb | database | NRCS soils survey database |
| CHIC | Soils | soils.shp | shapefile | soil survey of CHIC |
| CHIC | Transportation | area_roads_detail.shp | line | detailed local area roads |
| CHIC | Transportation | bridges | coverage | bridges at CHIC |
| CHIC | Transportation | bridges.shp | polygon | bridges at CHIC |
| CHIC | Transportation | local_area_roads.shp | line | local area roads |
| CHIC | Transportation | paved | coverage | paved roads |
| CHIC | Transportation | paved_roads_line.shp | line | paved roads |
| CHIC | Transportation | paved_roads_poly.shp | polygon | paved roads – graphic display |
| CHIC | Transportation | road_trail.shp | line | roads and trails at CHIC |
| CHIC | Vegetation | buffalo pasture_nad83.shp | polygon | pasture area |
| CHIC | Vegetation | cnramap | coverage | vegetation map |
| CHIC | Vegetation | fin_1997.shp | polygon | vegetation map |
| CHIC | Vegetation | pasture | coverage | pasture area |
| CHIC | Vegetation | pasture_nad83.shp | polygon | pasture area |
| CHIC | Vegetation | veg.shp | polygon | vegetation map – Platt National Park area |
| CHIC | Vegetation | veg1937.shp | polygon | 1937 vegetation map – Platt National Park area |
| CHIC | Wqgis | access_pt.shp | point | boat ramps |
| CHIC | Wqgis | campground.shp | point | campground locations |
| CHIC | Wqgis | catalog_unit.shp | polygon | USGS Catalog Units |
| CHIC | Wqgis | city.shp | point | cities |
| CHIC | Wqgis | county.shp | polygon | county boundaries |
| CHIC | Wqgis | highway.shp | line | highways |
| CHIC | Wqgis | interstate.shp | line | interstates |
| CHIC | Wqgis | lake.shp | polygon | lakes |
| CHIC | Wqgis | mine.shp | point | mines |
| CHIC | Wqgis | park_polygon.shp | polygon | park boundary |
| CHIC | Wqgis | parkhead.shp | point | headquarters location |
| CHIC | Wqgis | place.shp | polygon | Boundaries of incorporated areas that appear on 100K scale maps |
| CHIC | Wqgis | railroad.shp | line | railroads |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| CHIC | Wqgis | rf3_hydro.shp | line | River Reach File Hydrography Version 3 |
| CHIC | Wqgis | road.shp | line | roads |
| CHIC | Wqgis | springs.shp | polygon | springs |
| CHIC | Wqgis | state.shp | polygon | state boundary |
| CHIC | Wqgis | study_area.shp | polygon | Retrieval area for water quality data |
| CHIC | Wqgis | trail.shp | line | trails |
| CHIC | Wqgis | visitor_center.shp | point | park visitor centers |
| CHIC | Wqgis | wq_station.shp | point | water quality testing sites |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Fort Larned NHS** | | | | |
| FOLS | Boundary | folsbndp | coverage | FOLS boundary (old file) |
| FOLS | Boundary | FOLS_bound.shp | polygon | FOLS boundary (old file) |
| FOLS | Boundary | FOLS_bound_actual.shp | polygon | FOLS boundary – actual ownership |
| FOLS | Boundary | FOLS_bound_legistative.shp | polygon | FOLS boundary – authorized |
| FOLS | Boundary | FOLS_scenic_easment.shp | polygon | FOLS boundary – scenic easement area |
| FOLS | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| FOLS | Elevation | hillshade | raster | hillshade model produced from DEM's |
| FOLS | Hydrology | folsgagt | coverage | Fort Larned NHS Water Gages |
| FOLS | Hydrology | folswaqt | coverage | Fort Larned NHS Water Quality Monitoring Sites |
| FOLS | Transportation | folstrll | coverage | trails |
| FOLS | Transportation | folstrll.shp | line | trails |
| FOLS | Transportation | MAJORRDS.shp | line | main roads |
| FOLS | Vegetation | FOLS_veg | coverage | FOLS vegetation map |
| FOLS | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| FOLS | Imagery | DRG | raster | USGS digital topographic maps |
| FOLS | Imagery | ortho_e1-1_s_ks145.sid | raster | USDA-FSA-APFO Digital Ortho Mosaic – Pawnee County |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Fort Union NHS** | | | | |
| FOUN | Boundary | FOUN_bound.shp | polygon | FOUN boundary |
| FOUN | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| FOUN | Elevation | hillshade | raster | hillshade model produced from DEM's |
| FOUN | Imagery | DOQ | raster | USGS digital ortho quads |
| FOUN | Imagery | DRG | raster | USGS digital topographic maps |
| FOUN | Imagery | ft_union_aerial_1984.tif | raster | FOUN aerial photo |
| FOUN | Vegetation | final_founveg3.shp | polygon | vegetation map |
| FOUN | Vegetation | FOUN_bindweed_bound.shp | polygon | bindweed areas |
| FOUN | Vegetation | FOUN_vegetation | polygon | vegetation map |
| FOUN | Wqgis | 24k_quad.shp | polygon | 24K quad boundaries |
| FOUN | Wqgis | catalog_unit.shp | polygon | USGS Catalog Units |
| FOUN | Wqgis | dirt_road.shp | line | area unpaved roads |
| FOUN | Wqgis | highway.shp | line | highways |
| FOUN | Wqgis | land_fill.shp | point | landfill locations |
| FOUN | Wqgis | mine.shp | point | mines |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| FOUN | Wqgis | park_polygon.shp | polygon | park boundary |
| FOUN | Wqgis | parkhead.shp | point | headquarters location |
| FOUN | Wqgis | place.shp | polygon | Boundaries of incorporated areas that appear on 100K scale maps |
| FOUN | Wqgis | rf3_hydro.shp | line | River Reach File Hydrography Version 3 |
| FOUN | Wqgis | springs.shp | polygon | springs |
| FOUN | Wqgis | trail.shp | line | trails |
| FOUN | Wqgis | visitor_center.shp | point | park visitor centers |
| FOUN | Wqgis | wq_station.shp | point | water quality testing sites |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Lake Meredith NRA and Alibates Flint Quarries NM** | | | | |
| LAMR/ ALFL | Boundary | ALFL_bound.shp | polygon | ALFL boundary |
| LAMR/ ALFL | Boundary | LAMR_alfl_bound.shp | polygon | combined ALFL and LAMR boundary |
| LAMR/ ALFL | Boundary | LAMR_bound.shp | polygon | LAMR boundary |
| LAMR/ ALFL | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| LAMR/ ALFL | Elevation | hillshade | raster | hillshade model produced from DEM's |
| LAMR/ ALFL | Facilities | lamr_oilgas | coverage | oil and gas points |
| LAMR/ ALFL | Facilities | lamr_pfacil | coverage | park facilities points |
| LAMR/ ALFL | Geology | LAMR_geology | coverage | geologic map |
| LAMR/ ALFL | Hydrology | Lake_Meredith_high_water.shp | polygon | Lake Meredith record high water mark |
| LAMR/ ALFL | Hydrology | lamr_rhwl | coverage | record high water level for Lake Meredith |
| LAMR/ ALFL | Hydrology | LAMR_srchg | coverage | Lake Meredith surcharge pool |
| LAMR/ ALFL | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| LAMR/ ALFL | Imagery | DRG | raster | USGS digital topographic maps |
| LAMR/ ALFL | Imagery | lm1_mosaicked.img | raster | false color satellite imagery |
| LAMR/ ALFL | Imagery | lm1_saltcedar.img | raster | saltcedar location imagery |
| LAMR/ ALFL | Imagery | lmra_14jul2002 | raster | orthophoto mosaic of LAMR/ALFL |
| LAMR/ ALFL | Imagery | USDA APFO Digital Ortho Mosaic | raster | orthophoto mosaic of counties covering LAMR/ALFL |
| LAMR/ ALFL | Wetland | LAMR_nwi | coverage | National Wetlands Inventory areas at LAMR |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Lyndon B. Johnson NHP** | | | | |
| LYJO | Boundary | JC_bnd.shp | polygon | Johnson City District boundary |
| LYJO | Boundary | LYJO_bound.shp | polygon | LYJO boundary |
| LYJO | Boundary | RanchActual.shp | polygon | Ranch district actual boundary |
| LYJO | Boundary | RanchAuthorized.shp | polygon | Ranch district authorized boundary |
| LYJO | Boundary | TPWD.shp | polygon | LBJ State Park boundary |
| LYJO | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| LYJO | Elevation | hillshade | raster | hillshade model produced from DEM's |
| LYJO | Facilities | hydrants.shp | point | fire hydrant locations |
| LYJO | Facilities | jc_fences.shp | line | fence locations (Johnson City district) |
| LYJO | Facilities | jc_structures.shp | polygon | building footprints (Johnson City district) |
| LYJO | Facilities | ranch_fences.shp | line | fence locations (Ranch district) |
| LYJO | Facilities | ranch_structures.shp | polygon | building footprints (Ranch district) |
| LYJO | Facilities | ranch_tracts.shp | polygon | LBJ ranch tracts |
| LYJO | Facilities | water_tanks.shp | polygon | water tank locations (Ranch district) |
| LYJO | Hydrology | pedernales_line.shp | line | Pedernales River |
| LYJO | Hydrology | pedernales_poly.shp | polygon | Pedernales River |
| LYJO | Hydrology | sediment_transects.shp | points | sampling locations from sediment survey |
| LYJO | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| LYJO | Imagery | DRG | raster | USGS digital topographic maps |
| LYJO | Land Use/Land Cover | llano_lluc | coverage | land use/land cover – Llano County |
| LYJO | Soils | blanco_gillespiesoil.shp | polygon | soils map (Blanco and Gillespie Counties) |
| LYJO | Soils | LYJO_soilsE.shp | polygon | soils map (Johnson City district) |
| LYJO | Soils | LYJO_soilsW.shp | polygon | soils map (Ranch district) |
| LYJO | Soils | Soil_CenterTX_utm.shp | polygon | soils map (Central Texas region) |
| LYJO | Transportation | JC_Park_Road.shp | line | Johnson district roads |
| LYJO | Transportation | JC_walking_path.shp | line | walking trails (Johnson City district) |
| LYJO | Transportation | JOHCIRD.shp | line | Johnson City quad area roads |
| LYJO | Transportation | LBJ_Ranch_Roads.shp | line | paved roads (Ranch district) |
| LYJO | Vegetation | 1976 Johnson Settlement Pastures.shp | polygon | 1976 pasture areas (Johnson City district) |
| LYJO | Vegetation | 1997 Conservation Plan Pastures.shp | polygon | conservation pastures (Ranch district) |
| LYJO | Vegetation | Grazed Land.shp | polygon | grazed areas (Ranch district) |
| LYJO | Vegetation | lyjo_city | coverage | 2005 vegetation map (Johnson City district) |
| LYJO | Vegetation | lyjo_ranch | coverage | 2005 vegetation map (Ranch district) |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Pecos NHP** | | | | |
| PECO | Boundary | PECO_bound.shp | polygon | PECO boundary |
| PECO | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| PECO | Elevation | hillshade | raster | hillshade model produced from DEM's |
| PECO | Hydrology | peco_riparian_areas.shp | polygon | riparian corridor at PECO |
| PECO | Hydrology | rf3_hydro.shp | line | River Reach File Hydrography Version 3 |
| PECO | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| PECO | Imagery | DRG | raster | USGS digital topographic maps |
| PECO | Soils | peco_soils.shp | polygon | soils map (Pecos unit) |
| PECO | Soils | peco_soils_canoncito.shp | polygon | soils map (Canoncito unit) |
| PECO | Soils | peco_soils_glorieta.shp | polygon | soils map (Glorieta unit) |
| PECO | Transportation | peco_trails.shp | line | trails |
| PECO | Vegetation | peco_vegetation.shp | polygon | vegetation map |
| PECO | Vegetation | peco_vegetation_glorieta.shp | polygon | vegetation map (Glorieta unit) |
| PECO | Wetlands | peco_wetlands.shp | polygon | wetlands |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Sand Creek Massacre NHS** | | | | |
| SAND | Boundary | landowners_gcdb.shp | polygon | land ownership map |
| SAND | Boundary | massacre_site_bound_l.shp | line | massacre site area |
| SAND | Boundary | massacre_site_bound_p.shp | polygon | massacre site area |
| SAND | Boundary | sand_bound_authorized_l.shp | line | SAND authorized boundary |
| SAND | Boundary | sand_bound_authorized_p.shp | polygon | SAND authorized boundary |
| SAND | Boundary | sand_bound_established_p.shp | polygon | SAND current ownership boundary |
| SAND | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| SAND | Elevation | hillshade | raster | hillshade model produced from DEM's |
| SAND | Facilities | fences_gcdb.shp | line | fence locations |
| SAND | Facilities | signs.shp | point | sign locations |
| SAND | Hydrology | big_sandy_creek.shp | line | Big Sandy Creek |
| SAND | Hydrology | pond.shp | polygon | ponds |
| SAND | Imagery | DOQQ | raster | USGS digital ortho quarter quads |
| SAND | Imagery | DRG | raster | USGS digital topographic maps |
| SAND | Natural Resources | exotic_plants.shp | point | exotic plant locations |
| SAND | Natural Resources | prairie_dog_towns.shp | polygon | prairie dog town locations |
| SAND | Transportation | Roads.shp | line | roads |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Washita Battlefield NHS** | | | | |
| WABA | Boundary | WABA_bound.shp | polygon | WABA boundary |
| WABA | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| WABA | Elevation | 24K Resolution DEM | raster | USGS digital elevation models (feet and meters) |
| WABA | Elevation | hillshade | raster | hillshade model produced from DEM's |
| WABA | Elevation | hillshade | raster | hillshade model produced from DEM's |
| WABA | Imagery | DRG | raster | USGS digital topographic maps |
| WABA | Imagery | USDA APFO Digital Ortho Mosaic | raster | orthophoto mosaic of Roger Mills county |
| WABA | Transportation | waba_rr | coverage | historic railroad grade |
| WABA | Transportation | waba_rr.shp | line | historic railroad grade |
| WABA | Transportation | waba_trail2 | coverage | trails |
| WABA | Transportation | waba_trail2.shp | line | trails |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| **Nationwide Data** | | | | |
| SOPN | Air Quality | CASTNET.shp | point | Clean Air Status and Trends Network stations (SOPN area) |
| SOPN | Air Quality | Improve_II.shp | point | Interagency Monitoring of Protected Visual Environments stations (SOPN area) |
| SOPN | Air Quality | MDN_sites.shp | point | Mercury Depositional Network stations (SOPN area) |
| SOPN | Air Quality | Nadpmonsites_II.shp | point | National Atmospheric Deposition Program (SOPN area) |
| SOPN | Air Quality | Usozonesites_II.shp | point | EPA AirData and NPS AirWeb ozone monitoring stations (SOPN area) |
| US | Boundaries | County_xx.shp | polygon | Counties grouped by state (SOPN area only) |
| US | Boundaries | fedland020.shp | polygon | federally-owned land |
| TX | Boundaries | tx_fed_land.shp | polygon | federal land boundaries (Texas) |
| US | Climate | Precipitation | polygon | annual precipitation (US and SOPN area states) |
| US | Climate | Temperature | raster | seasonal and annual average high and low temperature grids for entire US |
| SOPN | Elevation | 250K resolution DEM | raster | USGS digital elevation models for all SOPN states |
| US | Geology | geology map | mixed | Generalized Geologic Map of the Conterminous United States |
| SOPN | Hydrology | National Hydrography Dataset | geodatabase | High and medium resolution datasets covering SOPN park areas |
| US | Hydrology | rad_303d_a_sde.shp | polygon | EPA-designated impaired water bodies – 303(d) |
| US | Hydrology | rad_303d_l_sde.shp | line | EPA-designated impaired water bodies – 303(d) |
| NM | Soils | NM_soils83.shp | polygon | general soil map of New Mexico |

| Park | Category | Layer Name | Layer Type | Description |
|---|---|---|---|---|
| NM/CO | Soils | SSURGO | mixed | Soil Survey Geographic databases (selected areas in New Mexico and Colorado) |
| CO | Vegetation | colandcover | raster | GAP vegetation analysis – Colorado |
| US | Vegetation | ecoregp075.shp | polygon | Bailey's Ecoregions – United States |
| KS | Vegetation | kslandcovgclp | raster | GAP vegetation analysis – Kansas |
| NM | Vegetation | nmveggrd | raster | GAP vegetation analysis – New Mexico |
| TX | Vegetation | tx_vegpy.shp | polygon | generalized vegetation map - Texas |
| World | Vegetation | world_ecoregions.shp | polygon | Bailey's Ecoregions – worldwide |

## APPENDIX O NATURAL RESOURCES AND STRESSORS DERIVED FROM SCOPING SESSIONS AND RANKED BY PARK STAFF

All issues were ranked by assigning an issue a point value. High priority issues were assigned 4 points; medium priority issues were assigned 3 points, low priority issues were assigned 2 points, and non-issues were assigned 1 point. All the scores were averaged to arrive at an overall score for the issue.

| Issue Name | Average Score | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exotic Plants (Kochia, tamarisk, cheatgrass etc.) | 3.64 | Medium | High | High | Medium | High | Low | High | High | High | High | High |
| Grassland community | 3.45 | High | High | High | Medium | Medium | Low | High | High | Low | High | High |
| Prairie Restoration | 3.36 | High | High | High | Medium | High | Not An Issue | High | High | Not An Issue | High | High |
| Viewshed | 3.18 | High | Medium | Medium | Medium | High | Medium | Medium | Medium | Low | Medium | High |
| Erosion - Slopes, lakeshores, banks | 3.09 | High | Low | High | High | High | Low | High | High | Not An Issue | Medium | Low |
| Funding (lack of money and staff) | 3.09 | High | Medium | Medium | High | High | Low | High | Medium | Low | Medium | Low |
| Adjacent Land Use (mining, feedlots, agriculture, grazing, fire, development, etc.) | 2.91 | Medium | Medium | Medium | Medium | Medium | Not An Issue | Medium | Medium | Low | High | High |
| Fire (lack of, frequency, effects of, prevention, etc.) | 2.91 | Not An Issue | High | High | Medium | Medium | Low | Not An Issue | Medium | High | High | Medium |
| Water Quantity | 2.91 | High | Low | Not An Issue | High | High | Not An Issue | High | Medium | Medium | Medium | Medium |
| Water Quality | 2.82 | High | Low | Not An Issue | High | Medium | Not An Issue | High | Medium | Medium | Medium | Medium |
| Cottonwood Riparian Community | 2.73 | Medium | High | Not An Issue | Low | High | Not An Issue | Medium | Not An Issue | High | High | Medium |
| Riverine community (River, stream) | 2.73 | Not An Issue | Medium | Not An Issue | High | Medium | Not An Issue | Not An Issue | High | High | High | High |
| Wildlife Diseases effects on staff and visitors (west nile, hantavirus) | 2.73 | Low | High | Low | Medium | Medium | Medium | Low | Medium | Medium | Medium | Low |
| Grassland/Succession to more woody vegetation | 2.64 | Medium | Not An Issue | High | Medium | Low | Not An Issue | Medium | Medium | High | Not An Issue | High |

| Issue Name | Average Score | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lack of long-term management plan | 2.64 | Low | Not An Issue | Medium | Low | High | Low | High | Medium | Medium | High | Not An Issue |
| Night sky | 2.64 | High | Low | Medium | Low | Low | Low | Medium | Medium | Low | Medium | Medium |
| Soundscape | 2.64 | High | Low | Low | Medium | Low | Not An Issue | Medium | Medium | Low | Medium | High |
| Weather patterns (drought, wet periods) | 2.64 | Low | Medium | Low | Low | Medium | Medium | Low | High | Medium | Medium | Low |
| Woody Invasive Species (Mesquite, Cedar, PJ, shrubs, etc.) | 2.64 | High | Not An Issue | High | High | Not An Issue | Not An Issue | Medium | Medium | Medium | Not An Issue | High |
| Air Quality | 2.55 | Medium | Low | Low | Medium | Low | Low | Medium | Medium | Medium | Medium | Low |
| Big Game (Deer, pronghorn antelope) | 2.55 | Low | Low | Low | Medium | Low | Not An Issue | Medium | High | High | Medium | Low |
| Grassland birds | 2.55 | Medium | Medium | Medium | Medium | Low | Not An Issue | Medium | Medium | Low | Medium | Low |
| Groundwater levels | 2.55 | Not An Issue | Medium | Low | High | Medium | Not An Issue | Low | Medium | Medium | Medium | Medium |
| Reptile Community | 2.55 | Medium | Low | Low | Medium | Low | Not An Issue | Medium | Medium | High | Medium | Low |
| Small mammal community (mice, voles, shrews, moles) | 2.55 | Low | Medium | Low | Medium | High | Medium | Low | Medium | Low | Low | Low |
| Wetlands in upland systems (prairie wetlands, ponds) | 2.55 | Medium | High | Not An Issue | Medium | Low | Not An Issue | Medium | Low | Low | Medium | High |
| Flooding process along river/stream/lake | 2.45 | Medium | High | Not An Issue | Medium | Medium | Not An Issue | Low | Medium | Low | Medium | Low |
| Bald Eagle | 2.36 | Medium | Low | Low | Medium | Not An Issue | Not An Issue | Medium | Low | High | Medium | Low |
| Boundary survey/fencing | 2.36 | Medium | Medium | Not An Issue | Medium | Medium | Not An Issue | Medium | Low | Low | Medium | Low |
| Migratory songbird stopover area | 2.36 | Medium | Low | Low | Medium | Low | Not An Issue | Medium | Low | High | Low | Low |
| Effects of Park visitors on natural resources (Trails, camping, fishing, hunting, unauthorized, authorized, etc) | 2.27 | High | Not An Issue | Medium | Medium | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | High | Low |
| Pollution from non-park sources | 2.27 | Medium | Medium | Low | Medium | Low | Not An Issue | Medium | Low | Low | Low | Low |
| Texas horned lizard | 2.27 | High | Not An Issue | Low | Medium | Not An Issue | Not An Issue | High | Medium | Low | Low | Low |
| Insect diseases on ecosystem (Ips beetle, Armillaria) | 2.18 | Low | Not An Issue | Medium | Low | Not An Issue | Not An Issue | Low | Medium | High | Medium | Low |
| Water use (rights within park, rights of others outside the park, aquifers) | 2.18 | Not An Issue | Medium | Not An Issue | High | Medium | Not An Issue | Not An Issue | Medium | Low | Medium | Low |

| Issue Name | Average Score | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mineral, Oil, and Gas Extraction | 2.09 | Medium | Medium | Not An Issue | Low | Low | Not An Issue | Medium | Not An Issue | Not An Issue | Medium | Medium |
| Upland Springs | 2.09 | Medium | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Medium | Not An Issue | Low | Medium | Medium |
| Black-tailed prairie dogs | 2.00 | Low | Medium | Not An Issue | Not An Issue | High | Not An Issue | Low | Not An Issue | Low | Medium | Low |
| Hunting | 2.00 | Low | Low | Not An Issue | Medium | Low | Not An Issue | Medium | Medium | Not An Issue | Medium | Not An Issue |
| Small game (rabbits, squirrels) | 2.00 | Low | Low | Low | Medium | Low | Not An Issue | Low | Low | Low | Low | Low |
| Contamination of Water Supply (from sewer, oil spill, feedlots etc,) | 1.91 | Not An Issue | Not An Issue | Not An Issue | High | Medium | Not An Issue | Medium | Low | Low | Not An Issue | Low |
| Game birds (quail, ducks, turkey) | 1.91 | Not An Issue | Low | Low | Medium | Low | Not An Issue | Low | Low | Low | Medium | Not An Issue |
| Off-road vehicle use | 1.91 | Medium | Low | Not An Issue | Low | Not An Issue | Not An Issue | Medium | Not An Issue | Low | Medium | Low |
| Effects of Grazing (overgrazing, lack of grazing, etc.) | 1.82 | Low | Not An Issue | Low | Low | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | High | Medium |
| Hazardous spill on adjacent highway, railroad | 1.82 | Not An Issue | Medium | Not An Issue | Medium | Low | Not An Issue | Medium | Low | Low | Not An Issue | Not An Issue |
| Burrowing owl | 1.73 | Low | Low | Not An Issue | Low | Medium | Not An Issue | Low | Not An Issue | Low | Low | Not An Issue |
| Feral Dogs | 1.73 | Not An Issue | Low | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Low | High | Not An Issue | Low |
| Contaminants in Fishery | 1.64 | Not An Issue | Low | Not An Issue | Medium | Not An Issue | Not An Issue | Medium | Not An Issue | Medium | Not An Issue | Not An Issue |
| E.coli levels | 1.64 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Medium | Low | Low | Not An Issue | Low |
| Fishing | 1.64 | Not An Issue | Not An Issue | Not An Issue | Medium | Low | Not An Issue | Medium | Not An Issue | Medium | Not An Issue | Not An Issue |
| Game Fish | 1.64 | Not An Issue | Not An Issue | Not An Issue | Medium | Low | Not An Issue | Medium | Not An Issue | Low | Not An Issue | Low |
| Large Carnivores (bear, mountain lion, jagarundi) | 1.64 | Not An Issue | Not An Issue | Low | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | High | Not An Issue | Medium |
| Lesser Prairie Chicken | 1.64 | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Low | High | Low |
| Swift fox | 1.64 | Low | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Low | Not An Issue | Low | Medium | Low |
| Exotic Game (axis deer, blackbuck antelope, fallow deer) | 1.55 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Low |

| Issue Name | Average Score | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feral Cats | 1.55 | Not An Issue | Low | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Low | Low | Not An Issue | Low |
| Feral Hogs | 1.55 | Low | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Medium | Not An Issue |
| Fire Ants | 1.55 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Low |
| Montane/grassland/desert interface (easternmost location) | 1.55 | Low Not An Issue | Not An Issue | Not An Not An | | High Issue | Medium Issue | Not An Issue | Issue | Not An | Not An Issue | Not An Issue |
| Raccoons | 1.55 | Not An Issue | Not An Issue | Not An Issue | Medium | Low | Not An Issue | Not An Issue | Low | Low | Not An Issue | Low |
| Endemic invertebrates | 1.45 | Not An Issue | Not An Issue | Low | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Low |
| Ferruginous hawk | 1.45 | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Medium | Low |
| Lacustrine Community (Lakes) | 1.45 | Not An Issue | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Mississippi Kites | 1.45 | Low | Not An Issue | Not An Issue | Low | Low | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Non-vascular plants (lichens mosses) | 1.36 | Not An Issue | Not An Issue | Low | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue |
| Porcupine | 1.36 | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Low | Not An Issue | Low |
| Townsend's big-eared bat | 1.36 | Not An Issue | Not An Issue | Medium | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue |
| Alberta arctic butterfly | 1.27 | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Arkansas darter | 1.27 | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Arkansas river shiner | 1.27 | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Bottomland eastern deciduous hardwood community | 1.27 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low |
| Crytobiotic soils | 1.27 | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Low | Not An Issue |
| Echinacea | 1.27 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low |
| Mountain plovers | 1.27 | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Low | Not An Issue |
| SW Willow flycatcher | 1.27 | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Low | Not An Issue | Not An Issue |

| Issue Name | Average Score | ALFL | BEOL | CAVO | CHIC | FOLS | FOUN | LAMR | LYJO | PECO | SAND | WABA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Volcanic cinder cone | 1.27 | Not An Issue | Not An Issue | High | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Africanized honeybee | 1.18 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Low |
| Black-footed ferret | 1.18 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Low |
| Dwarf milkweed | 1.18 | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Low | Not An Issue | Not An Issue |
| Marsh rice rat | 1.18 | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Nutria | 1.18 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Medium | Not An Issue | Not An Issue | Not An Issue |
| Zebra mussels | 1.18 | Not An Issue | Low | Not An Issue | Low | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Colorado bursage | 1.00 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Giant mole cricket | 1.00 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |
| Palo Duro canyon mouse | 1.00 | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue | Not An Issue |

## APPENDIX P ECOSYSTEM WORKSHOP REPORTS

TABLE OF CONTENTS


Table of Contents ..... A-293
P.1. GRASSLAND WORKSHOP, FEBRUARY 1-2, 2005. HOSTED BY WASHITA BATTLEFIELD NHS COYOTE HILLS GUEST RANCH, CHEYENNE, OKLAHOMA ..... A-294
*P.1.1. Overview ..... A-294*
*P.1.2. Objectives ..... A-294*
*P.1.3. Conceptual Model Review ..... A-294*
P.1.3.1.Conceptual Model Summary and Future Directions ..... A-294
P.1.3.2. Future Directions for Grassland Models ..... A-295
*P.1.4. Grassland Issues and Vital Signs ..... A-296*
Appendix P1 Narrative and pictures of draft conceptual models developed by Dr. Dan Tinker and Dr. Ann Hild and presented at the grassland workshop ..... A-310
Appendix P2. Reviews of conceptual models from breakout groups, comments on feedback forms, and comments on model drawings ..... A-322
P.2. REPORT FROM THE AQUATIC AND LANDSCAPE WORKSHOP, AUGUST 9-10, 2005. HOSTED BY FORT UNION NATIONAL MONUMENT AT HIGHLANDS UNIVERSITY, LAS VEGAS, NEW MEXICO ..... A-327
*P.2.1. Overview ..... A-327*
*P.2.2. Objectives ..... A-327*
*P.2.3. Conceptual Model Review ..... A-327*
P.2.3.1.Conceptual Model Summary and Future Directions ..... A-327
P.2.3.2. Future Directions for Landscape Models ..... A-327
P.2.3.3. Additional Comments for Landscape Models ..... A-328
P.2.3.2. Future Directions for River and Stream Models ..... A-328
P.2.3.3. Additional Comments for River and Stream Models ..... A-329
P.2.3.2. Future Directions for Reservoir Models ..... A-329
P.2.3.3. Additional Comments for Reservoir Models ..... A-330
*P.2.4. Aquatic and Landscape Issues and Vital Signs ..... A-330*
P.2.4.1. Landscape Group ..... A-331
P.2.4.2. Rivers and Streams Group ..... A-331
P.2.4.3. Reservoir Group ..... A-332
*F. Fort Union National Monument ..... A-148*
*G. Lake Meredith National Recreation Area ..... A-150*
*H. Lyndon B. Johnson National Historical Park ..... A-152*
*I. Pecos National Historical Park ..... A-154*
*J. Sand Creek Massacre National Historic Site ..... A-156*
*K. Washita Battlefield National Historic Site ..... A-158*
K.6. ACKNOWLEDGMENTS ..... A-160
K.7. LITERATURE CITED ..... A-160

## P.1. GRASSLAND WORKSHOP, FEBRUARY 1-2, 2005. HOSTED BY WASHITA BATTLEFIELD NHS COYOTE HILLS GUEST RANCH, CHEYENNE, OKLAHOMA

### *P.1.1. Overview*

This two day workshop was part of the process to develop a long-term ecological monitoring program for natural resources in the Southern Plains Inventory and Monitoring Network (SOPN). Developing conceptual models is one of the first steps towards selecting a suite of efficient and cost-effective indicators ("vital signs") of ecological integrity. During the first day draft versions of the grassland conceptual models were presented by Dr. Dan Tinker and then given a thorough review by workshop participants. The second day used the previous day's discussion of conceptual models as a framework to develop a list of potential grassland vital signs for SOPN. The workshop was attended by 26 people, including 12 outside experts and at least one representative from all 11 SOPN parks (Table 1 - Final Participant List).

### *P.1.2. Objectives*

1) Review grassland conceptual models. Provide model developer with suggestions for modifications and possible additional models.
2) Review the important natural resources and stressors of the network.
3) Develop/review list of potential vital signs with preliminary justification statements and monitoring objectives.

### *P.1.3. Conceptual Model Review*

Dusty Perkins started the day with an introductory talk on the Inventory and Monitoring Program and the Southern Plains Network. Then Dan Tinker presented his draft conceptual models (Appendix 1 for a description of the models presented). Then workshop participants were divided up into a short-grass (facilitated by John Gross) and a mixed-grass (facilitated by Dan Tinker) breakout group. Each group was assigned to review the models that corresponded to their breakout group. Due to the similarity of the short-grass and mixed-grass models, many of the comments made by each group were relevant to the other model. A complete report of the notes of each breakout group, comments made on conceptual model forms, and comments written on the conceptual model posters are in Appendix 2.

#### P.1.3.1. Conceptual Model Summary and Future Directions

This section briefly summarizes the major comments and concerns of the workshop and provides an outline of revisions to the existing models and the new models that will be developed jointly by Dan Tinker, Ann Hild and SOPN staff.

Many workshop attendees wanted to see more process-based (mechanistic, state-transition) models that they thought would be more useful to them in management decisions and for understanding the system for use in vital signs development and selection. These types of models will do a better job of showing the temporal and spatial effects of the stressors, which is hard to show in the stressor models that were presented. Specifically these types of models should be developed to address and include grazing, fire, keystone species, land legacies, and their major interactions.

There was some debate about the usefulness of conceptual models for park management. If models were customized to an individual park, they would lose their usefulness to the network because they would be so specific. It would take a large amount of resources to create 11 conceptual models for grasslands at each individual park. Conceptual models are not intended to be a guidebook for managers on specific management practices, but should be designed so they are helpful in understanding the system and understanding the potential implications of management practices. The solution will be to develop conceptual diagrams that are customized

to a group of parks or in some cases, individual parks. These diagrams will highlight the important components of the mechanistic grassland models.

There was discussion about how cultural resource management issues that are affected by natural resources fit into models and potential vital signs (e.g. prairie dogs effects on Santa Fe trail ruts, small mammals burrowing under ruins, landscape composition as it relates to viewsheds). These types of issues are hard to represent in conceptual models because they are often so specific.

There was debate in both groups over whether a species-specific keystone model incorporating prairie dogs should be developed. SOPN staff has decided to pursue this type of model due to this species' importance for biological, cultural and management reasons for at least five parks. We will first look to literature for examples.

The models currently ignore decomposition/microbial/soil animal interactions. This may be acceptable if: a) impacts are adequately captured by other interactions displayed in the model, and b) the fossorial biota in this group doesn't radically change soil processes and trophic levels (e.g. invasive earthworms in riparian zone). Revisions to stressor models and all future models need to be sure these impacts are included.

P.1.3.2. Future Directions for Grassland Models:

SOPN staff and the grassland model PIs will work collaboratively on the grassland models to do the following:

1.) Adopt the Jenny-Chapin model as the overarching conceptual model for the Southern Plains Network (Figure 1).
2.) Develop mechanistic/state-transition/process model(s) for grazing and fire and their interactions (Figures 2-4 are examples of these types of models). These models should be modified to fit short- and mixed-grass systems. These models should also incorporate what is currently depicted in the vegetation dynamics and successional stressor submodels. Fire and grazing models should capture variables such as time of year, extent, intensity of fire and grazing, and could potentially incorporate thresholds in a state-transition type model (such as woody species invasion, prairie dog colony expansion, invasive species invasion, etc.). The model(s) should also include land legacy, or the current land condition (agricultural field, prairie fragment), since certain conditions are harder to restore than others (farmland is harder to restore than ranchland because the soil has been disturbed).
    - -Westoby et al. Journal of Range Management was suggested as a good state-transition model for fire and grazing
    - -For a basis for exotics and woody invasives, Evans et al. 2001 had a model for invasives with cheatgrass as an example
    - -USGS Northern Prairie Research Center also has some state-transition models
    - -Heartlands Network has some grassland conceptual models
    - -Grazing model paper from Roy Roath
    - -NRCS Ecological Site descriptions that incorporate state-transition models and are currently under development around the country. They may be willing to focus on park sites.
3.) Consider decomposition/microbial/soil animal interactions and belowground biomass in revised stressor models and new mechanistic models.
4.) Portions of the models mentioned in #2 above as well as the general grassland models should also be depicted as pictorial models. These models are information rich and easy to read and understand (see Figure 5 for an example). These types of models give the audience an overview of the system before getting into the details that are included the stressor and process models.
5.) Develop conceptual diagrams that are customized to a group of parks or in some cases individual parks. These will not be full models but will highlight the important components

in information rich and aesthetically pleasing format that will increase understanding of the major grassland components and be useful for park managers and interpretive staff.

6.) Develop a prairie dog conceptual model. This species is important for management, biological, and cultural reasons at five SOPN parks. This model will include the prairie dog's affect on the flora (grazing), fauna (reduced cover that can create habitat for some rare species), disease (plagues can quickly decimate a colony), and management implications (colonies often abruptly end at NPS boundaries).
7.) Be sure to develop or borrow landscape vulnerability models. We will wait until other landscape level products that are being developed by other I+M networks are available before proceeding with the development of our own models. There are many grassland issues that are affected by landscape level issues, however these same issues are also likely to affect other terrestrial ecosystems (piñion-juniper, deciduous forest) and aquatic ecosystems (reservoir, rivers, streams, wetlands) which will be developed and assessed in late FY2005 and early FY2006.
8.) Keep the short-and mixed-grass stressor models because they show important links between drivers, stressors, ecological effects, indicators, and measures. Make the following changes to these stressor models:
    A.) Consider eliminating lines between components. If you thought long enough you could probably legitimately connect every component on the model. Too many connections makes the model too complicated. Specific important interactions can be shown on the detailed sub-models. Keep the model hierarchical (drivers, stressors, ecological effects, etc.) and keep things most associated in a linear fashion.
    B.) Rename the elevation driver to topography to better represent slope, aspect, and elevation.
    C.) Change grazing to herbivory/defoliation as grazing only implies impacts from ungulates. Herbivory/defoliation will incorporate many other processes can result in reduction of plant biomass (insects, ice storms, pathogens).
    D.) Precipitation/temperature should be moved to a stressor. Leave climate as a driver that describes the long-term temporal scale and what makes a grassland as opposed to a forest. Precipitation and temperature will reflect the annual and seasonal variations in weather conditions.
    E.) Insect outbreaks and wildlife diseases should be too separate stressors.
    F.) Add carbon change and woody invasives as a potential measure under grassland community composition.
    G.) Grassland birds should be added as a potential measure for wildlife and grassland indicators.
    H.) Consider including the absence of keystone species (no wolves, more coyotes, less swift foxes).
    I.) Write a more clearly defined narrative.

*P.1.4. Grassland Issues and Vital Signs*

During the second day, the workshop divided into the same two working groups as the day before, mixed-grass and short-grass. The goal was our Access database that contained 73 issues that individual parks had raised during the 2004 scoping sessions and any additional issues that surfaced during our literature review. Each group ranked all of the issues as high, medium, low, or not an issue (Table 2 - Grassland Issue Ranking Results). Each group went to each of their highly ranked issue to review the possible vital signs, monitoring objectives and justification statements. Each group was also given half of the issue list to review as a starting point and then told to move on to the second half of the list if there was time. With this method each group reviewed all of their high ranking issues (most of these were the same between the two groups), and all of the remaining issues were reviewed by at least one group (most were reviewed by both groups).

In ranking each issue the breakout groups were given the following guidelines, an issue would only be ranked high or low if there was consensus among the group that it was high or low. This method resulted in a list of high priority issues that were most important across the entire network. Issues that were high priority to one park, but not highly ranked across the network, were captured by the individual park's ranking that occurred prior to the workshop. All issues that both groups ranked as low were dropped from future consideration as potential vital signs. All non-consensus issues were ranked medium. A fourth category, "not an issue" was created for issues that were important but could not be monitored in a meaningful way or did not fit the guidance for the inventory and monitoring program (budgets, lack of long-term management).

The breakout groups were in almost complete agreement with their rankings. The issues that ranked high for both groups were exotic plants, carbon balance, grassland plant community, prairie restoration, water quality, water quantity, weather patterns and invasive plant species. In addition, the short-grass group had four issues that they ranked high, but the mixed-grass group ranked as medium: effects of park visitors on natural resources, fire frequency, grassland birds, and viewshed. The mixed-grass group had two issues that they ranked high, but the short-grass group ranked as medium: erosion and exotic game. Ten issues were ranked as low by both groups and will be dropped from consideration as vital signs: Africanized honeybee, black-footed ferret, Colorado bursage, echinacea, feral cats, giant mole cricket, hazardous spill on adjacent land, marsh rice rat, Palo Duro Canyon mouse, and porcupine. The groups ranked two additional issues were ranked as "not an issue" by both groups: lack of funding and lack of long-term management planning.

Several new objectives and vital signs were recommended. The groups suggested combining two high ranked issues, grassland vegetation community and prairie restoration, into one issue because the same vital signs could be used for both issues. There was discussion in both groups that the grassland community issue should incorporate belowground processes, and that subsequent vital signs should incorporate grazing and fire processes. The groups suggested that carbon dioxide and nitrogen pathways, C3 and C4 grasses, and carbon balance were possible measures to answer some of these questions. The short-grass group also suggested that hunting should be eliminated as a stand-alone issue, and instead incorporate hunting concerns into the small mammals, game birds, and big game issues.

There was discussion regarding how cultural resource management issues that are affected by natural resources fits into the monitoring program (black tailed prairie dogs [*Cynomys ludovicianus*] effects on Santa Fe Trail ruts, small mammals burrowing under ruins, landscape composition as it relates to viewsheds). The consensus was if the potential vital sign is only being considered because it affects a cultural resource, then it should not be part of the monitoring program. If the vital sign also affects an important natural resource then the cultural aspect may elevate the priority of that vital sign. As a result, viewshed and soundscape were eliminated as independent issues and will be incorporated into land cover/land use.

Three new issues were added to our database: carbon balance, keystone invertebrates, keystone vertebrate species, and meso-mammals/carnivores. Changes in carbon balance will precede other changes in ecosystem health and function. Carbon balance can be measured through soil respiration and productivity (NDVI – normalized distribution vegetation index). Some invertebrates can be keystone species and some introduced species (i.e. earthworms) can have drastic affects on biogeochemical feedbacks, soil processes, and altering trophic levels that can then affect flora and fauna. There are several keystone species that are important to individual parks (black-tailed prairie dogs, top predator [lack of], white-tailed deer [*Odocoileus virginianus*]). The meso-mammal issue was added by the mixed-grass group as an issue that would combine several other individual issues (porcupines [*Erethizon dorsatum*], raccoons [*Procyon lotor*], swift fox [*Vulpes velox*]). The group recognized that these meso-carnivores are an important part of the ecosystem and at many parks may represent the top trophic level that resides in the park (larger carnivores have home ranges larger then most SOPN parks).

At the conclusion of the workshop, a list of 53 issues related to grassland ecosystems was developed (Tables 3). In addition, the groups discussed issues related to grasslands, but will receive increased attention at our aquatic workshop or forested systems review (Table 3b). They were discussed at the grassland workshop because we recognize that some issues cannot be pigeonholed into only one particular type of ecosystem.

SOPN will hold a similar workshop this summer for aquatic systems, and will conduct the same process at a reduced level for forested systems (piñion-juniper and eastern deciduous forest). In fiscal year 2006, SOPN will evaluate the list of issues and vital signs developed at these workshops and prioritize, and then select the vital signs for our monitoring program.

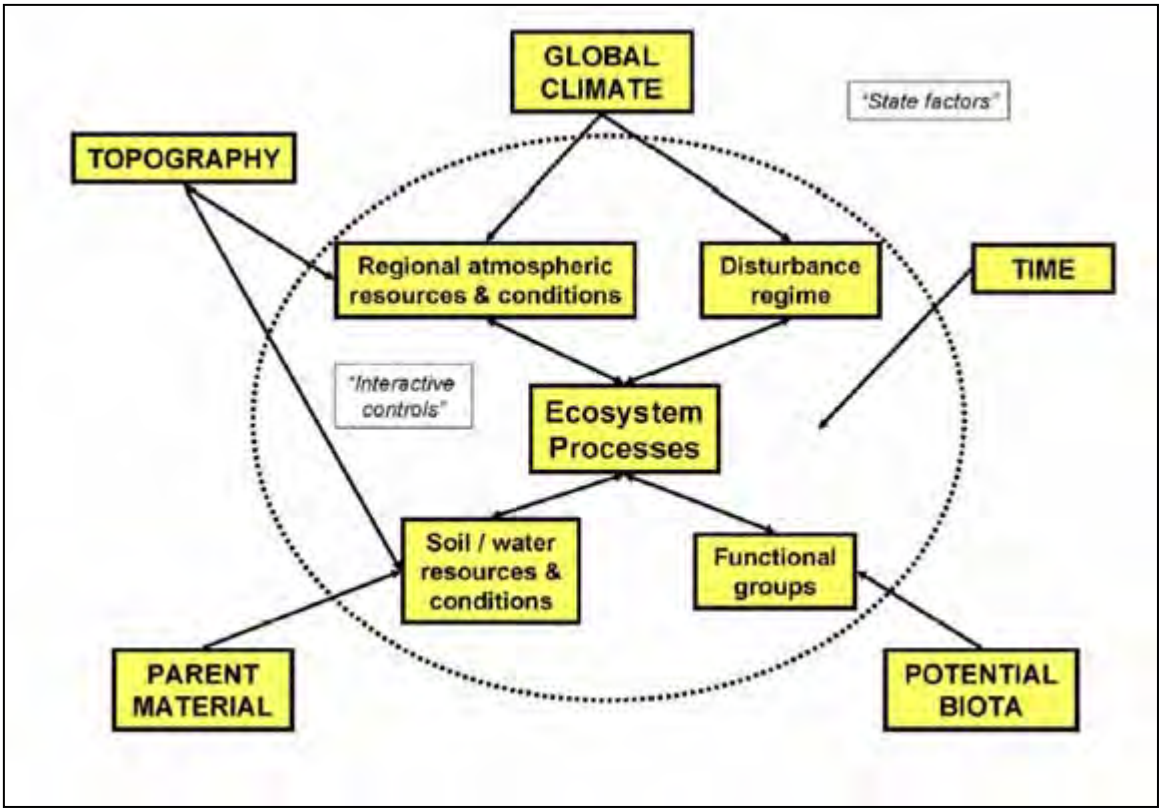



**Figure 1. Relationship between Jenny's (1941) state factors, interactive controls, and ecosystem processes. The circle represents the boundary of the system (Chapin et al. 1996).**

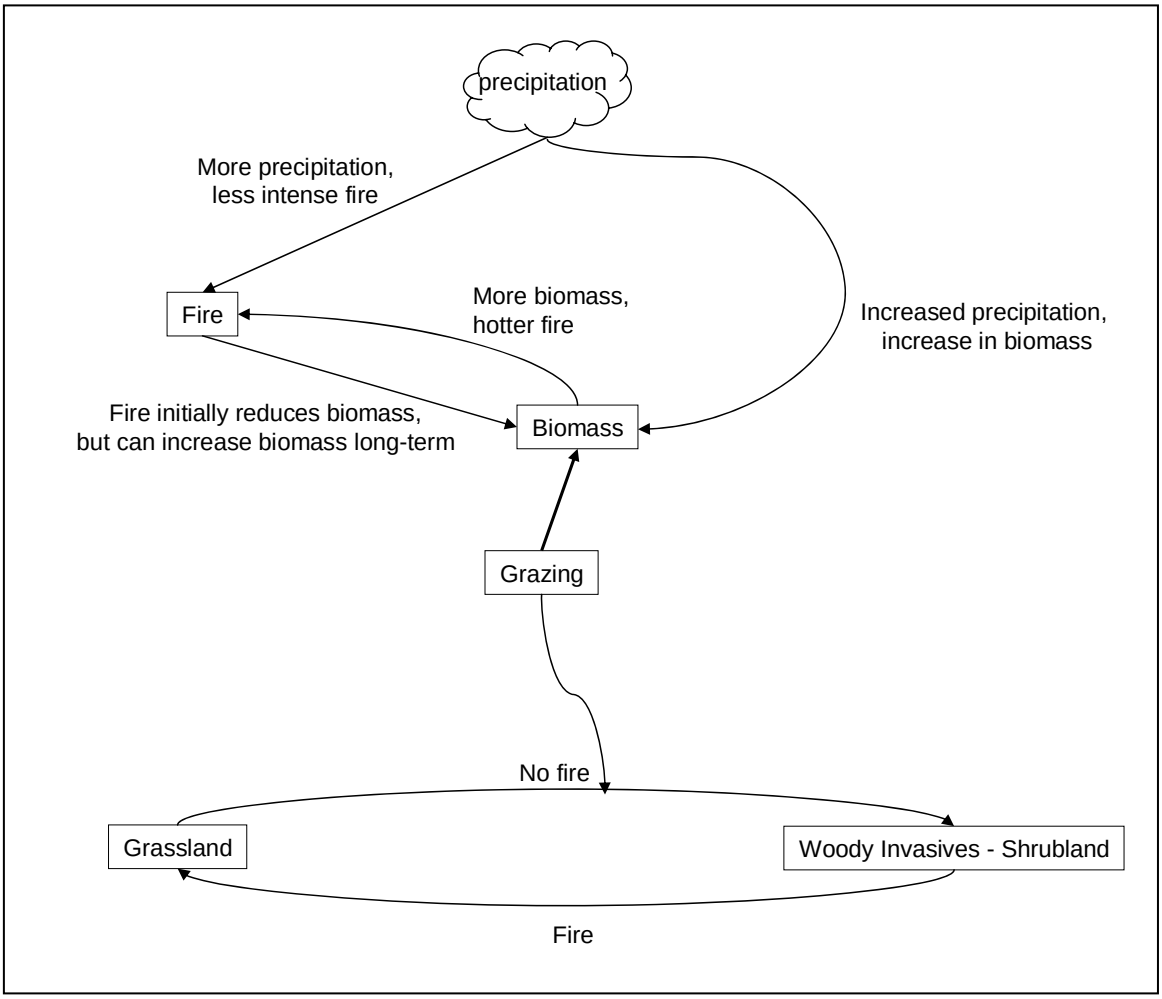



**Figure 2. Short-grass Breakout Group Simple Mechanistic Grassland Model**

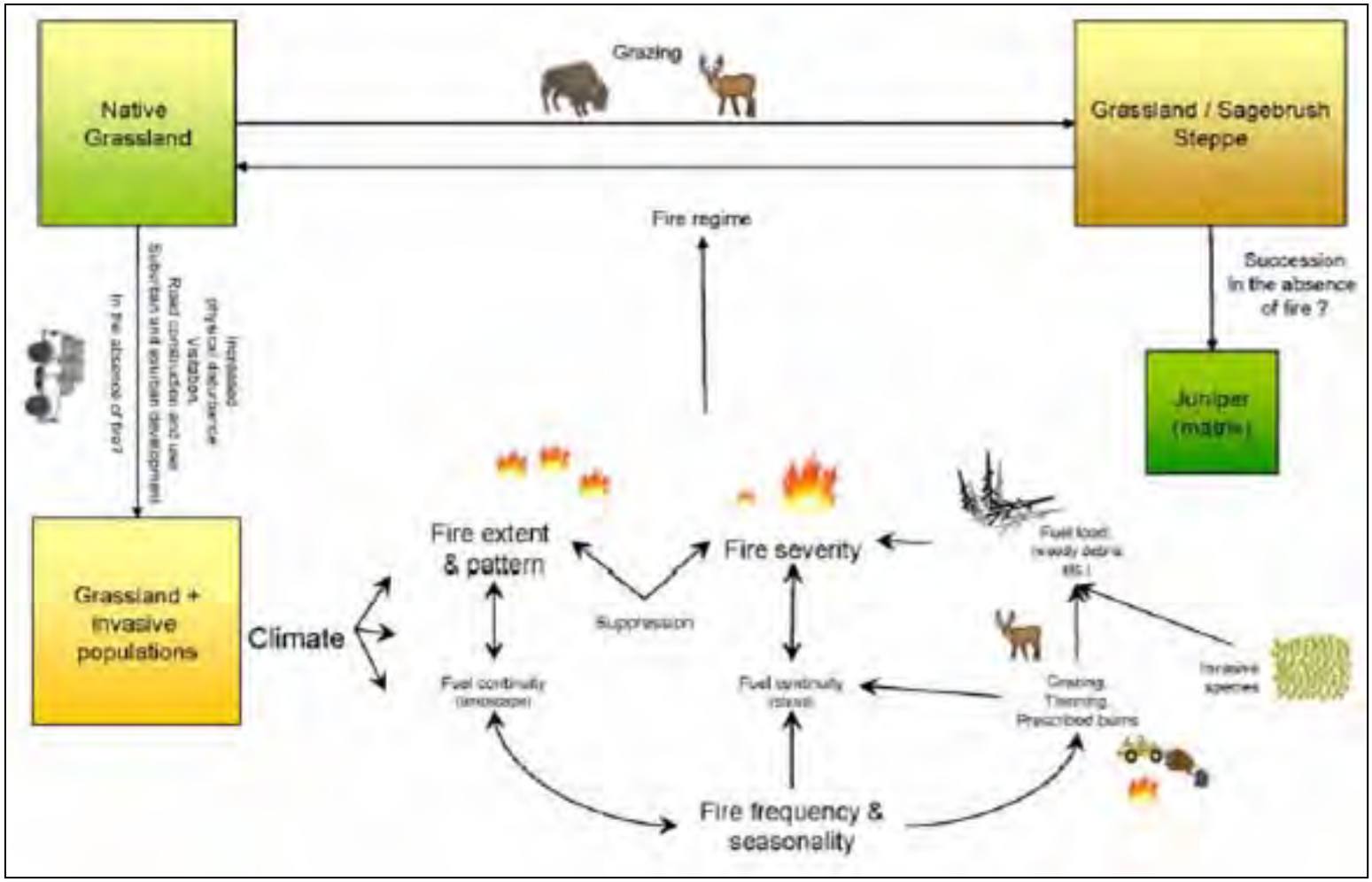



**Figure 3. Rocky Mountain I+M Conceptual Model for grazing, fire interactions in grassland systems.**

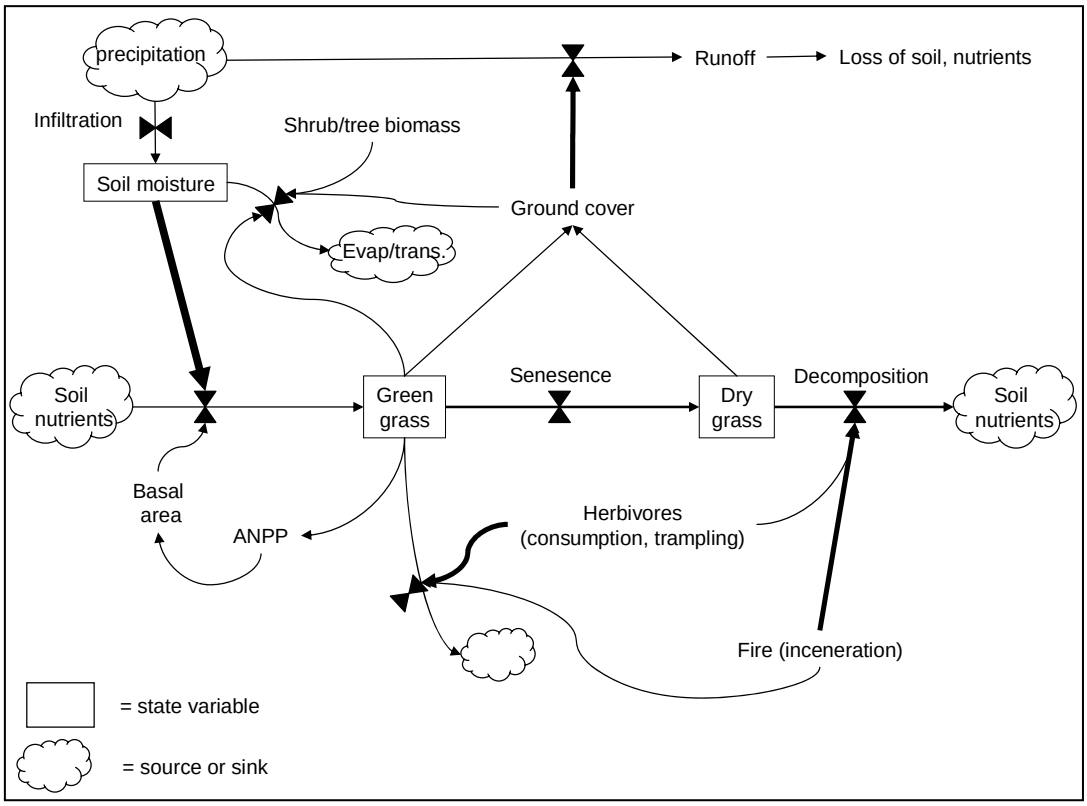



**Figure 4. John Gross Grassland Model**

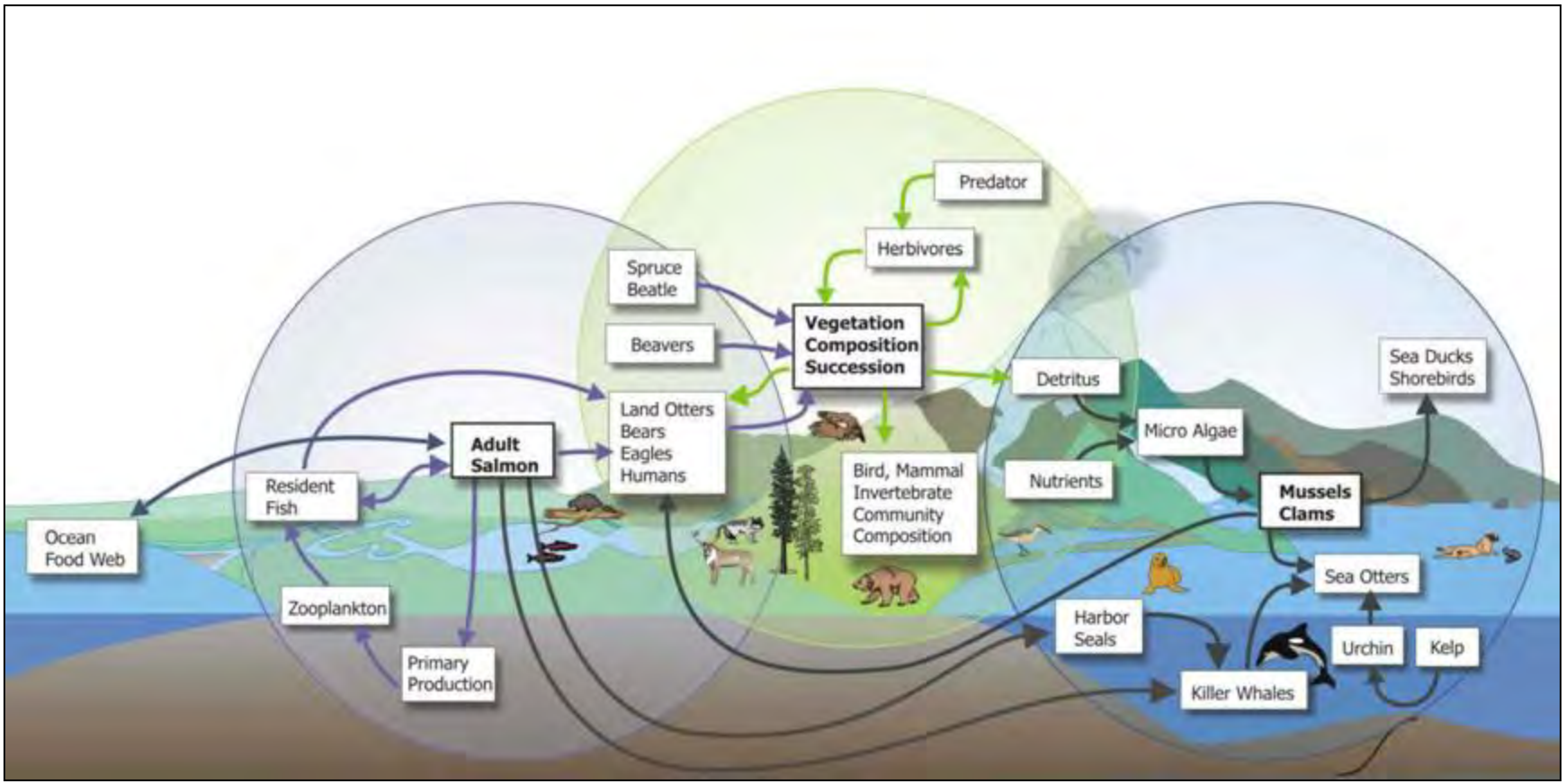



**Figure 5. Example of pictorial conceptual model from the Southwest Alaska I+M Network.**

**Table 1. Final Participant List**

| NPS Park Staff | | | |
|---|---|---|---|
| *Person* | *Position* | *Park* | *Breakout Session* |
| Ruben Andrade | Supervisory Park Ranger | Fort Union NM | Short-grass |
| Steve Burrough | Chief of Resource Management | Chickasaw NRA | Mixed-grass |
| Paul Eubank | Natural Resource Specialist | Lake Meredith NRA / Alibates Flint Quarries NM | Short-grass |
| Daniel Jacobs | Chief Ranger | Pecos NHP | Short-grass |
| Jason Lott | Integrated Resources Program Manager | Lyndon B. Johnson NHP | Mixed-grass |
| Alden Miller | Chief of Resources + Facilities | Washita Battlefield NHS | Mixed-grass |
| Fran Pannebaker | Natural Resource Specialist | Bent's Old Fort NHS | Short-grass |
| Maggie Johnston | Superintendent | Capulin Volcano NM | Short-grass |
| Brian Quigley | Chief Ranger | Capulin Volcano NM | Short-grass |
| Karl Zimmermann | Park Ranger | Bent's Old Fort NHS | Short-grass |
| Felix Revello | Chief Ranger | Fort Larned NHS | Mixed-grass |
| Alexa Roberts | Superintendent | Sand Creek Massacre NHS | Short-grass |
| NPS Inventory and Monitoring Staff | | | |
| *Person* | *Position* | *Location* | *Breakout Session* |
| Dusty Perkins | SOPN Network Coordinator | Lyndon B. Johnson NHP | Floater |
| Heidi Sosinski | SOPN Data Manager | Lyndon B. Johnson NHP | Mixed-grass |
| Subject-Matter Experts | | | |
| *Person* | *Organization* | *Expertise* | *Breakout Session* |
| Dan Tinker | University of Wyoming | PI for Conceptual Models | Mixed-grass |
| Gail Stakes | University of Wyoming | Assisted with Model Dvlpt. | Short-grass |
| Linda Wallace | University of Oklahoma | Grazing-Plant Interactions, Plant competition | Mixed-grass |
| John Gross | NPS - Inventory and Monitoring Program | Conceptual Models, Landscape ecology | Short-grass |
| Tim Seastedt | University of Colorado-Boulder | Soil biodiversity, invasive plants | Short-grass |
| Karie Cherwin | University of Colorado-Boulder | SOPN Ph.D. Graduate Student | Short-grass |
| Sue Braumiller | NPS | Hydrology, aquatic model developer | Mixed-grass |
| Dan Licht | NPS – N. Great Plains Network | Grasslands, vertebrates | Mixed-grass |
| Steve Windhager | Ladybird Johnson Wildflower Center | Restoration, exotic vegetation | Mixed-grass |
| Brian Hajney | USFS-Black Kettle National Grasslands | Wildlife, grasslands | Mixed-grass |
| Roy Roath | Colorado State | Grazing Management, Rangeland monitoring | Short-grass |
| Kris Johnson | Natural Heritage New Mexico | Avian Conservation, Vertebrate Ecology | Short-grass |

**Table 2. Grasslands Workshop Issue Ranking Results**

| | |
|---|---|
| *Total Number of Issues Ranked:* | *74* |
| *Issues Ranked "High" or "Medium" :* | *61* |
| *Issues Ranked "Low" or "Not an Issue":* | *13* |

**High**

Issues were ranked as "High" priority only if both the mixed-grass and short-grass groups agreed. If an issue was ranked "high" by only one group, it was moved down to "Medium".

Carbon balance
Exotic Plants
Grassland plant community
Prairie Restoration
Water Quality
Water Quantity
Weather patterns
Woody Invasive Species

**Medium**

Issues were ranked as "Medium" priority under the following circumstances: Both groups ranked it as "Medium"; the issue was ranked "high" by one group and "Medium" by the other group; or the issue was ranked as "medium" by one group and "Low" by the other group.

Adjacent Land Use
Air Quality
Alberta arctic butterfly
Bald Eagle
Big Game
Black-tailed prairie dogs
Boundary survey/fencing
Burrowing owl
Cryptobiotic soils
E.coli levels
Effects of Grazing
Effects of Park visitors on natural resources*
Endemic invertebrates
Erosion^
Exotic Game^
Feral Dogs
Feral Hogs
Ferruginous hawk
Fire*
Fire Ants
Game birds
Grassland birds*
Groundwater levels
Hunting
Insect diseases on ecosystem
Lacustrine Community
Large Carnivores
Lesser Prairie Chicken
Medium sized mammals
Meso Mammals / Carnivores
Migratory songbird stopover area
Mineral, Oil, and Gas Extraction
Mississippi Kites
Mountain plovers
Montane/grassland/desert interface
Night sky
Non-vascular plants
Nutria
Off-road vehicle use
Pollution from non-park sources
Raccoons

Reptile Community

Small mammal community

Soundscape

SW Willow flycatcher

Swift fox

Texas horned lizard

Townsend's big eared bat

Viewshed*

Volcanic Cinder Cone

Upland Springs

Wetlands in upland systems

Wildlife Diseases effects on staff and visitor

* denotes a high ranked issue by the short-grass group but a medium ranking by the mixed-grass group
^ denotes a high ranked issue by the mixed-grass group but a medium ranking by the short-grass group

**Low**

Issues can be ranked as "Low" priority only if both the mixed-grass and short-grass groups both agreed on that ranking.

Africanized honeybee

Black-footed ferret

Colorado bursage

Echinacea

Feral Cats

Giant mole cricket

Hazardous spill on adjacent highway, railroad

Marsh rice rat

Palo Duro canyon mouse

Porcupine

**Not An Issue**

These are issues are not directly related to vital signs monitoring.

Funding (lack of money and staff)

Lack of long-term management plan

**Table 3a. Final List of Grassland Issues. These issues are being considered as potential vital signs for grassland systems. They are shown here according to their proposed classifications within the National Vital Signs classification system.**

| Level 1 | Level 2 | Level 3 | Issue Name |
|---|---|---|---|
| Air and Climate | Air Quality | Air contaminants | Air quality[1] |
| | | | |
| | Weather and Climate | Weather and climate | Weather patterns[1] |
| | | | |
| Biological Integrity | At-risk Biota | T&E species and communities | Alberta arctic butterfly |
| | | | Bald eagle |
| | | | Black-tailed prairie dog |
| | | | Burrowing owl |
| | | | Ferruginous hawk |
| | | | Lesser prairie chicken |
| | | | Mountain plovers |
| | | | Southwestern willow flycatcher |
| | | | Swift fox |
| | | | Texas horned lizard |
| | | | Townsend's big-eared bat |
| | | | |
| | Focal Species or Communities | Keystone species | Specific keystone species |
| | | | |
| | | Amphibians and reptiles | Reptile community |
| | | Birds | Grassland birds |
| | | | Migratory songbird stopover area |
| | | | Mississippi kites |
| | | | |
| | | Grassland vegetation | Grassland community (includes prairie restoration) |
| | | | |
| | | Mammals | Large carnivores |
| | | | Large ungulates |
| | | | Meso mammals / carnivores |

| Level 1 | Level 2 | Level 3 | Issue Name |
|---|---|---|---|
| Biological Integrity | Focal Species or Communities | Mammals | Raccoons |
| | | | Small mammal community |
| | | | |
| | | Terrestrial invertebrates | Endemic invertebrates |
| | | | Keystone invertebrates |
| | | | |
| | | Vegetation communities | Non-vascular plants |
| | | | Montane/grassland/desert interface |
| | | | |
| | Infestations and Disease | Animal diseases | Wildlife diseases effects on staff and visitors |
| | | | |
| | | Insect pests | Insect diseases on ecosystem |
| | | | Fire ants |
| | | | |
| | Invasive Species | Invasive / exotic animals | Exotic game |
| | | | Feral dogs |
| | | | Feral hogs |
| | | | Nutria |
| | | | |
| | | Invasive / exotic plants | Exotic plants |
| | | | Woody invasive species |
| | | | |
| Ecosystems Patterns and Processes | Fire | Fire and fuel dynamics | Fire |
| | | | |
| | Land Cover and Use | Land cover and use | Boundary survey / fencing |
| | | | Land Use / land cover[1] |
| | | | Adjacent land use[1] |
| | | | |
| | Nutrient Dynamics | Nutrient dynamics | Carbon balance |

| Level 1 | Level 2 | Level 3 | Issue Name |
|---|---|---|---|
| Geology and Soils | Geomorphology | Stream / river channel characteristics | Erosion[1] |
| | | | |
| | Soil Quality | Soil function and dynamics | Cryptobiotic soils |
| | | | |
| | Subsurface Geologic Processes | Volcanic features and processes | Volcanic cinder cone[1] |
| | | | |
| Human Use | Consumptive Use | Consumptive use | Effects of grazing |
| | | | Game birds |
| | | | Mineral, oil, and gas Extraction |
| | | | |
| | Non-point Source Human Effects | Non-point source human effects | Pollution from non-park sources[1] |
| | | | |
| | Visitor and Recreation Use | Visitor usage | Effects of park visitors on natural resources |
| | | | Off-road vehicle use |
| | | | |
| Water | Hydrology | Groundwater dynamics | Groundwater levels[1] |
| | | | |
| | Water Quality | Microorganisms | E. coli[1] |

Table 3b: Aquatic issues that were discussed briefly at the grasslands workshop and will be discussed in more detail at the aquatic workshop.

| Level 1 | Level 2 | Level 3 | Issue Name |
|---|---|---|---|
| Biological Integrity | Focal Species or Communities | Freshwater communities | Lacustrine community |
| | | Wetland communities | Wetlands in upland systems |
| | | | |
| Water | Hydrology | Groundwater dynamics | Upland springs |
| | Water Quality | Surface water dynamics | Water quality |
| | | | Water quantity |

Appendix P1. Narrative and pictures of draft conceptual models developed by Dr. Dan Tinker and Dr. Ann Hild and presented at the grassland workshop.

**Short-grass and Mixed-grass Ecosystems in the Southern Plains**
**A Narrative Conceptual Model**

**Prepared by Daniel Tinker and Ann Hild**
**Departments of Botany and Renewable Resources**
**University of Wyoming**
**Laramie, Wyoming**

## Introduction

Grasslands were historically the largest vegetation type in North America, covering more than 300 million ha (Küchler 1964), yet still occupy over 125 million ha in the United States (U.S. Forest Service 1980). However, short-grass and mixed-grass prairie grasslands are currently some of the most endangered ecosystems in North America (Rickletts et al. 1999). Short-grass prairies are dominated by two species of grass, *Bouteloua gracilis* and *Buchloë dactyloides*, but other species such as *Stipa comata*, *Koeleria macrantha*, and *Sporobolus cryptandus* are also important components. These ecosystems are found primarily east of the Rocky Mountains, from Nebraska and Wyoming southward through the High Plains (Sims and Risser 2000). Mixed-grass prairies, which extend from south-central Canadian provinces to central Texas, are more floristically rich, and are characterized by vegetation intermediate to tall-grass and short-grass prairies. Dominant species vary across a latitudinal gradient, and include species of *Elymus*, *Pseudoroegneria*, *Bouteloua*, along with various species of sedges (*Carex* sp.) (Barbour et al. 1987).

## Conceptual Model Development

### Drivers

The **climate** found in short-grass and mixed-grass ecosystems is quite variable across central North America. Notably, in the majority of these systems, approximately two-thirds of the annual rainfall in central grasslands occurs during the growing season (Sims et al. 1978). The usual rainfall deficiency that occurs late in the growing seasons provides conditions more favorable for the maintenance of grasslands than to deciduous forests (Sims and Risser 2000). In particular, grasslands of the Great Plains are strongly influenced by north-south and east-west climatic patterns, with precipitation decreasing from east to west, and air temperature increasing from north to south (Singh et al. 1983). Precipitation also acts as a strong driver of grassland ecosystem processes, and the relationship between rainfall and productivity is generally linear (Lauenroth 1979). The distribution of grasslands within the central U.S., as well as their vegetative composition, is further related to the interactions of a variety of other environmental and edaphic factors, including physiographic and topographic conditions, **elevation**, and herbivory (McNaughton, Coughenour, and Wallace 1982). With respect to **bedrock geology and soils**, Mollisols are typically associated with cool, wet grasslands of the central plains, while more arid sites are most often characterized by Aridisols (Sims and Risser 2000). In the southern plains, soil texture varies from fine sandy soils to clay soils. There is a swath of relatively fertile Alfisols that stretches from southeastern Kansas into central Texas, following the general distribution of the cross timbers vegetation, as mapped by Küchler (1984), while Mollisols are most abundant throughout the rest of the southern plains (Sims and Risser 2000).

### Stressors

**Wet and dry cycles**, along with periodic **drought** in short-grass systems, may be both harmful and beneficial, depending on the timing and intensity of the cycles. Dickinson and Dodd (1976) found that increases in water may affect the phenology of some grass species, e.g.,

*Bouteloua gracilis*, and flowering may occur earlier than in drier periods. Notably, some grassland systems have developed adaptations to aridity, which may manifest themselves as morphological changes such as small stature and basal meristems (Coughenour 1985). These adaptations may also be advantageous for recovery from herbivore grazing. In general, grassland ecosystem responses to **grazing** are quite variable, and many systems have evolved grazing resistance to herbivory (e.g., Milchunas and Lauenroth 1993). However, grazing may be detrimental to many short-grass and mixed-grass ecosystems, depending on the intensity and duration of the grazing activity.

**Erosion** of surficial soils may occur as a result of intense, episodic rainfall events, or from road building, agricultural activities, and other human land uses. Stream bank erosion may also occur from human land use practices such as grazing. Excessive grazing, which can cause increases in bare ground, may be positively correlated with increases in runoff following precipitation events (Hart et al. 1988; Hart and Frasier 2003). Similarly, **flooding** of rivers and streams can occur in arid areas where human activities have rerouted water courses and where soil texture prevents rapid infiltration.

**Fire** may also be a stressor, although most grassland systems have evolved with relatively frequent recurring fires (Sauer 1950; Curtis 1962; Alelrod 1985). Consequently, the suppression and removal of fire as an ecological process could actually act as a more direct stressor than fire itself, although fire may be detrimental in some short-grass prairie ecosystems (Wright and Bailey 1980).

**Invasive exotic plant species** may colonize disturbed areas in and around NPS lands, and can be transported into parks via humans, vehicles, or other biotic vectors. These plants may outcompete some native vegetation and persist for decades. **Exotic animal species** and feral domestic species can also compete with native species for limited resources. Along with invasive species, **insect and wildlife diseases**, both natural and exotic, may infest native populations of plants and animals. While they may not be exotic, black-tailed prairie dogs and their colonies may play a significant role as a stressor in avian community structure and composition in some areas of short-grass plains (Smith and Lomolino 2004), and their presence may be either beneficial or detrimental to other fauna and flora.

A critical stressor that could, in many ways, also be considered a driver, is **human impacts** and **adjacent land use and land use change**. The many different ways that humans use the land is an important contributor to landscape pattern and process (Turner et al. 2001). For example, residential, commercial, and industrial development on adjacent lands are the direct result of human use (Meyer 1995), and may create hard boundaries around parks that can interrupt natural flows and fluxes of ecosystem processes and services, including recycling of nutrients and maintenance of clean air and water – this may be particularly problematic for some of the smaller parks in the Southern Plains Network. Many of the historically intact landscapes are rapidly becoming fragmented, largely through human land uses (Harris 1984). Unfortunately, these human “footprints” on the landscape are usually one-directional and are long-lasting legacies on the landscape (Turner et al. 1988). Species-area relationships are important for identifying biodiversity hotspots (Myers et al. 2000), and for helping predict reductions in populations or species in areas subjected to habitat fragmentation (Pimm and Askins 1995). This increases the difficulty in managing small areas, as are common for some parks within SOPN. Closely related to human land uses is the issue of **non-park source pollution**, which may include a variety of unwanted materials such as fertilizers and airborne pollutants.

Ecological Outcomes and processes

Ecological outcomes and processes describe complex, interactive relationships between various biotic and abiotic components of the ecosystem. These processes are more fully explained by way of individual schematic submodels, and include many of the drivers, stressors, and indicators discussed in this narrative.

Indicators

**Bird and other wildlife populations** are directly and indirectly affected by many of the stressors contained in the animal population dynamic submodel, including human impacts such as land use change, and the invasion of exotic and feral species. Inventories of big game, ungulates and other small mammals may serve as important indicators of ecosystem function. The interactions of temperature, precipitation, and soil type, along with annual and decadal wet and dry cycles can determine the structure and activity of **wetland areas and upland springs**.

Regeneration of **Cottonwood riparian woods** relies heavily on episodic flooding events. Regulation of water flows, through impoundments and irrigation, may reduce the likelihood of such events and, consequently inhibit natural regeneration of new individuals along these important corridors. In mixed-grass ecosystems, small patches of **deciduous hardwood forests** are quite sensitive to many stressors such as human impacts, grazing and invasive plant species.

**Grassland community composition** is an excellent indicator of the condition of these ecosystems. Further, resource islands in temperate grasslands, which develop from spatially heterogeneous plant cover, can be areas of accumulated soil materials. These islands may take decades to create, but can disappear within three years of the death of an individual plant, and may be good indicators of ecosystem condition (Burke et al. 1998). Further, the **habitat quality** of the grassland ecosystems responds to a variety of drivers and stressors, most notably human impacts, grazing, and periodic drought.

Water quality and quantity respond to a myriad of drivers and stressors. **Water quantity** is directly affected by annual precipitation and periodic drought, along with water allocation by human uses. **Water quality** may be impacted by specific non-park source pollution, and also by non-point source pollution such as atmospheric deposition. **Night skies and soundscapes**, arguably some of the most desired resources in national parks and recreation areas, are primarily affected by human impacts and adjacent land uses, including construction of roads and buildings. Other impacts to soundscapes can include fire suppression efforts. However, night skies may also be impacted by other natural causes such as dust, which may be caused by periods of drought.

**References**


Axelrod, D.I. 1985. Rise of the grassland biome, central North America. Bio. Rev. 51: 163-201.

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial Plant Ecology. Second Edition. Benjamin/Cummings Publishing, Menlo Park, CA.

Burke, I.C., W.K. Lauenroth, M.A. Vinton, P.B. Hook, R.H. Kelly, H.E. Epstein, M.R. Aguiar, M.D. Robles, M.O. Aguilera, K.L. Murphy, and R.A. Gill. 1998. Plant-soil interactions in temperate grasslands. Biogeochemistry 42: 121-143.

Coughenour, M.B. 1985. Graminoid responses to grazing by large herbivores: adaptations, exaptations and interacting processes. Annals of the Missouri Botanical Garden 72: 852-863.

Curtis, J.T. 1962. the modification of mid-latitude grasslands and forests by man, pp. 721-736 in W.L. Thomas, Jr., ed., Man's role in changing the face of the earth. University of Chicago Press, Chicago.

Dickinson, C.E., and J.L. Dodd. 1976. Phenological pattern in the short grass prairie. American Midland Naturalist 96: 367-378.

Harris, L.D. 1984. The Fragmented Forest. University of Chicago Press, Chicago, Illinois, USA.

Hart, R.H., M.J. Samuel, P.S. Tewst, and M.A. Smith. 1988. Cattle, vegetation and economic responses to grazing systems and grazing pressure. J. Range Management 41: 282-286.

Hart, R.H., and G.W. Frasier. 2003. Bare ground and litter as estimators of runoff on short- and mixed-grass prairie. Arid Land Research and Management. 17: 485-490.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society special publication 36, New York.

Lauenroth, W.K. 1979. Grassland primary production: North American grasslands in perspective, pp. 3-24 in N.R. French, ed., Perspectives in grassland ecology. Springer-Verlag, New York.

McNaughton, S.J., M.B. Coughenhour, and L.L. Wallace. 1982. Interactive processes in grassland ecosystems, pp. 167-193 n J.R. Estes, R.J. Tyrl, and J.N. Brunken (eds.), Grasses and grasslands, systematics and ecology. University of Oklahoma Press, Norman, OK.

Meyer, W.B. 1995. Past and present land use and land cover in the USA. Consequences, Spring 1995: 25-33.

Milchunas, D.G., and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63: 327-366.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Pimm, S.L., and R.A. Askins. 1995. Forest losses predict bird extinctions in eastern North America. Proceedings of the National Academy of Sciences (USA) 92: 9343-9347.

Rickletts, T.H., E. Dinerstein, D.M. Olsen, C.J. Loucks, W. Eichbaum, D. DellaSala, K. Kavanagh, P. Hedao, P.T. Hurley, K.M. Carney, R. Abel, and S. Waiters. 1999. Terrestrial ecoregions of North America. Island Press, Washington, D.C.

Sauer, C.O. 1950. Grassland, climax, fire, and man. J. Range Mgt. 3: 16-22.

Sims, P.L., and P.G. Risser. 2000. Grasslands. *In*: Barbour, M.G., and W.D. Billings, eds., North American Terrestrial Vegetation, Second Edition. Cambridge University Press, New York, pp. 323-356.

Singh, J.S., W.K. Lauenroth, R.K. Heitschmidt, and J.L. Dodd. 1983. Structural and functional attributes of the vegetation of the mixed prairie of North America. Bot. Rev. 489: 117-149.

Smith, G.A., and M.V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the short grass plains. Oecologia 138: 592-602.

Turner, M.G., S.R. Carpenter, E.J. Gustafson, R.J. Naiman, and S.M. Pearson. 1988. Land use. *In*: M.J. Mac, P.A. Opler, P. Doran, and C. Haecker, eds. Statu8s and Trends of Our Nation's biological Resources, volume 1, pp. 37-61. National Biological Service, Washington, DC, USA.

Turner, M.G., R.H. Gardner, and R.V. O'Neill. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer-Verlag, New York.

U.S. Forest Service. 1980. An assessment of the forest and range land situation in the United States. USDA publication FS-345. Forest Service, Washington, D.C.

Wright, H.A., and A.W. Bailey. 1980. Fire ecology and prescribed burning in the Great Plains – a research review. USDA Forest Service general technical report INT-77. Intermountain Forest and Range Experiment Station, Ogden, Utah.

**Conceptual Models**

- DRIVER – The major external driving forces that have large scale influences on natural systems. Drivers can be natural forces or anthropogenic.

- STRESSOR – Physical, chemical, or biological agents that cause significant changes in the ecological components, patterns and relationships in natural systems. The effects of stressors on park resources can be positive or negative.

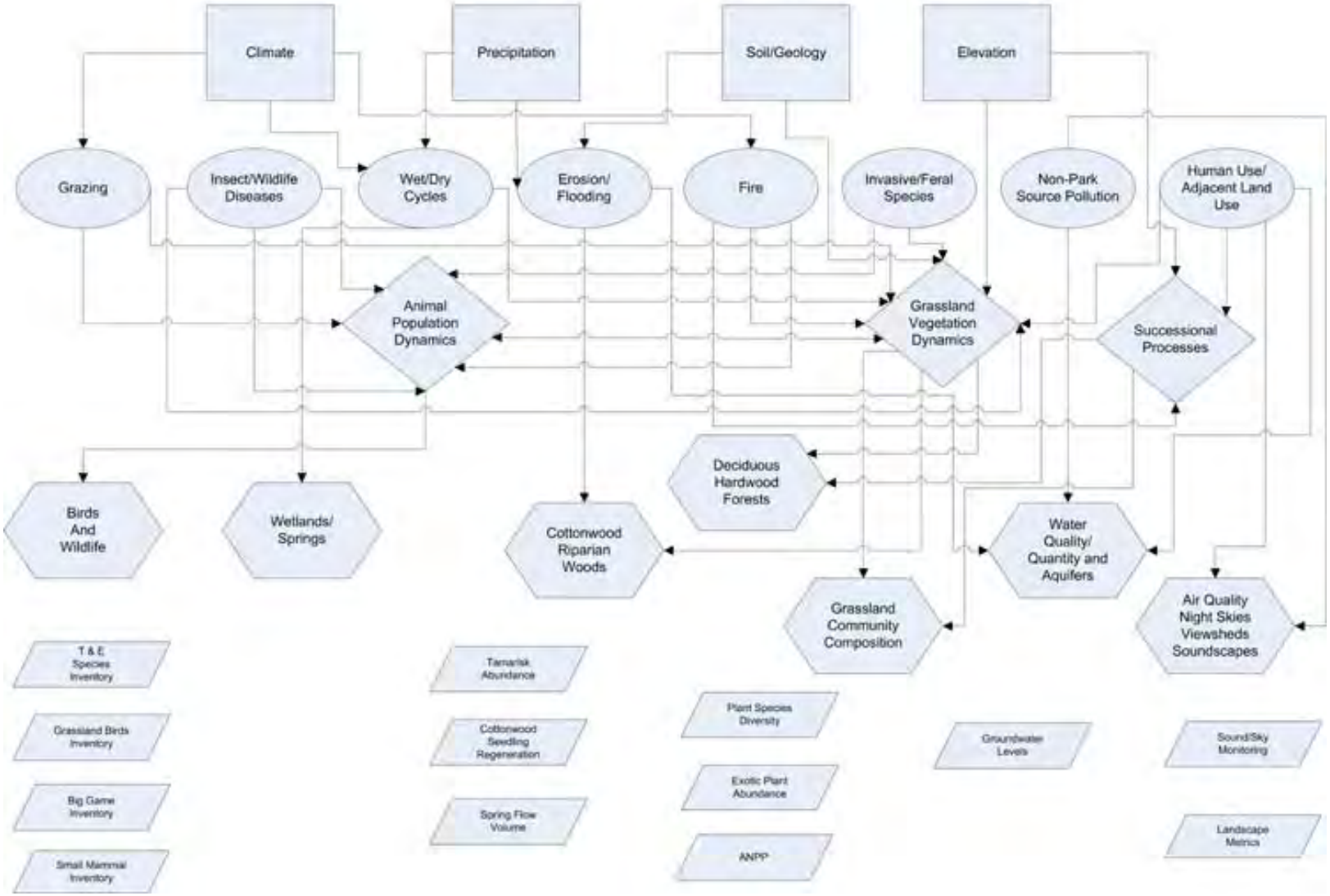
- ECOLOGICAL OUTCOME OR PROCESS – Physical, chemical, and biological/ecological responses to drivers and stressors.

- INDICATORS – Any living or nonliving feature of the environment that can be measured or estimated and that provides insights into the state of the ecosystem. Indicators are sometimes defined as a subset of attributes that are particularly information-rich in the

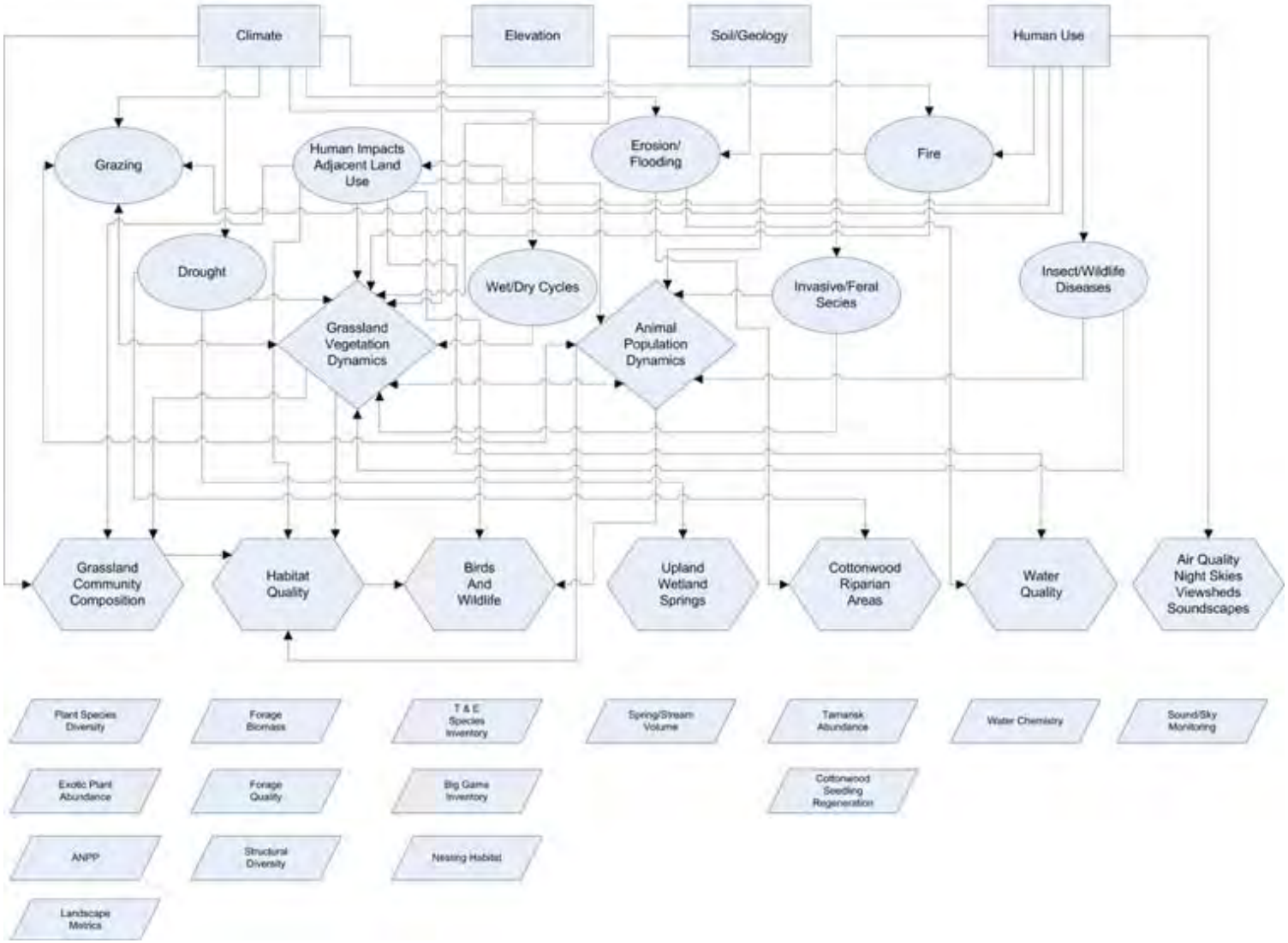
sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong.

- MEASURES – Specific measures used to quantify the indicators. Analysis of this information will assess how well the indicator is responding to the ecological effect.

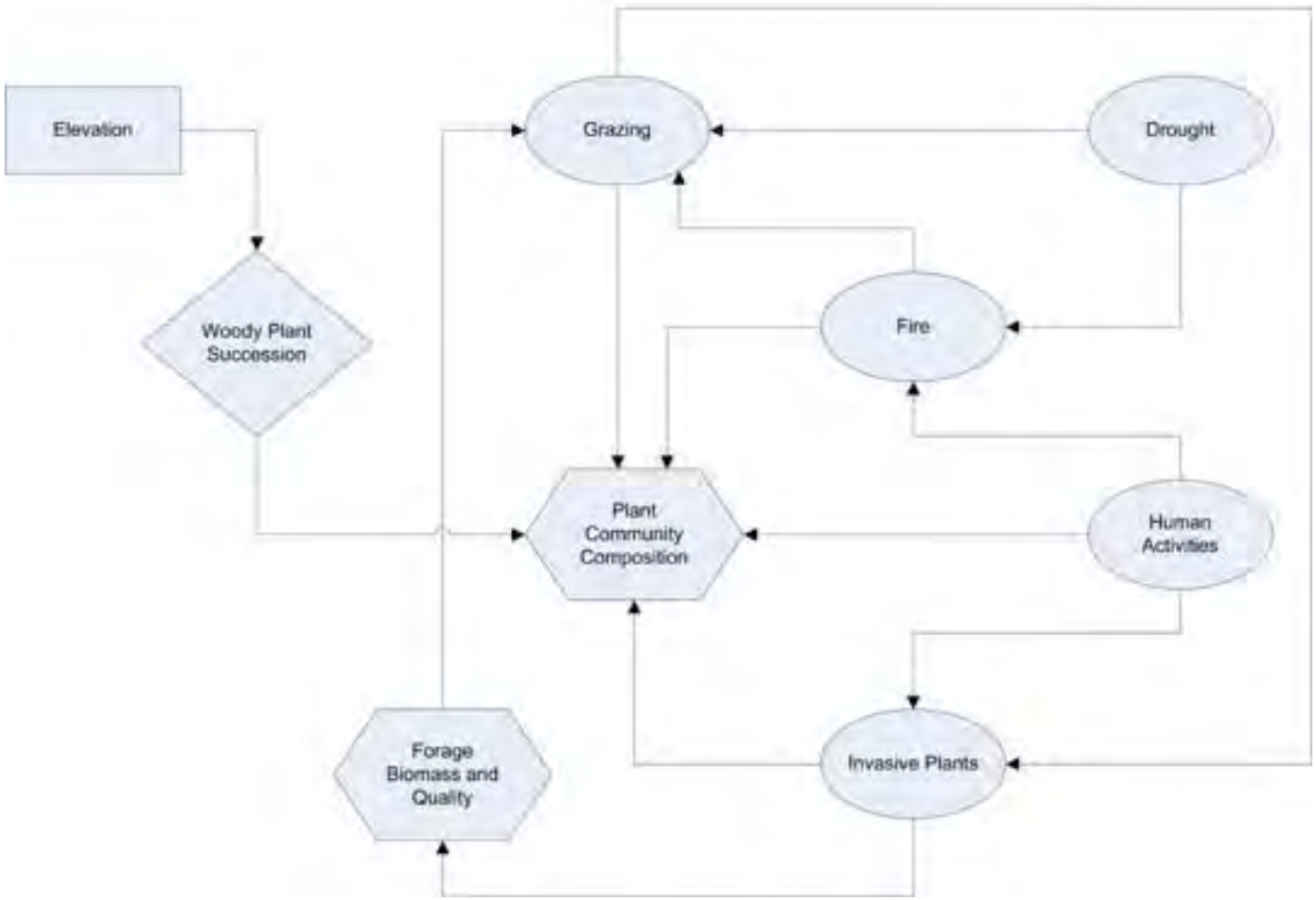
# Mixed Grass Ecosystem Model



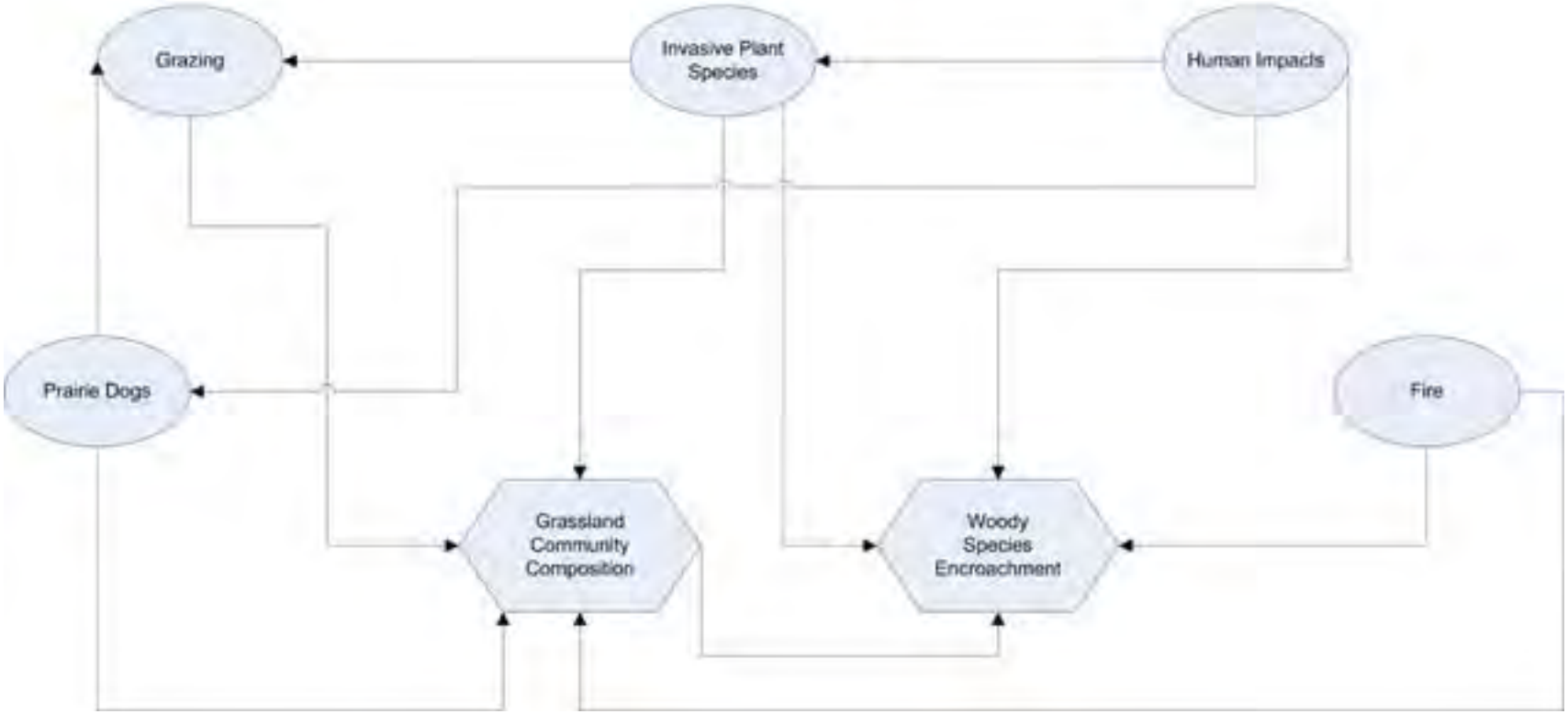
## Short Grass Ecosystem Model



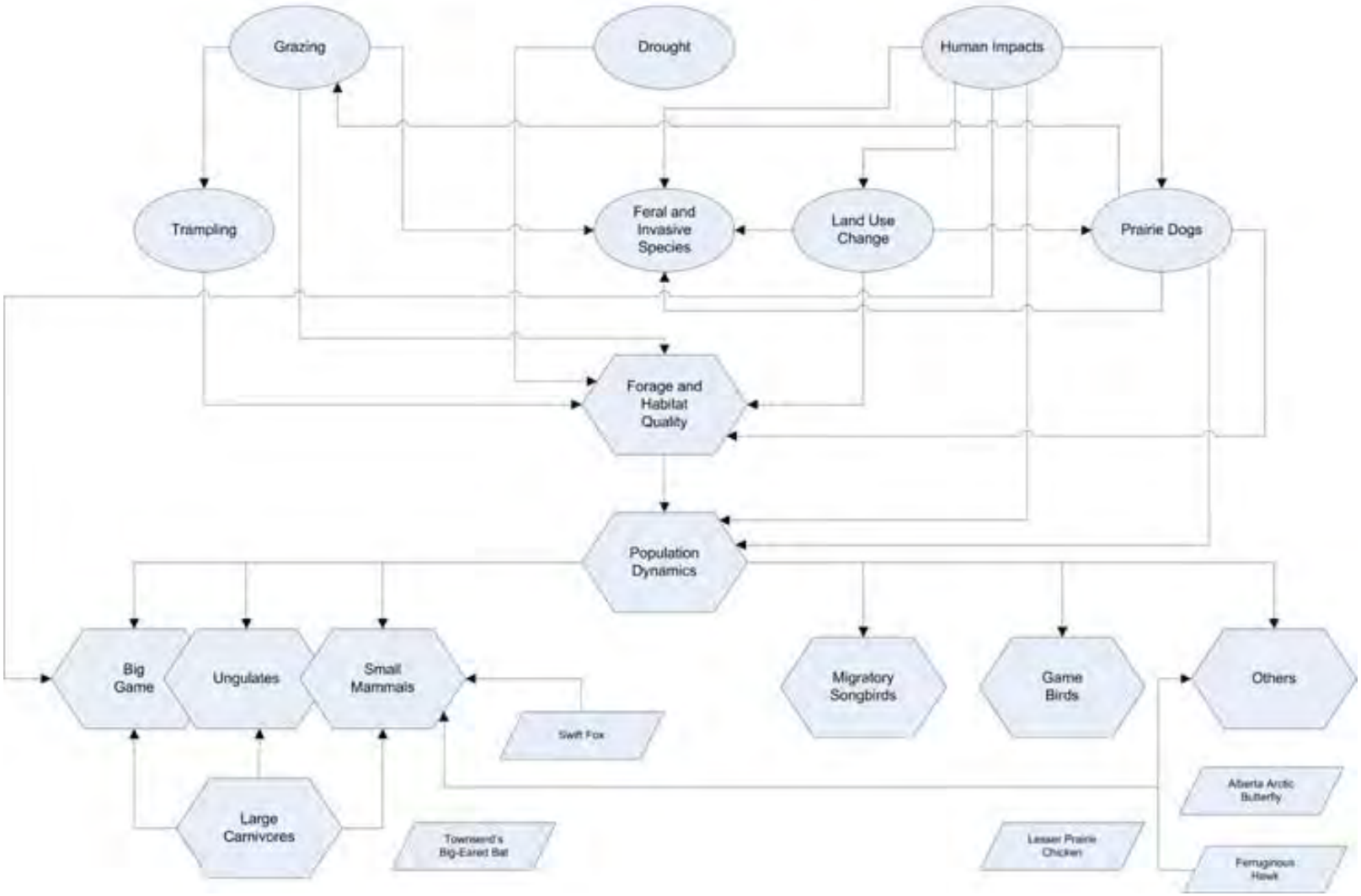
## Vegetation Dynamics Submodel



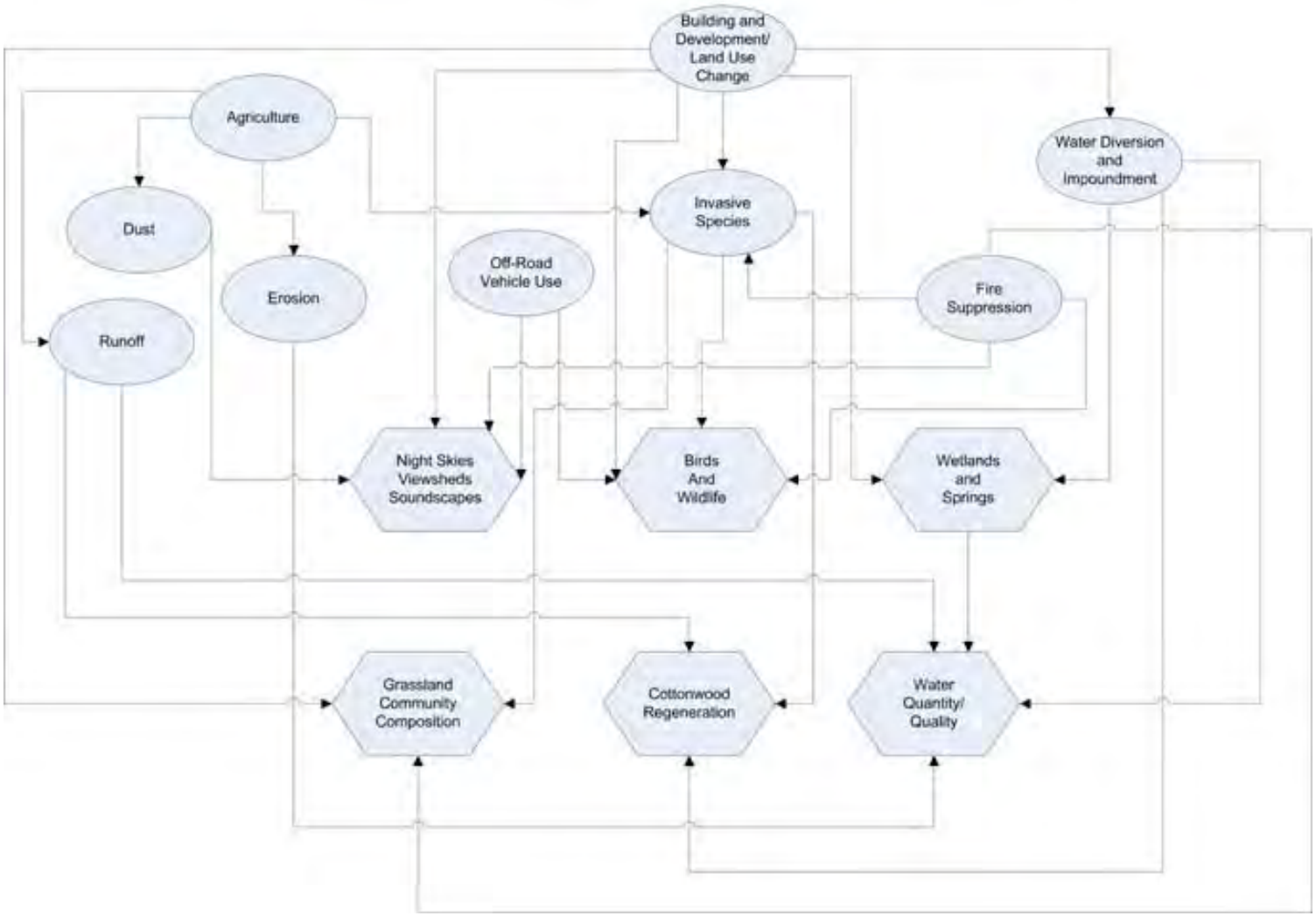
## Successional Processes Submodel



## Animal Population Dynamics Submodel



## Human Impacts Submodel



Appendix P2. Reviews of conceptual models from breakout groups, comments on feedback forms, and comments on model drawings.

**Short-grass Breakout Group**

*Comments for Short grass Model* – The group agreed that the stressor model type was useful as an overarching model, but some additional models would add more information, organizational clarity and management assistance.

The group suggested adopting the Jenny-Chapin Model (Figure 1) either as is, or with slight modifications pertinent to SOPN. This would give all an understanding of the overall processes and elements that pertain to any conceptual model within SOPN (grassland or other).

In addition to the stressor models developed by Dr. Tinker, they suggested building some additional, more process based models that emphasize the major interactions, rather then try to characterize all interactions in the process model. Park staff participants in particular thought that more process or mechanistic models would be more useful in relating them to management. The group built a simple example of a grassland mechanistic model (Figure 2). An example from the Rocky Mountain Network (Figure 3) was put forward, as well as a model developed by John Gross (Figure 4) as examples. These types of models will do a better job of showing the temporal effects of the stressors, which is hard to show in a stressor model.

For a primary driver the group suggested using topography instead of elevation. They also suggested changing grazing to defoliation recognizing that defoliation can be due to insects, weather disturbances, etc. as well as large ungulates. Below-ground biomass and soil microbiology are very important and should be added to the existing stressor models and incorporated into the new process/mechanistic based models. In the short-grass model, grassland birds and keystone species should be added as measures to the list of potential vital signs under the birds and wildlife indicator, and woody invasives should be added as a measure under the grassland community composition indicator. They thought that wet and dry cycles should be combined with drought, and if they are not combined, then the differences should be thoroughly explained in the narrative.

The group wanted to see a more clearly defined narrative in the final product. This narrative should have more details and clearly define the processes (nutrient turnover in successional processes). The vegetation dynamics and animal sub-models needed a narrative to be more useful.

*Comments for Sub-Models* – The group suggested combining the successional process and vegetation dynamics submodels into one model. The group suggested developing a land-use, land-cover conceptual model, however Dusty Perkins explained later that we will probably look to tackle this type of model at a later date as landscape level models will also affect other ecosystems in addition to grasslands. SOPN had originally planned to pursue a landscape vulnerability model, but John Gross (WASO I+M) had persuaded SOPN to wait until several other landscape projects are completed by other networks to see what we can use from those projects. The group emphasized that this was an important topic to tackle in the future. The group thought that some of the process based models described above should be developed for fire and grazing interactions instead of the stressor type models. These fire and grazing models should capture variables like time of year, extent, intensity, and preceding (legacy) conditions.

There was some debate over whether there should be a prairie-dog specific animal model given their importance as a rare keystone species with large management implications. Are there other keystone species that models should also be developed for? The group thought that the grassland vegetation and animal population dynamics model needed more explanation.

**Mixed-grass Breakout Group**

*Comments for Mixed-Grass Model* – This group spent the majority of their time going through the specifics of the mixed-grass stressor model, by looking at drivers, stressors, ecological outcomes, indicators, and measures.

-Climate Driver – The model should include temperature and precipitation as stressors connected to climate, the latter is currently listed as an individual driver. If precipitation is included as a separate driver, clarify the differences from climate. Climate is more of a long-term

temporal scale, setting the ecosystem to be a grassland instead of forest, while temperature and precipitation are more like weather, they are short-term changes affecting the vegetation in the grassland. The model should include/consider wet/dry cycles (amount, timing), precipitation quality (example: nitrogen, acid levels in rain, snow), precipitation variability (timing may affect different species differently), vegetation interactions with precipitation variability and intensity (example: buffalo grass sheds rain, leading to more runoff). This climate/precipitation/temperature could be turned into a state transition model.

-Elevation Driver – This should be changed to topography that would include slope, aspect, lat/long, other physiographic characteristics.

-Soils and Geology Driver – Soils should be considered more as a driver (example: past land use and its affect, certain uses may have changed soil characteristics, preventing the return of grassland. Farmland is harder to restore then ranchland because the soil has been disturbed on farms) and could be its own separate driver or stressor, soils can affect the vegetation present, hence affecting the species present. Should be up somewhere at the top. This legacy of past land use should be more of a driver than a stressor (a stressor is an agent that causes significant change, while a driver is a major external force, i.e. a legacy condition not a transient condition)

-Grazing Stressor - should be changed to herbivory

-Insect/wildlife Diseases Stressor – What is meant by this stressor? Insect outbreaks, ips beetle? Lack of insects could also be a problem. Wildlife diseases (hanta virus, west Nile virus) should be a separate stressor or removed and renamed to pathogens that implies the focus is on the wildlife impacts of diseases.

-Arrow Connection Comments – The group suggested several new ways to draw new arrows connecting components of the model: wet/dry cycles and erosion/flooding, wet/dry cycles to fire both ways, fire regime to grassland vegetation dynamics both ways, animal dynamics can affect cottonwood and forest regeneration. The group debated if the chart would become too busy if we connect drivers to drivers, stressors to stressors. The current model is pretty simple. Could take two approaches, one approach would connect the major components and mention in text that other components connect. Models are difficult in that you strive for simplicity, but you still want to be inclusive (a paradox). The second approach was to remove all connections, group items drivers, stressors, indicators, etc. and connect the groups with arrows. Specific arrows and connections could be incorporated into the submodels.

-Question – Cultural resource management and how it affects natural resource management, is there a good place on the model to capture this? (Example: prairie dogs on Santa Fe trail ruts, landscape composition and its relation to viewsheds, small mammals burrowing under ruins). If or when should these issues be included in priority ranking of vital signs. This topic fits better in the human impact sub-model than in the overall mixed-grass model. If the potential vital sign is only included because it affects a cultural resource, then it should not be a vital sign. If the vital sign also affects an important natural resource then the cultural aspect may elevate its priority.

*General Comments*

-Rename cottonwood riparian woods to “Riparian Woods”.

-Absence of keystone species (example: wolves can have a trickle down effect upon an entire system, more wolves [*Canis lupus*] = less coyotes [*Canis latrans*] = affect small mammal abundance). Keystone species should be added to the animal population sub-model?

-Smaller parks – Adjacent land use or non-park source pollution is an issue.

-Human use and adjacent land use – accounts for affect of fragmentation. Plan on developing at some point a landscape vulnerability conceptual model.

- Combine vegetation dynamics and successional sub-model processes into a state transition model.

*Candidate Vital Signs/Indicators*

-Birds and Wildlife – need to make sure we consider not just the animal, but the habitat of the animal. Monitor community composition, but what does that tell you about habitat? Any habitat process starts with at least three different species that can use the habitat. Gather the data right and you can use it for a number of species. Get some basic criteria (example: canopy

cover). Does it include exotics, do you sample differently? Each park needs to decide what communities to measure to get statistically relevant results.

-Candidate indicators – Vegetation community composition, rare and invasive plant species, animals of management concern (T&E, invasive, others as important to the park; keystone species for trend monitoring (i.e. small mammals, ungulates).

-Candidate indicators – May want to monitor birds, hogs (*Sus scrofa*), etc. because they are important to park management, even though they are not effective habitat indicators. In some cases, species presence/absence may be an easier to measure (example – amphibians).

-Candidate indicator – Carbon balance (are parks a net source or sink for CO2?). There are various ways to measure (example: satellite imagery, soil sample testing). Monitoring CO2 from the soil. This is a good indicator of ecosystem health and is applicable across all parks.

**Model Comments on Posters and Feedback Forms**

*Mixed-Grass Model*

-The water quality/quantity indicator should include/consider both surface water and ground water.
-Carbon balance should be a measure for the grassland community composition indicator.
-Reptiles should be a measure for the birds and wildlife indicator.
-Human management could be included in the human use/adjacent land use stressor.
-Park-source pollution (e.g. E. coli) should be added to Non-park source pollution
-Invasive/exotic plants should be separate stressor from exotic animals
-The elevation driver should be renamed topography, which would incorporate slope, aspect, and elevation.
-Precipitation should be stressor underneath climate. Climate is long-term, where things like precipitation and temperature fluctuate annually and seasonally.
-Additional arrows were drawn from animal population dynamics to deciduous hardwood forest, cottonwood riparian woods, and grassland community composition.
-Double arrows were drawn connecting: erosion/flooding to vegetation dynamics; grazing to invasive/feral species; grazing to fire; grazing to erosion/flooding, wet/dry cycles to erosion/flooding
-Modified or tool might be better term then stressor which implies negative connotation.

*Short-grass Model*

-Precipitation should be stressor underneath climate. Climate is long-term, where things like precipitation and temperature fluctuate annually and seasonally.
-The elevation driver should be renamed topography, which would incorporate slope, aspect, and elevation.
-Erosion indicators can be good. These can change due to overgrazing, exotics, etc, can affect overland flow.
-Grazing should include herbivory.
-Human use driver should include land legacy (what is starting point, agricultural field, prairie fragment, overgrazed land).
-Carbon balance should be a measure for the grassland community composition indicator.
-Woody invasives should be a measure for the grassland community composition indicator.
-Grassland bird species richness and abundance and keystone species should be a measure for the birds and wildlife indicator.
-Additional arrows were drawn to connect: drought to wet/dry cycles; elevation to animal population dynamics.
-Modifier or tool might be better term then stressor, which implies negative connotation.
-A gap in our knowledge is the effects of invasive species, we can use model to generate hypotheses, but not for predictions.
-Submodels will need to have site-specific spatial analyses.
-This person preferred climate, topography, geology, time/land legacies, and human/biota as drivers. Soils are an interaction response of the drivers. Adding a “biotic” to human use allows for source identification of invasive/feral species. Time/legacies allow for acknowledgement of historical effects.
-The model ignores decomposition/microbial/soil animal interactions. This can be ok if: a) impacts are adequately captured by other interactions, and b) the biota in this group doesn’t radically change and change their impacts (e.g. invasive earthworms in riparian zone).
-Westoby et al. (1989) Journal of Range Management was suggested as a good state-transition model for fire and grazing
-Submodels should consider interactions with invasive species and woody species Evans et al. 2001 had a model for invasives with cheatgrass as an example

*Vegetation Dynamics Submodel*

-Change to state-transition model.

-Temperature was added as a stressor and lines from it were drawn to grazing, drought, fire, plant community composition, forage and biomass quality, woody plant succession, human activities, invasive plants, drought, and elevation.
-Burrowing and pollination was added as a stressor and lines from it were drawn to grazing, plant community composition, forage and biomass quality

*Successional Processes Submodel*
-Change to state-transition model with thresholds.
-Include biomass, both above and below ground.
-Why were prairie dogs included as a separate stressor? Is this too specific?
-Climate and time cycles should be incorporated.
-Disturbance, frequency, intensity, and homogeneity should be included in fire.
-Additional line drawn between grazing and prairie dogs.

*Animal Population Dynamics Submodel*
-Temperature should be added as a stressor and connected to grazing, drought, and feral and invasive species.
-Grazing should be changed to herbivory.
-Disease should be added as a stressor and connected to prairie dogs.
-Should prairie dogs have a whole separate submodel?
-Grazing should connect to prairie dogs.
-Drought should be renamed wet/dry cycles.
-Other prairie birds and herps should be added as indicators.
-The population dynamics indicator should connect to lesser prairie chicken and Alberta arctic butterfly.

*Human Impacts Submodel*
-Climate change added as a stressor
-Prescribed fire added as a stressor
-Arrow connecting off-road vehicle use to erosion
-non-point source pollution and recreational pollution (e.coli, sewage leaks into streams) should be added as a stressor

## P.2. REPORT FROM THE AQUATIC AND LANDSCAPE WORKSHOP, AUGUST 9-10, 2005. HOSTED BY FORT UNION NATIONAL MONUMENT AT HIGHLANDS UNIVERSITY, LAS VEGAS, NEW MEXICO

### *P.2.1. Overview*

This two-day workshop was part of the process to develop a long-term ecological monitoring program for natural resources in the Southern Plains Inventory and Monitoring Network (SOPN). Developing conceptual models is one of the first steps towards selecting a suite of efficient and cost-effective indicators ("vital signs") of ecological integrity. During the first day draft versions of the aquatic conceptual models were presented by Sue Braumiller and landscape models were presented by Todd Swannack. These models were given a thorough review by workshop participants. The second day used the previous day's discussion of conceptual models as a framework to develop a list of potential aquatic and landscape vital signs for SOPN. The workshop was attended by 37 people, including 17 outside experts and at least one representative from all 11 SOPN parks (Table 1).

### *P.2.2. Objectives*

1) Review aquatic and landscape conceptual models. Provide model developer with suggestions for modifications and possible additional models.
2) Review the important natural resources and stressors of the network.
3) Develop/review list of potential vital signs with preliminary justification statements and monitoring objectives.

### *P.2.3. Conceptual Model Review*

Dusty Perkins started the day with an introductory talk on the Inventory and Monitoring Program and the Southern Plains Network. This was followed by the presentation of landscape and aquatic models by Todd Swannack and Sue Braumiller, respectively (See Appendix 1 for figures of the models presented). Then, workshop participants were divided up into rivers and streams (facilitated by Sue Braumiller), reservoir (Facilitated by Cathie Jean) and landscape (facilitated by Andy Hubbard) breakout groups. Each group was assigned the task of reviewing the models pertinent to their breakout group.

#### P.2.3.1. Conceptual Model Summary and Future Directions

This section summarizes the major comments and concerns of each breakout group and provides an outline of revisions to the existing models. Listed first under the "*Future Directions*" heading are the comments that were consensus among the groups and these comments will be incorporated into the revised models. Listed under "*Additional Comments*" are points of contention within the group or comments that were written on the model posters that were not discussed in the breakout group. SOPN staff will work with the model developers and the Technical Committee to determine which of the additional comments should be incorporated into the models.

#### P.2.3.2. Future Directions for Landscape Models:

1.) Landscape Pattern Model – The group came to consensus on a few changes to the presented model (Figure 1). The first change being that all of the arrows should be changed to double-sided arrows. The justification being that natural processes also alter human processes and landscape pattern can affect natural processes and human disturbances. Secondly, landscape pattern should also be an oval making it at the same level as the processes and disturbance ovals. It was also suggested that "Human Disturbance" be changed to "Human Processes".
2.) Development Effects Model – The group agreed to simplify this model by just having the major processes on the top line and the major stressors on the bottom line (Figure 2). All stressor ovals except for "Fragmentation" and "Disturbance Regime" should be dropped.

A fourth box, “management” was added to the processes line. The two major stressors identified in the bottom line would then be further developed into submodels.

3.) Natural disturbance regime model – No consensus for any changes.
4.) Altered Natural Disturbance Regime – The group suggested a revised model (Figure 3). The group thought that the original model was only a fire and grazing disturbance model. The new model incorporates climate and catastrophic events. More details will be added.
5.) Decrease In Unique Habitat –It was suggested that this model be dropped. If this model was to stay the definitions of unique and habitat need to be more clearly defined. In addition the submodel seemed to be too focused on birds, the migratory bird component should be dropped.
6.) Fragmentation – A revised model was developed (Figure 4). “Decrease” and “increase” should be changes to “changes”. Rename the model to “Habitat Arrangement” or “Habitat Change”. More details will be added to the revised model. It was also mentioned that abandoned lands were a major issue for the prairie landscapes. Land abandonment was more of an issue than urbanization.
7.) Based on the conceptual model discussion, the group then came up with a list of potential vital signs for landscapes (Table 2) to use in the next day’s discussion.

P.2.3.3. Additional Comments for Landscape Models

1.) Landscape Pattern Model – It was suggested to change the name to “Landscape Pattern Process”. Long term dynamics in monitoring should be noted on the model.
2.) Development Effects Model – There was concern that the model did not have exotic animals and exotic plants emphasized enough. Exotic animals should be tied to land use. Climate change and disease transmission was also suggested as a potential process.
3.) Natural Disturbance Regime Model – Some disturbances can lead to increase in biomass. This model as presented is really more for fire processes. Some disturbances can increase diversity.
4.) Altered Natural Disturbance Regime Model – Some members wanted to more clearly define the temporal and spatial scale of the model. It was also noted that the temporal scale for each park varied widely and that some parks are managing for certain periods of significance relative to the parks mission.
5.) Decrease In Unique Habitat – Change “unique” to “important”. Change “decrease” to “change” or “loss of”. Clarify whether “Source populations” refers to a park as the source or as in an ecological sense, survival outweighs mortality rates.
6.) Fragmentation – Is this referring to the park or as a landscape as a whole, specify. Need to clarify what is meant by “edge” can mean two natural habitats or natural versus agriculture/urban.
7.) There were extensive discussions about feedlots and similar concentrated agricultural issues for the prairie landscape and how this issue should be factored into the models.

P.2.3.4. Future Directions for Rivers and Streams Models

1.) There was a general consensus that the river and stream models should be re-done in a fashion that fit prairie streams better. The group proposed several changes to the overarching model and suggested that three new sub-models be developed.
2.) Overarching stream model – This model has been revised (Figure 4) and many components were collapsed into each other.
    a. Disturbance and stream characteristics ovals were eliminated because they are intrinsically included in other parts of the diagram.
    b. “Changes in Stream Flow Regime” was changed to “Stream Flow Regime”.
    c. “Water quality” was renamed “water chemistry”.
3.) Need to better define scales of models.
    a. Issues have a wider scope than just within the park boundaries….for example, some of the issues may involve the entire watershed.
    b. It’s important to look at upstream land-use, upland watershed characteristics.

c. Management really affects the whole system (e.g., removing intrusive vegetation from the stream may facilitate “drying up” of stream).

4.) The group thought there should be three main submodels for abiotic factors beneath the stream model. They are Stream Flow Regime, Stream Geomophology, and Water Chemistry. Brief sketches are shown in Figures 5, 6, and 7. Additional details will be added to the revised models.

5.) Riparian Model - Amphibians and reptiles can form a link between aquatic and terrestrial ecosystems – they’re missing from riparian models

P.2.3.5. Additional Comments for Rivers and Streams Models

1.) Need to differentiate between what is stream and what is riparian area.
2.) Stream model – should this include services that streams provide? i.e. recharge?. Include a water physical attributes octagon.
3.) Potential vital sign - shifts in aquatic biota will reflect the factors (biotic/abiotic) affecting the stream/river assemblage in general.
4.) Need to consider fragmentation of riverine habitat.
5.) Streams are defined partially by their disturbance regimes. Floods are disturbances, which are not always bad – separate anthropogenic and natural.
6.) Water chemistry parameters (in addition to those listed on Figure 7) that could be measured at specific parks would be nitrogen, phosphorous, metals, bacteria levels, and protozoans.

P.2.3.6. Future Directions for Reservoir Models

1.) The lake model was very busy and could be simplified by emphasizing the dominant pathways.
2.) Lake Model
    a. Geology and time – These operate at much longer time range then a reservoir. Lake Meredith life is expected to be 100 years. Geology and time may be drivers for other natural ecosystems but for reservoirs it is in the background, might be better placed as such.
    b. Rename “Lake” model as “Reservoir Model”. All lakes in SOPN are manmade. Hydrology of reservoirs is very different from lakes. Reservoirs have a disproportionate amount of drainage compared to natural lakes, and are therefore more influenced by watersheds. Benefits of reservoirs are artificial, not natural (recreation, drinking water).
    c. This model should be specific for the three parks in SOPN with reservoir systems.
    d. Lake morphometry and lake habitat characteristics should be joined in a single box.
    e. Siltation should be incorporated into model.
    f. When considering watershed effects, think conservation pool at LAMR. The pool has never been reached due to upstream diversions of water. Major effects on the amount of riverine, wetland, lake habitat.
3.) Water quality is the primary issue for LAMR, CHIC, and LYJO.
4.) Should develop tamarisk submodel. Factors to consider in the tamarisk (*Tamrix spp.*) submodel. LAMR is saline and tamarisk contributes to that. Tamarisk uses more water than it puts back, cottonwood (*Populus deltoides*) doesn’t. Need to recognize that reservoirs are multiple use. For example they could raise water level and flood tamarisk to control it. However, NPS does not control the water level, and biological reasons are a low priority – leaving water in rivers is not considered useful by BOR or by water law.
5.) Submodel for salinity - Show tamarisk and it’s effects. Currently the water from LAMR must be diluted with 75% ground water to reduce the salinity to make it suitable for drinking. Remove tamarisk, get more water that will then get allocated. Lowered water levels can expose areas and increase erosion – which can increase salinity. Increased evaporation, increased salinity.

6.) Eastern red cedar (*Juniperus virginiana*) (CHIC) and juniper (*Juniperus spp.*) (CHIC and LAMR) should be considered in the main model or a submodel. They are native invasives that use a lot of water.
7.) The models could benefit form a consistent method of classifying the different types of habitat that are being evaluated. For example, the term aquatic habitat refers to areas that are permanently inundated with standing or flowing water. That would leave out other types of wetlands. It was recommended the application of the U.S. Fish and Wildlife service wetland classification system Classification of Wetlands and Deepwater Habitats of the US (http://www.npwrc.usgs.gov/resource/1998/classwet/lacustri.htm) as the criteria for defining the limits of the different wetland and aquatic habitats. This system has been formally adopted by the Secretary of Interior in Director's Order 77-1. Riparian habitats are critical and they are not defined by this classification system, so the character and limits of riparian habitats would have to be adopted from the literature.
8.) This group agreed that the limits of the reservoir group were the edges of the legally defined water level in the reservoir. This did not include any lacustrine emergent or submergent vegetation zones. As a result, the edges of the large lake systems were excluded and the list of vital signs pertains only to the open water areas (Table 3).

P.2.3.7. Additional Comments for Reservoir Models

1.) Where does water level management fall in the model? Under disturbance regime? Water levels are critical with how a lake acts. Should call it a disturbance regime, it's an artificial source.
2.) Discussion about herbicide use. Should that be incorporated into model?
3.) Add a box for political influence (allows uses which can increase erosion).
4.) Alternative model for reservoirs could be a bathtub model. Reservoirs have three basic subsystems: riverine, transitional areas, and main basin. Each should be modeled differently. For habitat, riverine areas and the transition from flowing to lentic are different then the main basin characteristics. Reservoir habitat is a result of lake morphology and changes with lake level. These submodels should be separated into riverine and reservoir habitats by the hydrology of the lake and the Cowardin classification system. A lacustrine system must be 2 meters at the driest area.
5.) Lake habitat has a central role in current model, maybe should be changed. Reservoirs are managed for sport fishing, not ecological values, therefore, lake habitat isn't as important in the model. Legislation at LAMR mandates that recreation is secondary to drinking water for panhandle communities. Presents a dilemma with the NPS mission to preserve. NPS Mission may be driving why the habitat characteristics octagon is central to the model.
6.) Watershed and riparian characteristics could be pulled out and placed into an ecotone submodel. Changes can be made to watershed and riparian elements that affect the system. Can't manage geology, time, landform, can watch climatic and atmospheric conditions.
7.) Reservoir depth affects water quality, they should be connected with an arrow.

*P.2.4. Aquatic and Landscape Issues and Vital Signs*

During the second day, the workshop divided into the same three working groups as the day before, reservoirs, rivers and streams, and landscapes. The goal was to review our Access database that contained issues that individual parks had raised during the 2004 scoping sessions and those that surfaced during literature reviews. Issues reviewed at this workshop pertained to aquatic systems and landscape level dynamics. Each group ranked all of the issues as high, medium, low, or not an issue (Tables 4, 5). Each group also reviewed and revised the possible vital signs, monitoring objectives and justification statements for each issue. Each group had the opportunity to add new issues and a total of seven new issues were added.

In ranking each issue the breakout groups were given the following guidelines, an issue would only be ranked high or low if there was consensus among the group that it was high or low. This

method resulted in a list of high priority issues that were most important across the entire network. Issues that were high priority to one park, but not highly ranked across the network, were captured by the individual park's ranking that occurred prior to the workshop. All issues that both groups ranked as low were dropped from future consideration as potential vital signs. All non-consensus issues were ranked medium. A fourth category, "not an issue" was created for issues that were important but could not be monitored in a meaningful way or did not fit the guidance for the inventory and monitoring program. Four issues were ranked low or not an issue and will be dropped from further consideration as a potential vital sign.

Each group had a list of issues that pertained to the breakout group. Some issues were reviewed by two or three groups, while some pertained to all three groups. When the groups had the same issues to review, their rankings were generally the same (Tables 4, 5). For example, all three groups ranked exotic plants as high.

At the conclusion of the workshop, a list of 47 issues related to aquatic ecosystems and landscape dynamics was developed (Tables 4, 5). In January, SOPN held a similar workshop for grassland systems. In fiscal year 2006, SOPN will evaluate the list of issues and vital signs developed at these workshops and prioritize, and then select the vital signs that will make up the monitoring program.

P.2.4.1. Landscape Group

The landscape groups examined 18 existing issues and added three new issues. They ranked weather patterns, exotic plants, woody invasive species, viewshed, and fire and fuel dynamics as high. Ozone was ranked low, and boundary survey and fencing and pollution from non-park sources were ranked not an issue. The former due to lack of reliable monitoring methods for ozone effects and the latter because the group felt it was a management issue, not a science/monitoring issue.

The group combined four issues pertaining to land cover (landscape pattern, land cover and land use, land condition, and connectivity) into one issue called landscape dynamics. The group ranked landscape dynamics as high. The group added native biotic populations and communities (ranked high) and petroleum and mineral exploration and extraction (ranked medium) as new issues. They justified the first category by saying that each park had individual species or groups that were listed as important and if you combined them across the network this category would rank high. The group proposed redoing the inventories periodically to determine the status and trend of focal species. The second issues pertaining to petroleum and minerals was justified because many of the parks do not own the mineral rights beneath the surface. If not done carefully this could affect both cultural and biological park values.

P.2.4.2. Rivers and Streams Group

The rivers and streams group examined 28 issues and added 4 new issues. They ranked Arkansas river shiners (*Notropis girardi*), cottonwood riparian community, riverine community, upland springs, zebra mussels, exotic plants, erosion, groundwater levels, water quality, and water quantity as high. They ranked southwestern willow flycatcher and marsh rice rat (*Orzomys palustris*) as low.

The group added invasive native fauna, aquatic exotic species, soil health, and riparian communities. Aquatic and exotic species and riparian communities were both ranked as high. There was debate within the group that these two new issues might be redundant with exotic plants and cottonwood riparian community, but the group ultimately decided that they should be stand-alone issues to ensure their inclusion. For the new riparian community issue, some thought this was inclusive enough to include cottonwood and bottomland hardwood forest communities, then what would be measured at each park would be determined by the particular type of riparian community present. Others thought that the cottonwood community was significant enough to be included as its own separate issue. Aquatic invasive plants were added due to the large impact these species can have on native systems. Early detection of these

species can be an indicator of ecosystem changes that could follow. Riparian areas were added because they are limited in extent, but are often areas of high species diversity. Invasive native fauna and soil health were both ranked as medium. Invasive native fauna were added because anthropogenic modifications to ecosystems may allow some species to become over-abundant. These species can serve as an indicator of anthropogenic modification. Soil health was added because it can impact the long-term health and sustainability of the native plant communities and increase the ecosystem's susceptibility to plant invasions.

P.2.4.3. Reservoir Group

The reservoir group examined 27 issues. They ranked lacustrine community, exotic plants, erosion, groundwater levels, water quality, and E. coli levels as high. The southwestern willow flycatcher (*Empidonax traillii extimus*) was not known to be breeding in the area of SOPN parks and was ranked low. Zebra mussels (*Dreissena polymorpha*), Arkansas darters (*Etheostoma cragini*), and mineral, oil, and gas extraction were all ranked low. The group did not add any additional issues to the database. Within water quality the group said that some parameter that could be included that are not listed are salinity, chlorophyll A, anions and cations, hydrocarbons, and discharge rates. However, the group did note that there has not been an inventory or search for spring-related ground water fauna. If a search was done and rare species were found, then this might be something to consider as a vital sign.

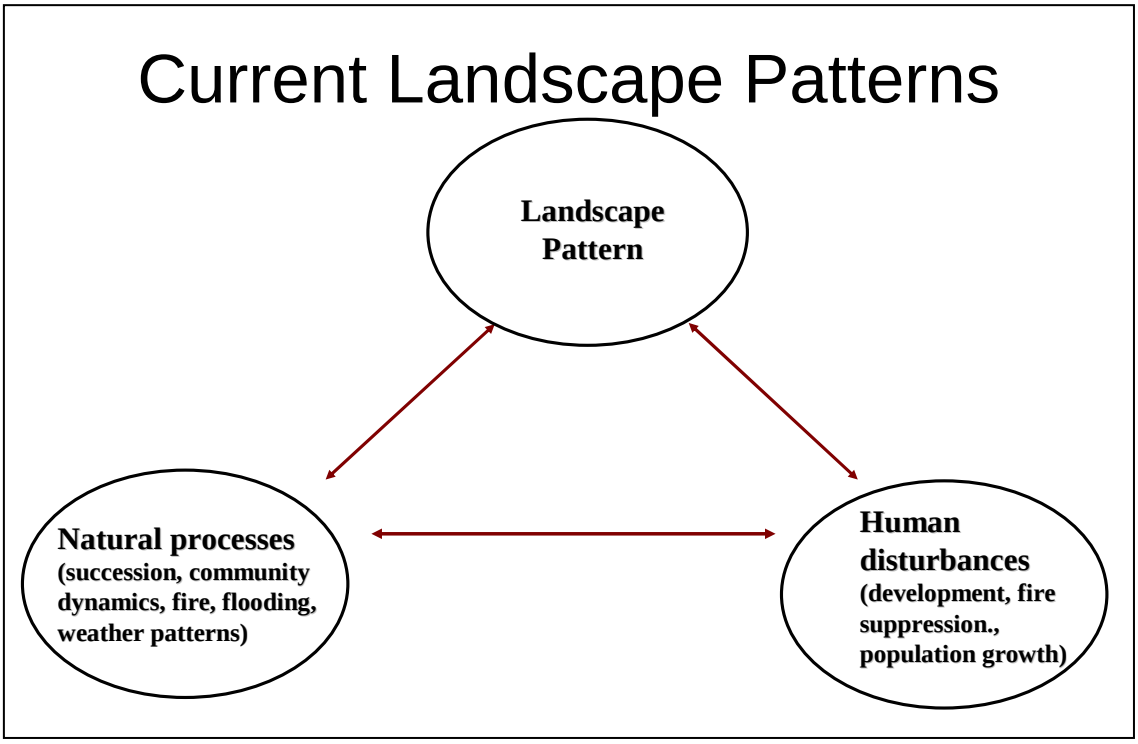



**Figure 1. Revised landscape pattern model.**

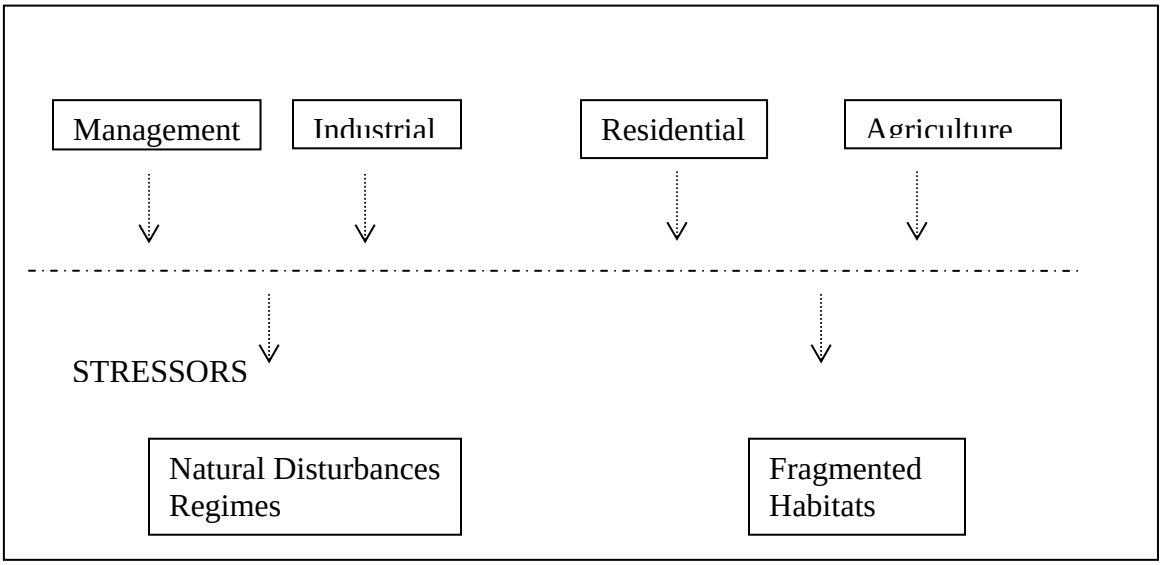



**Figure 2. Revised development effects model**

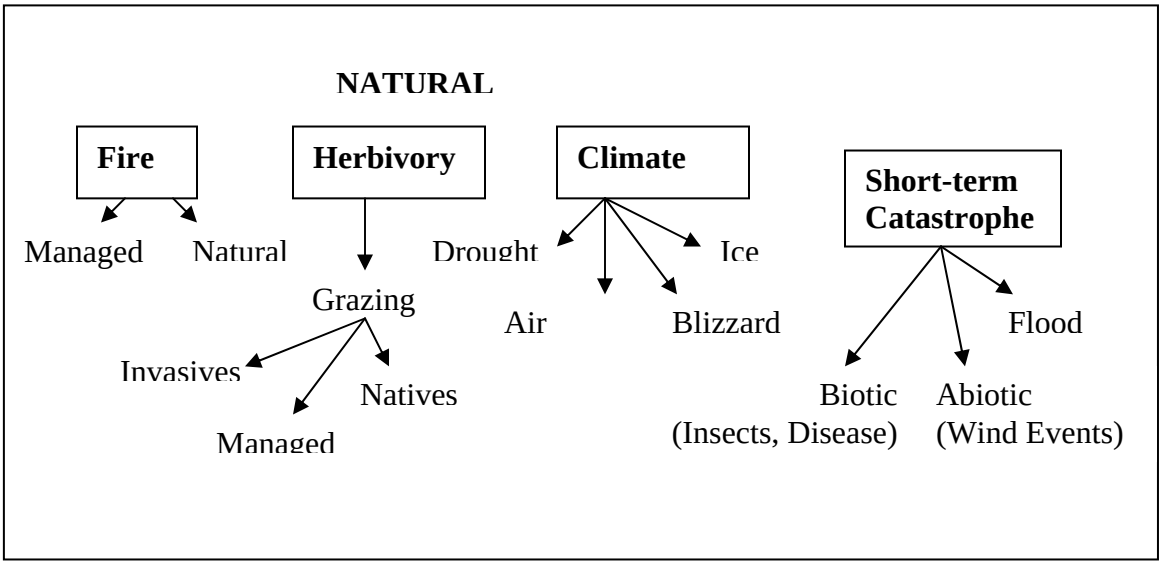



**Figure 3. Revised altered natural disturbance regime model.**

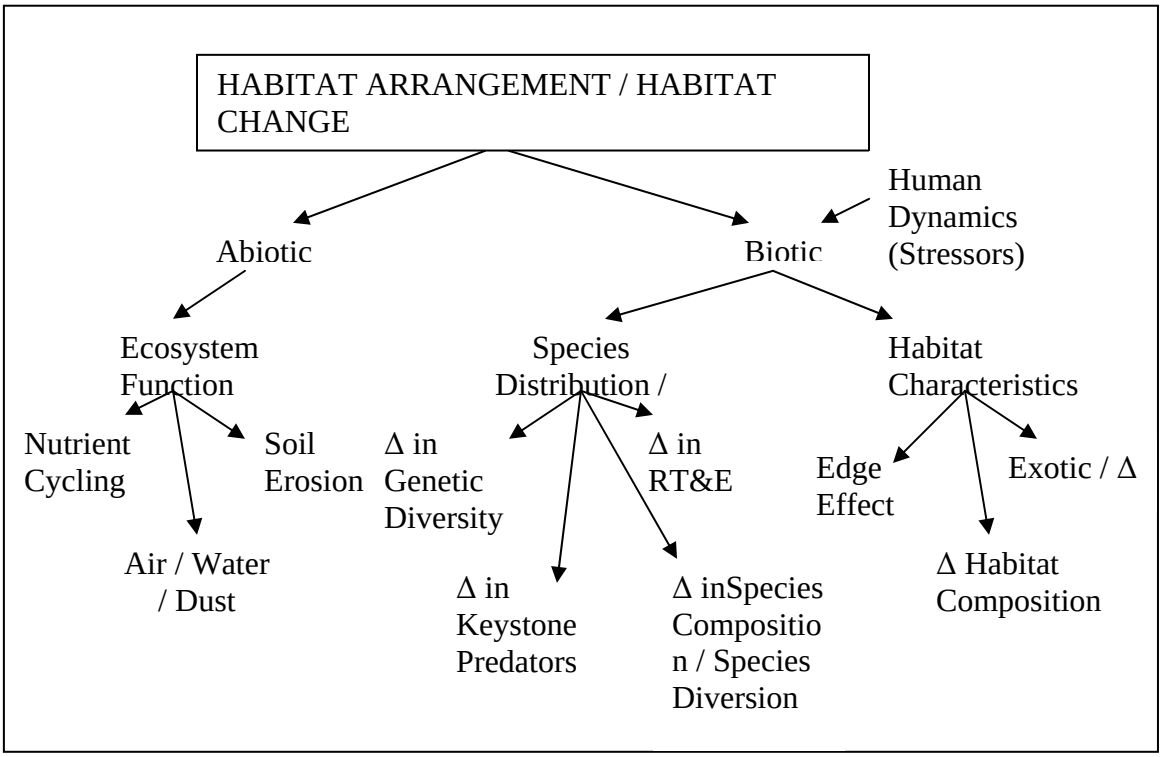



**Figure 4. Revised fragmentation model.**

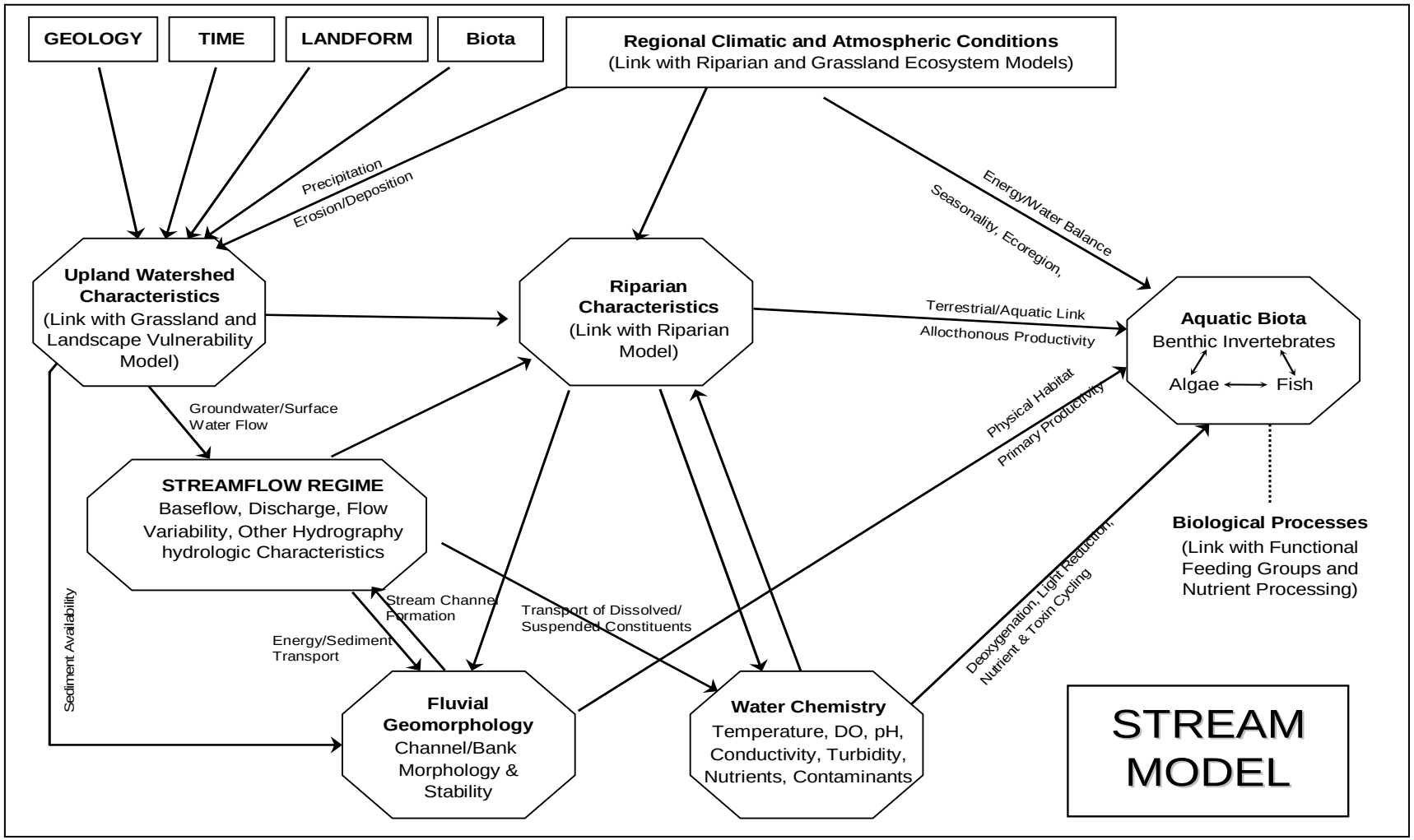



**Figure 5. Revised overarching stream model.**

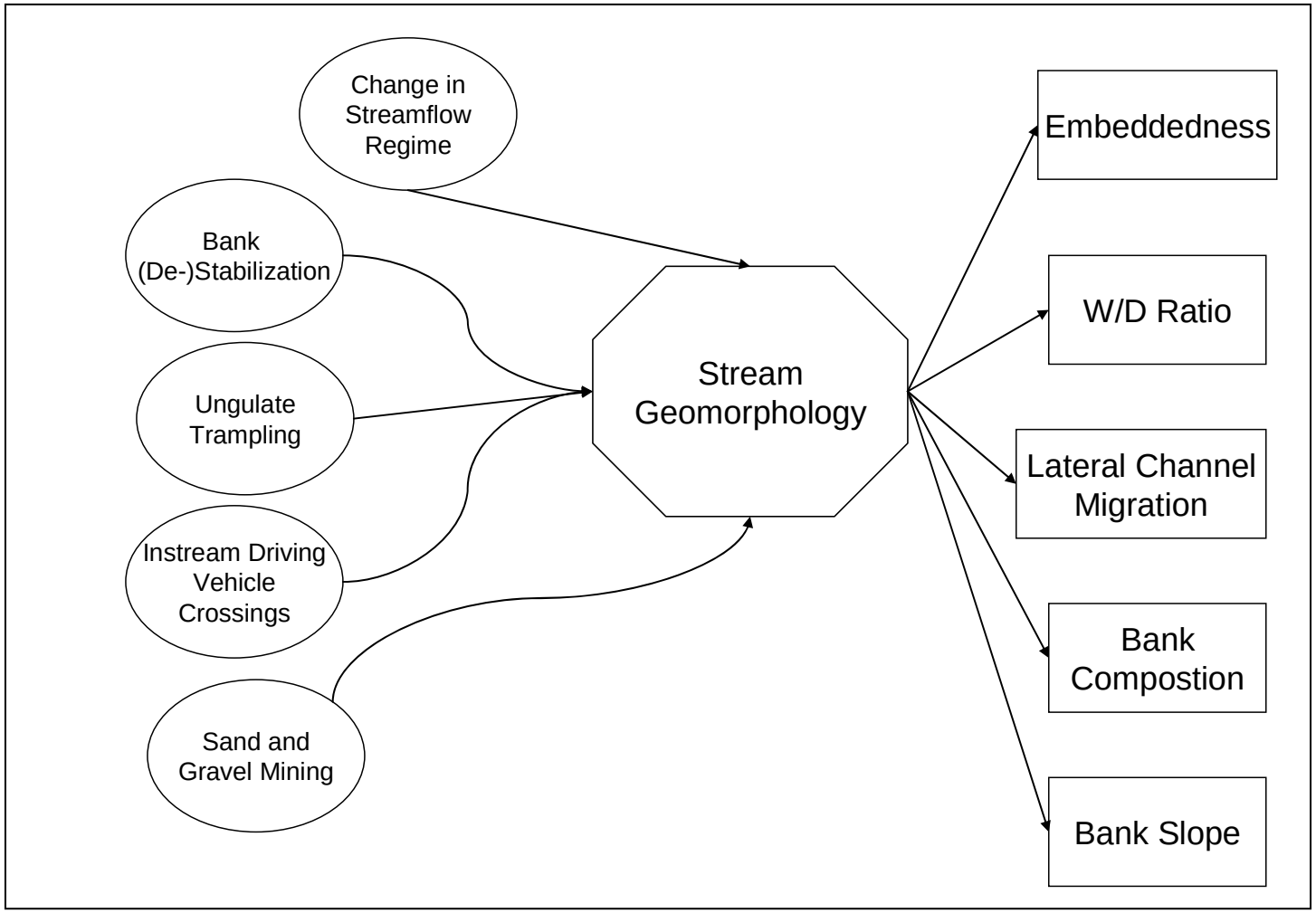



**Figure 6. Stream geomorphology submodel.**

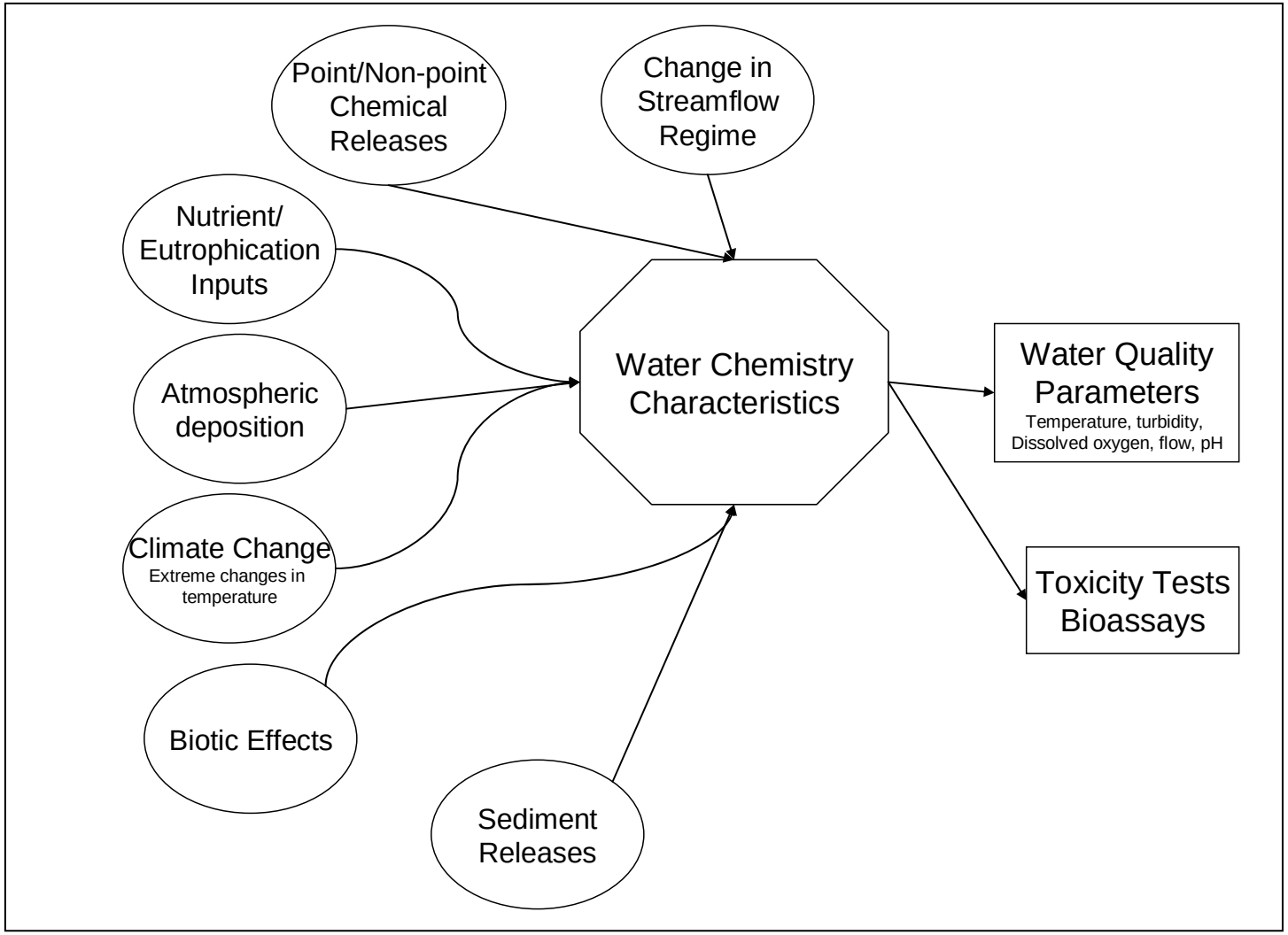



**Figure 7. Water chemistry characteristics submodel.**

**Table 1. Final Participant List**

| NPS Park Staff | | | |
|---|---|---|---|
| *Person* | *Position* | *Park* | *Breakout Session* |
| Ruben Andrade | Supervisory Park Ranger | Fort Union National Monument | |
| Steve Burrough | Chief of Resource Management | Chickasaw National Recreation Area | Reservoirs |
| Karren Brown | Superintendent | Lake Meredith National Recreation Area / Alibates Flint Quarries National Monument | Reservoirs |
| Dennis Ditmanson | Superintendent | Pecos National Historical Park | |
| Paul Eubank | Natural Resource Specialist | Lake Meredith National Recreation Area / Alibates Flint Quarries National Monument | Reservoirs |
| Jason Lott | Integrated Resources Program Manager | Lyndon B. Johnson National Historical Park | Reservoirs |
| Alden Miller | Chief of Resources + Facilities | Washita Battlefield National Historic Site | Rivers |
| Fran Pannebaker | Natural Resource Specialist | Bent's Old Fort National Historic Site | Rivers |
| Maggie Johnston | Superintendent | Capulin Volcano National Monument | Landscape |
| Arlene Wimer | Natural Resource Specialist | Lake Meredith National Recreation Area / Alibates Flint Quarries National Monument | Rivers |
| Tony Cyphers | Park Ranger | Fort Larned National Historic Site | Rivers |
| Ted Benson | Park Ranger | Pecos National Historical Park | Rivers |
| Felix Revello | Chief Ranger | Fort Larned National Historic Site | Landscape |
| NPS Inventory and Monitoring Staff | | | |
| *Person* | *Position* | *Location* | *Breakout Session* |
| Dusty Perkins | SOPN Network Coordinator | Lyndon B. Johnson National Historical Park | Floater |
| Heidi Sosinski | SOPN Data Manager | Lyndon B. Johnson National Historical Park | Reservoirs |
| Tulia De Fex | SOPN Ph.D. Student | Texas A+M University | Landscape |
| Todd Swannack | SOPN Ph.D. Student | Texas A+M University | Landscape |
| Tomye Zettner | SOPN Graduate Student | Texas A+M University | Landscape |
| Karie Cherwin | SOPN Research Associate | University of Colorado | Rivers |
| Subject-Matter Experts | | | |
| *Person* | *Organization* | *Expertise* | *Breakout Session* |
| Sue Braumiller | NPS | Hydrology, aquatic model developer | Rivers |
| Cathie Jean | NPS GRYN I+M Network | Network Coordinator | Reservoirs |

| | | | |
|---|---|---|---|
| Andy Hubbard | NPS SODN I+M Network | Network Coordinator | Landscape |
| Joseph Bidwell | Oklahoma State University | Toxicology, amphibians, invertebrates | Rivers |
| Kevin Noon | National Park Service | Wetland Ecology | Reservoirs |
| Tim O'Connell | Oklahoma State University | Landscape Ecology, birds, indicators | Landscape |
| Kathy Tonnessen | NPS – Rocky Mountain Cooperative Ecosystems Studies Unit | Air Quality | Landscape |
| Gillian Bowser | NPS- Gulf Coast Cooperative Ecosystems Studies Unit | Genetics, vertebrate landscape ecology | Landscape |
| Tim Bonner | Texas State University | Fish, stream ecology | Rivers |
| Carol Becker | USGS – Oklahoma City | Hydrology, Groundwater | Rivers |
| Bill Fisher | Oklahoma State University | Fish, stream ecology | Rivers |
| Keith Duncan | New Mexico State University | Exotic plants, vegetation | Rivers |
| Joanna Curran | Texas State University | Dam management, fluvial geomorphology | Reservoirs |
| Don Huggins | University of Kansas | Aquatic ecology, entomology | Reservoirs |
| Roel Lopez | Texas A+M | Wildlife Ecology, GPS, GIS | Landscape |
| Glen Longley | Texas State | Edwards Aquifer Water Quality | Reservoirs |
| Lisa Jameson | NPS - Gulf Coast Exotic Plant Management Team | Exotic plants | Rivers |
| Gary Willson | NPS – Great Plains Cooperative Ecosystems Studies Unit | Grasslands, fire | Landscape |

**Table 2. Potential landscape vital signs that were derived from the conceptual model discussion in the landscape group.**

**LANDSCAPE DYNAMICS**
(Things remotely sensed)

- Land use/land cover
- Road density
- Impervious cover
- Percentage of exotic vs. native plant cover
- Mosaic of natural areas (patch size & arrangement)
- House density
- Percentage wetland cover
- Disturbed/undisturbed lands
- Land use change
- Connectivity on an eco-region scale
- Fences
- Corridors
- Utilities & ROWs
- Vegetation change
- Percentage of Riparian exotics
- Landscape fuel characteristics
- Measurement of grazing pressures in region
- Oil & mineral exploration

**DEMOGRAPHIC DATA**
(things gathered from records)

- Human population density outside of park
- Land ownership patterns
- Visitor experience / Economic impact
- Traffic volume (numbers, patterns)
- Land value/zoning

**BIOTIC – FIELD BASED**

- General avian community indicators
- Exotic plants
- Feral/exotic animals
- Wildlife diseases
- Change in species diversity
- RT&E species
- Large scale herp declines
- Invertebrates
- Regional bird pop trends from Breeding Bird Surveys
- Reproductive success of focal species
- Small mammal communities
- Grazing invertebrates

**ABIOTIC**

- Soundscape / nightsky / viewshed
- Erosion index
- Extreme climate events
- Soil budget – inflow/outflow
- Nutrient / Carbon cycling

- Ozone levels
- Nitrogen/Sulphur deposition
- Visibility

**Table 3. Potential reservoir vital signs that were derived from the conceptual model discussion in the reservoir group.**

- Water quality should be a vital sign at LAMR, CHIC, and LYJO. Dissolved oxygen, pH, conductivity, temperature, and measure of flow. All can vary diurnally, have to insure to consistency with time and season sample is taken. As we move to monitoring there are already some people monitoring water quality parameters at these parks, see what we can use and maybe find a way to get them to monitor an additional parameter we can use, but they aren't currently collecting.
- Lake level: determine by comparing inflow and outflow. Siltation can affect lake levels, need to incorporate ace siltation scale. Lake level is currently recorded at LAMR.
- Total N and total P measurements.
- Contaminants - Mercury in fish tissue at LAMR. Measure in biota (more consistent than in water, state also does). Mercury is the parameter that causes LAMR to be listed as 303(d) impaired water body. Contaminants may be park specific.
- E.coli levels.
- Whatever the herbicide is that is being used for tamarisk control.
- Hydrocarbons
- Testing rain water quality separately, source of problem? There is some depositional monitoring currently occurring, but they are few and far between and generally located near cities.
- Turbidity with secchi disk.
- Amount of sediment and the contaminants contains in the sediment. Good place for indicators.
- Emergent environmental contaminants. Environmental contaminants from developed areas can get into the ecosystem because it can pass right though water treatment plants. This can subsequently affect fish populations (acting like hormones). Water testing has gotten sophisticated enough to start detecting these.
- Measure fish population (biomass) over time and that can tell about the health of the system.
- Chlorophyll: can be physical (amount suspended) or biological (amount present).
- Interest in chloride at Lake Meredith.

**Table 4. Aquatic and Landscape Workshop Issue Ranking Results**

| | |
|---|---|
| *Total Number of Issues Ranked:* | *47* |
| *Issues Ranked "High"* | *14* |
| *Issues Ranked "Medium"* | *29* |
| *Issues Ranked "Low" or "Not an Issue"* | *4* |

**High**

Issues were ranked as "High" priority if al groups that reviewed that issue ranked it as high.

| | |
|---|---|
| Weather patterns | Exotic plants |
| Erosion – Slopes, lakeshores | Aquatic exotic plants |
| Groundwater levels | Woody invasive species |
| Water quality | Viewshed |
| Riverine community | Landscape dynamics |
| Lacustrine community | Fire and fuel dynamics |
| Riparian community | Native biotic populations/communities |

**Medium**

Issues were ranked as "Medium" priority under the following circumstances: Both groups ranked it as "Medium"; the issue was ranked "high" by one group and "Medium" by the other group; or the issue was ranked as "medium" by one group and "Low" by the other group. Issues noted by an * indicate that one group marked it as high, while another ranked it as medium. Those noted with ^ indicate one group ranked it as a high and one ranked it as a low. Those noted with a # indicate one group ranked it as medium and one ranked it as low.

| | |
|---|---|
| Wet and dry deposition | Zebra mussels^ |
| Visibility and particulate matter | Mineral, oil, and gas# |
| Water quantity* | Game birds |
| E. Coli levels* | Fishing |
| Arkansas river shiner* | Pollution from non-park sources |
| Upland springs* | Park visitor effects on natural resources |
| Wetlands in upland systems | Off-road vehicle use |
| Cottonwood community* | Soundscape |
| Arkansas darter# | Night sky |
| Contaminants in fishery | Invasive native fauna |
| Migratory songbird stopover area | Soil health |
| Bald eagle | Flooding processes |
| Mississippi kites | Nutria |
| Insect diseases | Bottomland hardwood community |
| Wildlife disease effects | |

**Low/Not an Issue**

Issues were ranked as “Low” priority only if all groups ranking the issue ranked it as low.

| | |
|---|---|
| Ozone | Southwestern willow flycatcher |
| Marsh rice rat | Boundary survey/fencing |

**Table 5. Final List of Aquatic and Landscape Issues. These issues are being considered as potential vital signs for these systems. They are shown here according to their proposed classifications within the National Vital Signs classification system and their subgroup priority ranking.**

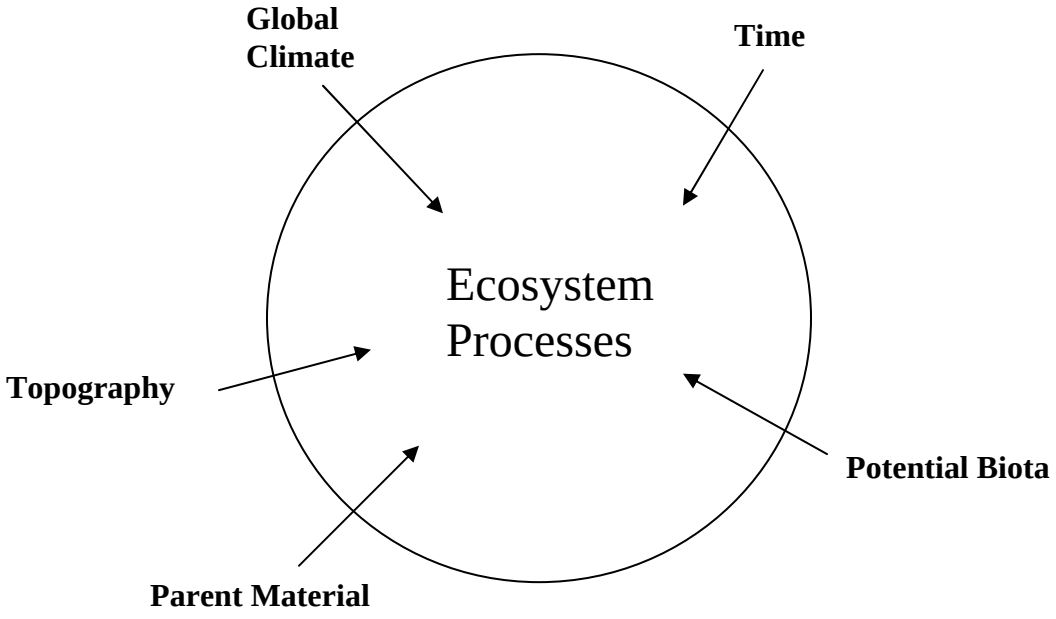
| Level 1 | Level 2 | Level 3 | Issue Name | Land-scape | Rivers + Streams | Reservoirs |
|---|---|---|---|---|---|---|
| Air and Climate | Air Quality | Ozone | Ozone | Low | | |
| | | Wet and Dry deposition | Wet and dry deposition | Medium | | |
| | | Visibility and Particulate <atter | Visibility and particulate matter | Medium | | |
| | Weather and Climate | Weather and Climate | Weather patterns | High | | |
| Geology and Soils | Geomorphology | Stream/River Channel Characteristics | Erosion – slopes, lakeshores, banks | | High | High |
| | Soil Quality | Soil Function and Dynamics | Soil health | | Medium | |
| Water | Hydrology | Groundwater Dynamics | Groundwater levels | | High | High |
| | | Surface Water Dynamics | Water quantity | | High | Medium |
| | | | Flooding processes along river/stream/lake | | Medium | Medium |
| | Water Quality | Water Chemistry | Water quality | | High | High |
| | | Toxics | E. Coli | | Medium | Medium |
| | | | Contaminants in fishery | | Medium | Medium |
| Biological Integrity | At-risk Biota | T&E Species and communities | Bald Eagle | | Medium | Medium |
| | | | Arkansas River Shiner | | High | Medium |
| | | | Arkansas darter | | Medium | Low |
| | | | Southwestern willow flycatcher | | Low | Low |
| | | | Marsh rice rat | | | Low |
| | Focal Species or Communities | Wetland Communities | Upland springs | | High | Medium |
| | | | Wetlands in upland systems | | Medium | |
| | | Riparian Communities | Cottonwood riparian community | | High | Medium |
| | | | Riparian community | | High | |
| | | | Bottomland hardwood community | | Medium | Medium |
| | | | Riverine community | | High | |

| Level 1 | Level 2 | Level 3 | Issue Name | Land-scape | Rivers + Streams | Reservoirs |
|---|---|---|---|---|---|---|
| | | Freshwater Communities | Lacustrine community | | High | |
| | | Birds | Migratory stopover area | | Medium | Medium |
| | | | Mississippi kites | | Medium | Medium |
| | | Native Biotic Species and Communities | Native biotic species and communities | High | | |
| | Invasive Species | Invasive/Exotic plants | Woody invasive species | High | | |
| | | | Exotic plants | High | High | High |
| | | | Aquatic exotic plants | | High | |
| | | Invasive/Exotic animals | Zebra mussels | | High | Low |
| | | | Nutria | | Medium | Medium |
| | | | Invasive native aquatic fauna | | Medium | |
| | Infestations and disease | Insect pests | Insect diseases on ecosystem | Medium | | |
| | | Animal diseases | Wildlife disease effects on staff and visitors | Medium | | |
| Human Use | Consumptive Use | Consumptive Use | Mineral, oil, and gas extraction | Medium | Medium | Low |
| | | | Game birds | | Medium | Medium |
| | | | Fishing | | Medium | Medium |
| | Non-point Source Human Effects | Non-point Source Human Effects | Pollution from non-park sources | Not an issue | Medium | Medium |
| | Visitor and Recreation Use | Visitor usage | Effects of park visitors on natural resources | | Medium | Medium |
| | | | Off-road vehicle use | | Medium | Medium |
| Landscapes | Viewscape | Viewscape/Night Sky | Viewshed | High | | |
| | | | Night sky | Medium | | |
| | Fire | Fire and Fuel Dynamics | Fire and fuel dynamics | High | | |
| | Landscape Dynamics | Landscape Dynamics | Boundary survey/fencing | Not an issue | | |
| | | | Landscape dynamics (land cover, condition, connectivity, pattern) | High | | |
| | Soundscape | Soundscape | Soundscape | Medium | | |

**Appendix P2. Draft landscape conceptual models developed by Todd Swannack and aquatic models by Sue Braumiller that were presented at the workshop.**

Figure 1. Jenny Chapin Model. Bold-type font indicates state factors, and italic-type font are the interactive controls. The circle represents the boundary of the ecosystem.

**A**




**B**

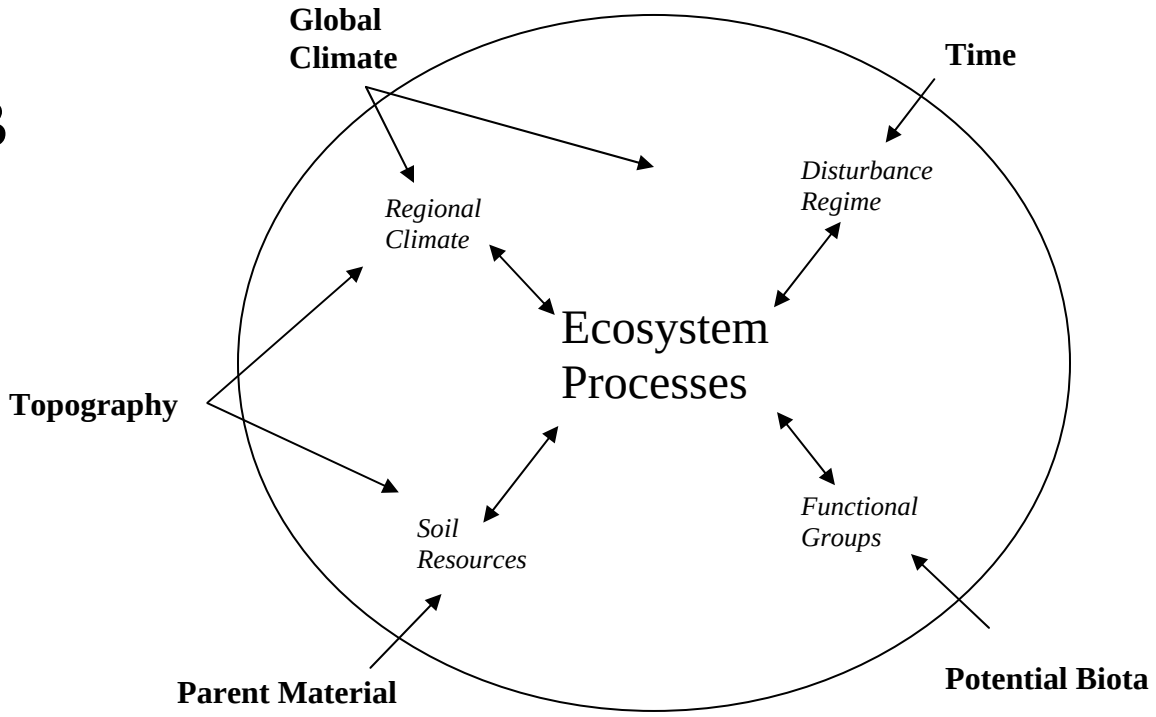


Figure 2. – Current processes creating landscape pattern. Circles represent processes responsible for creating landscape pattern. The square represents the landscape of interest (the park and surrounding lands). Arrows represent the direction of influence. The dotted line represents the indirect influence from human-mediated activities on natural processes (e.g., global climate change induced by growing human population)

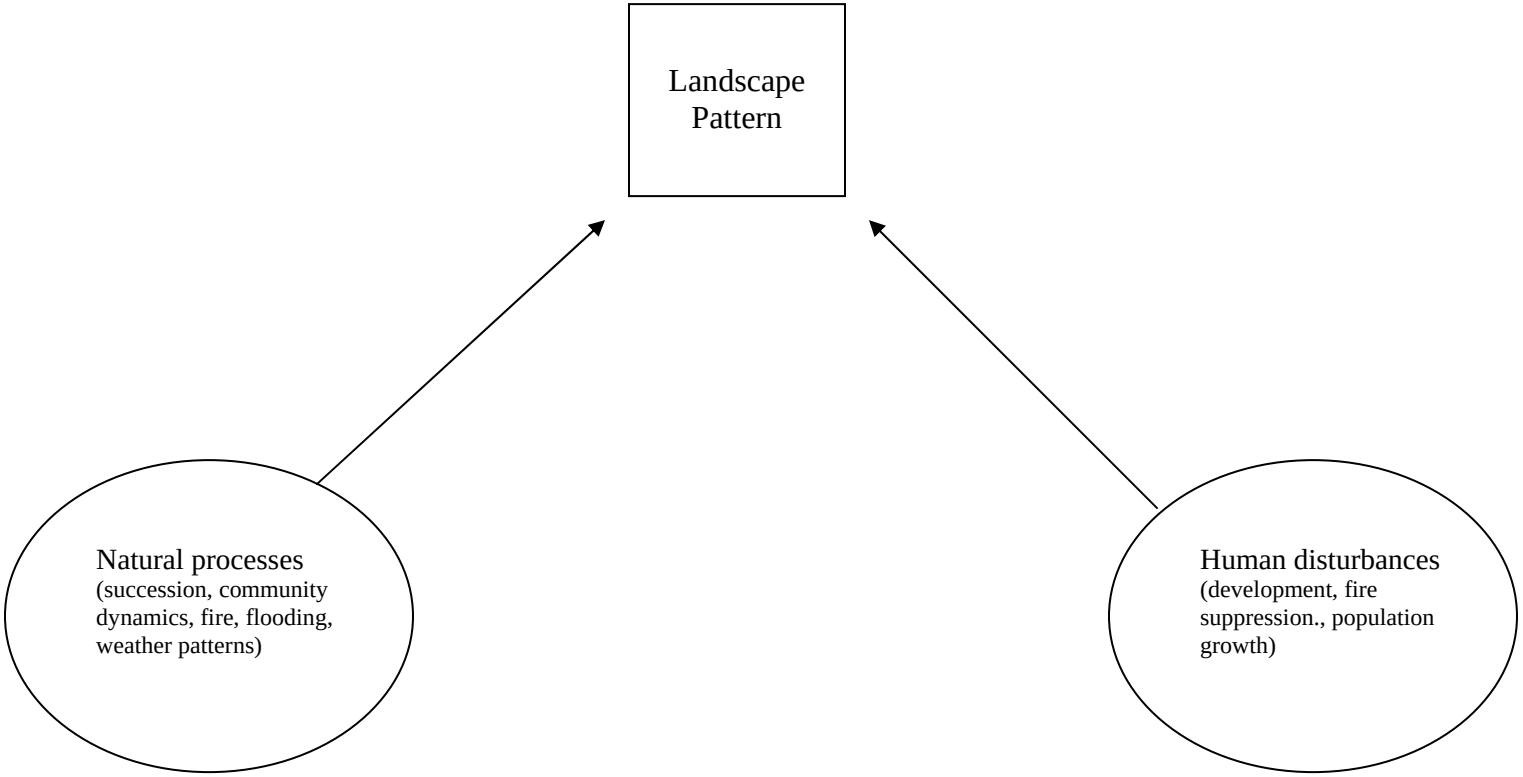


Figure 3. – Types of development and resulting effects on the landscape pattern of the SOPN. Squares represent development types (stressors). Circles are variables representing ecological effects of development. Bold-type font indicates the major ecological processes affected by development and each of those variables has its own submodel. Small arrows point to the major types of disturbance each development type causes, and the large solid arrow represents direction of influence.

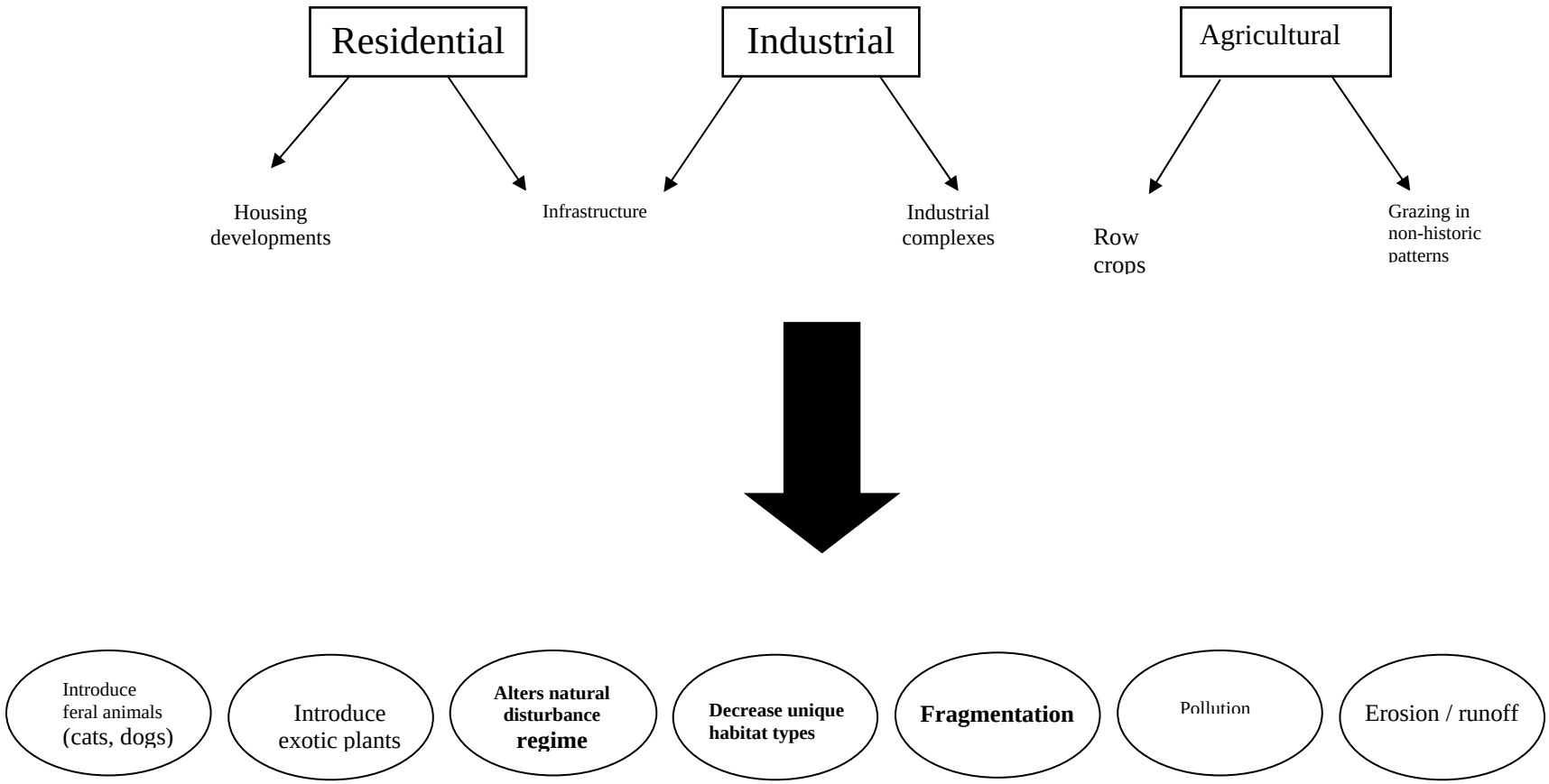


Figure 4. – Diagrammatic representation of a natural disturbance regime. The arrows represent the direction of influence.

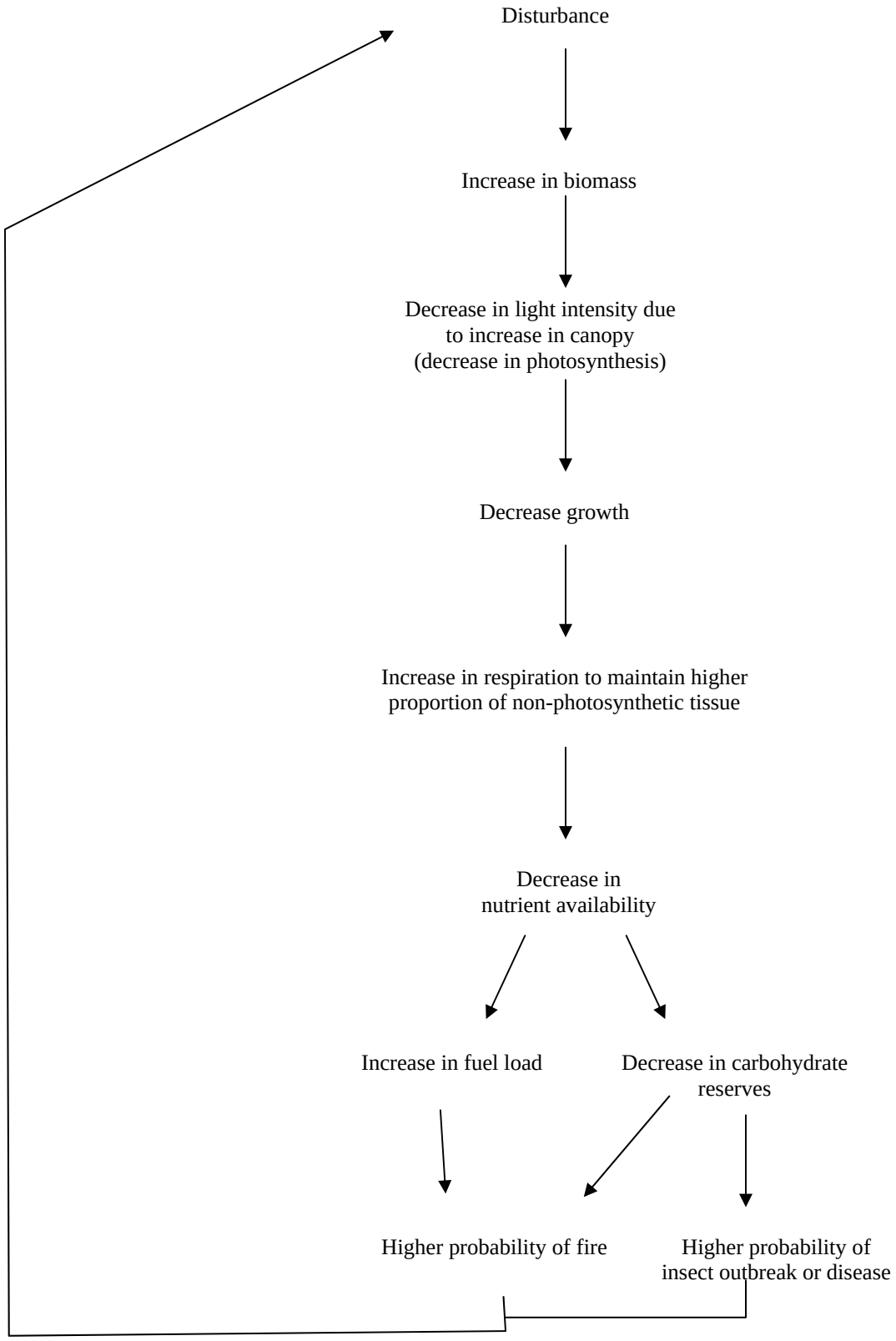


Figure 5. – Submodel representing the effects of altering the natural disturbance regime within an ecosystem. The arrows point to the factors resulting from an altered disturbance regime.

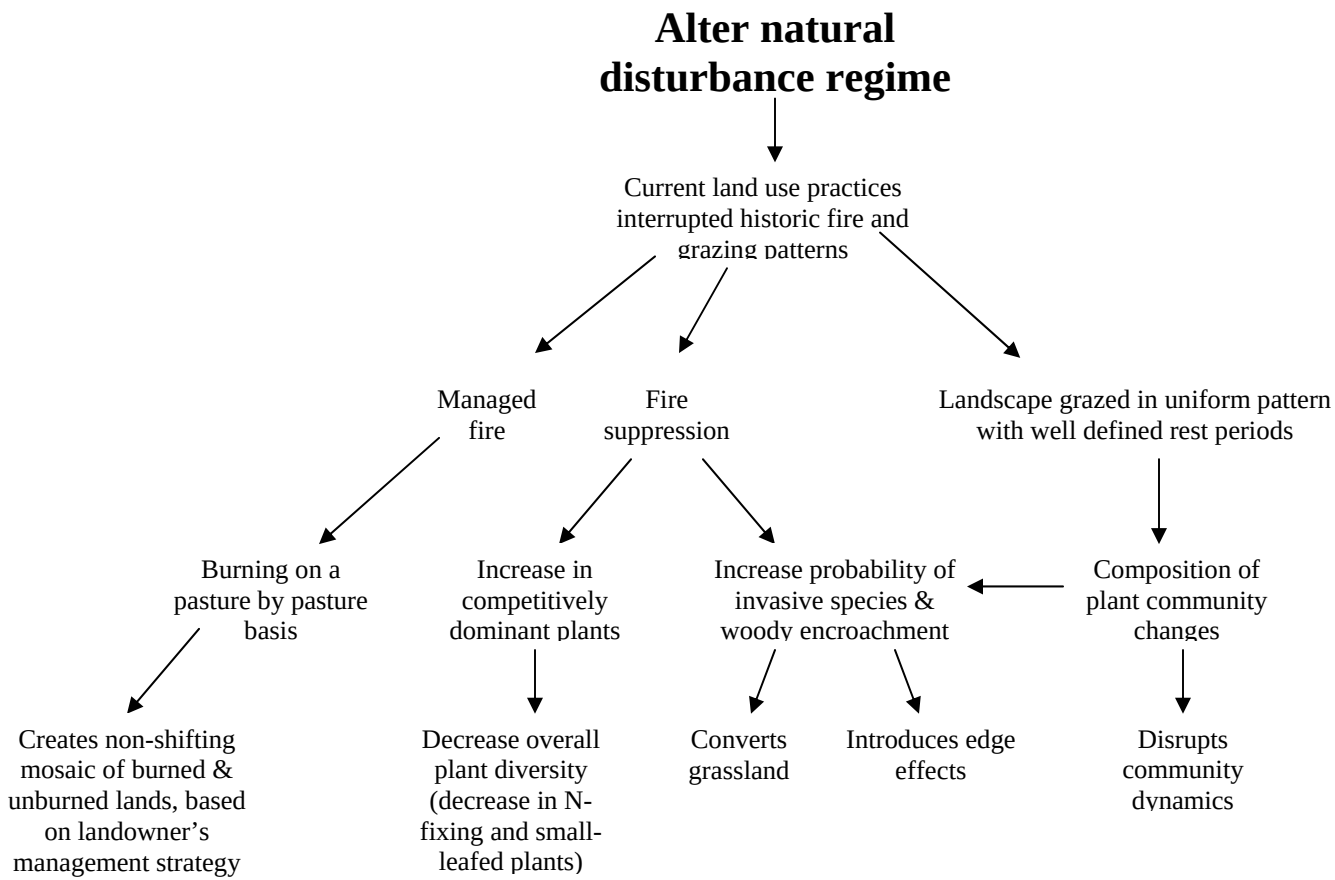


Figure 6. – Submodel representing the effects of decreasing or decimating rare and unique habitats. The arrows point to the factors resulting from a decrease in rare and unique habitat types.

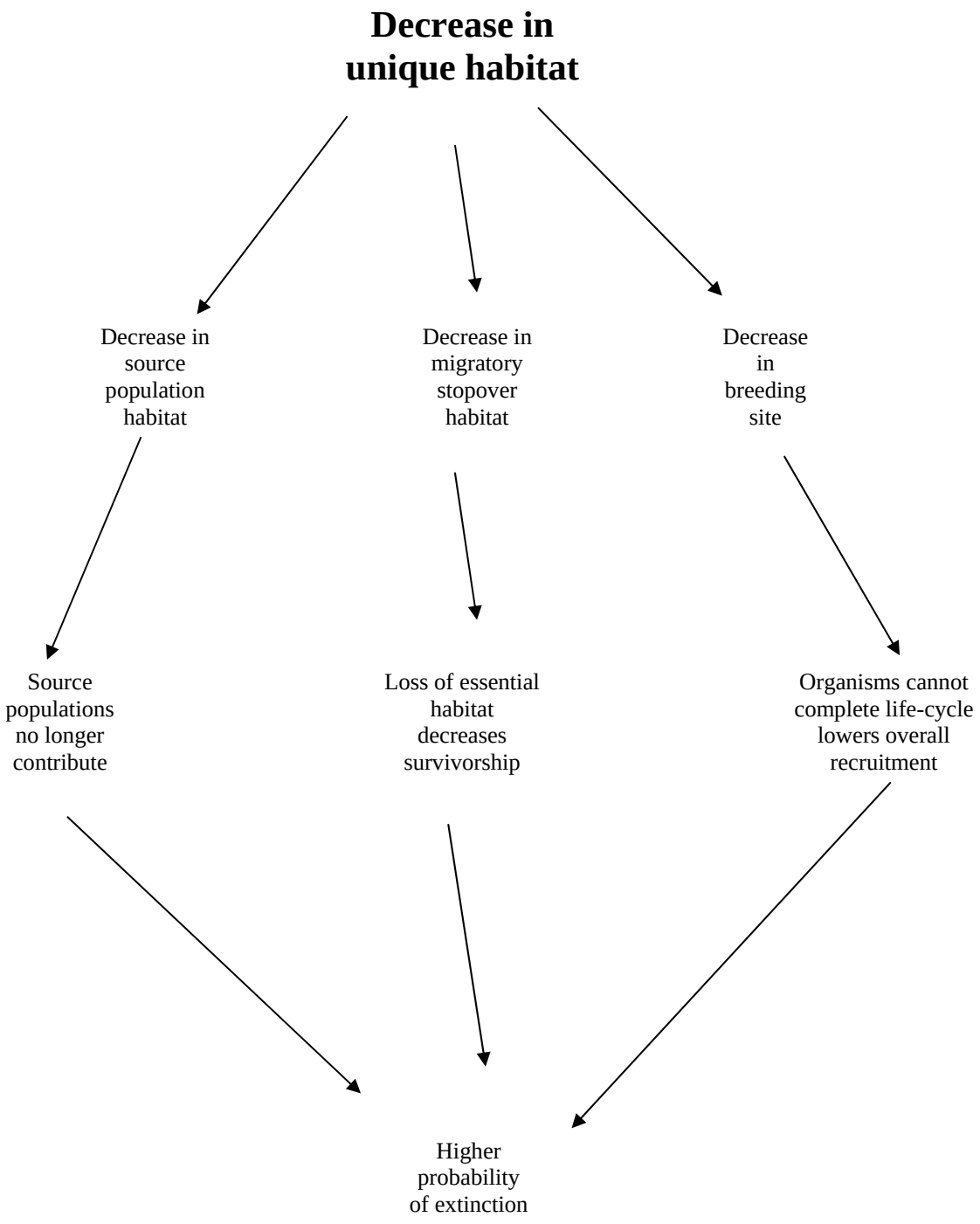


Figure 7. – Submodel diagramming the major effects of ecosystem fragmentation. The arrows point to the factors resulting from fragmentation. The dotted lines represent feedback into the variable.

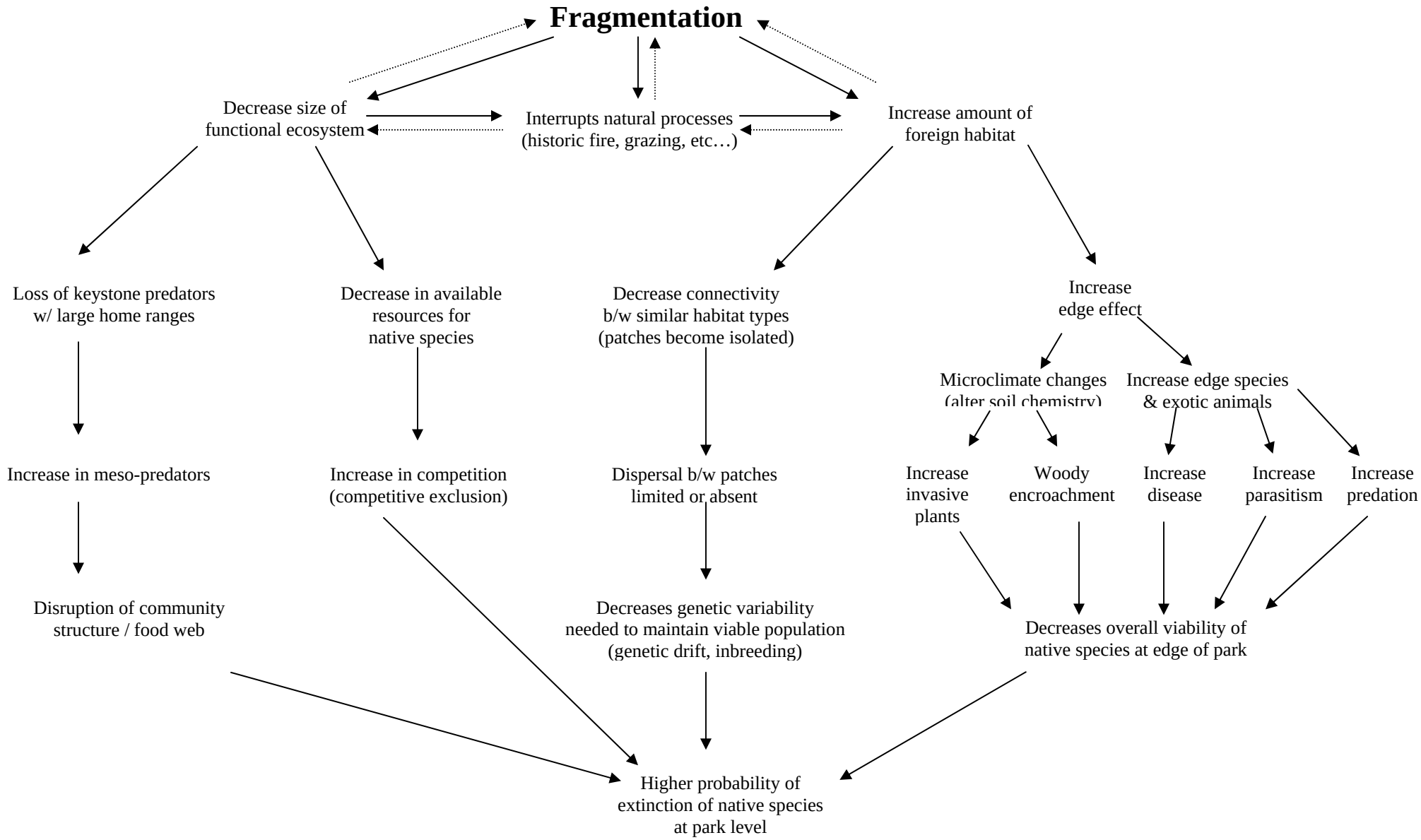


Figure 8. Overarching stream model.

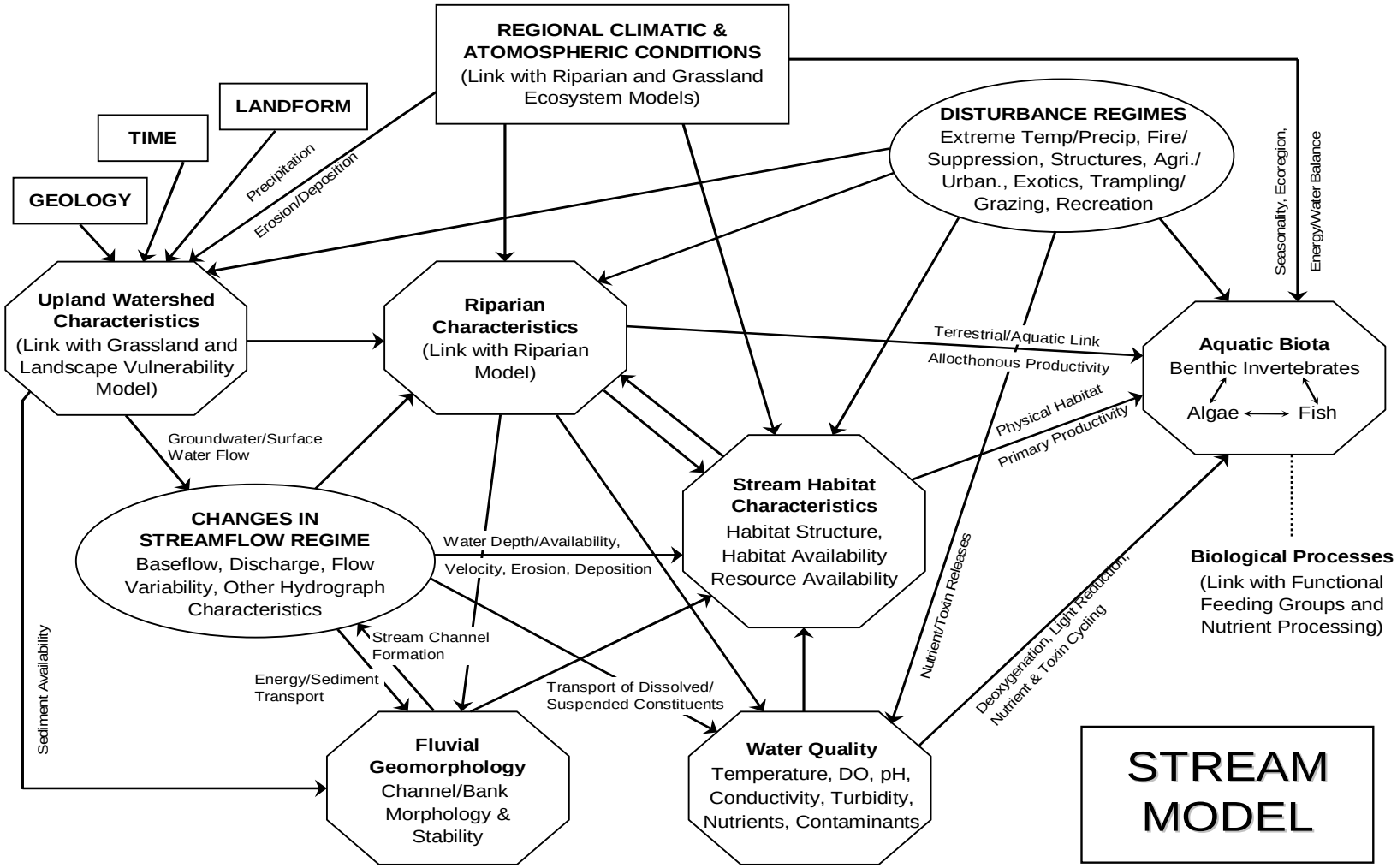


Figure 9. Stream drought submodel.

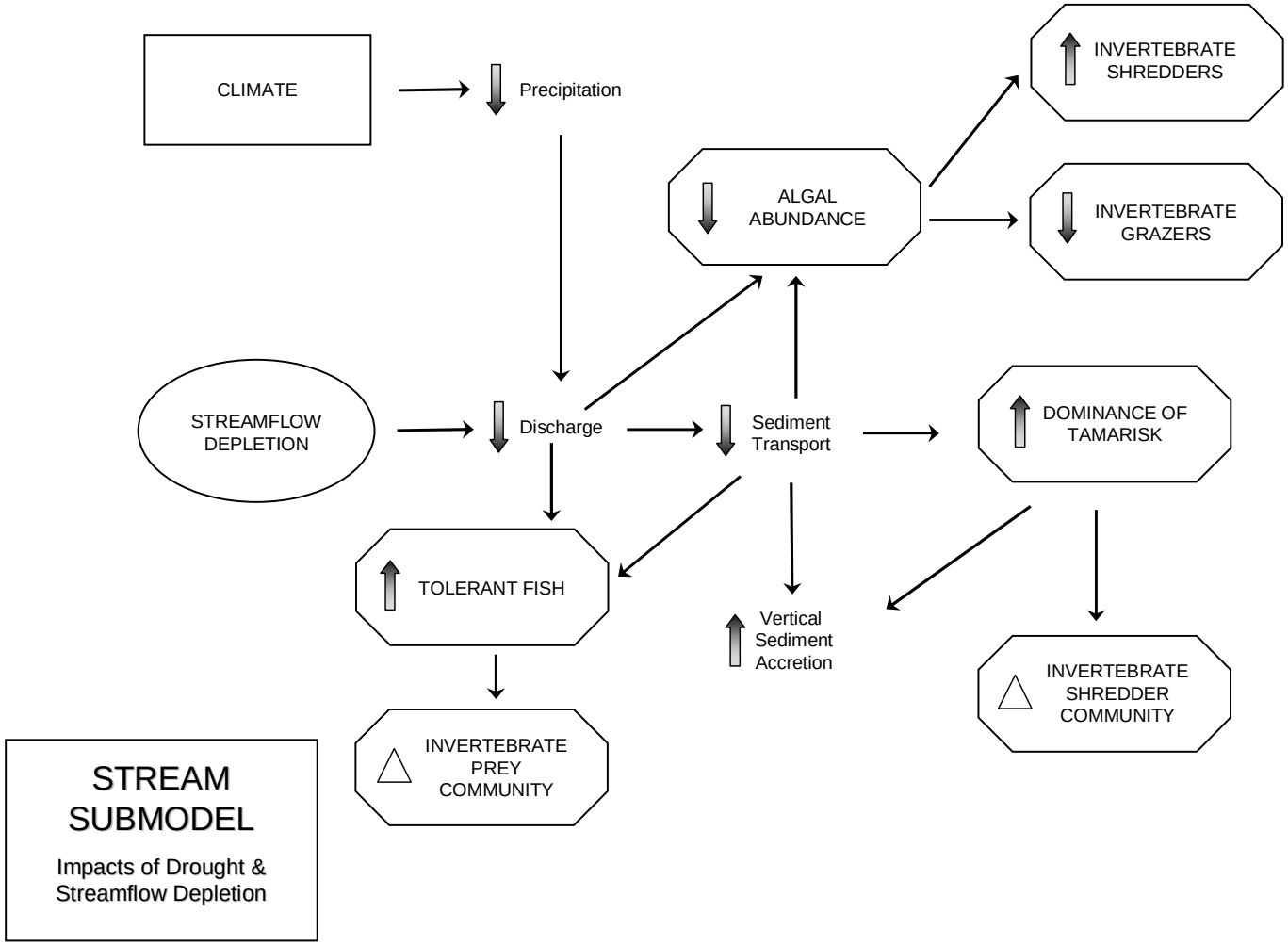


Figure 10. Stream roads submodel.

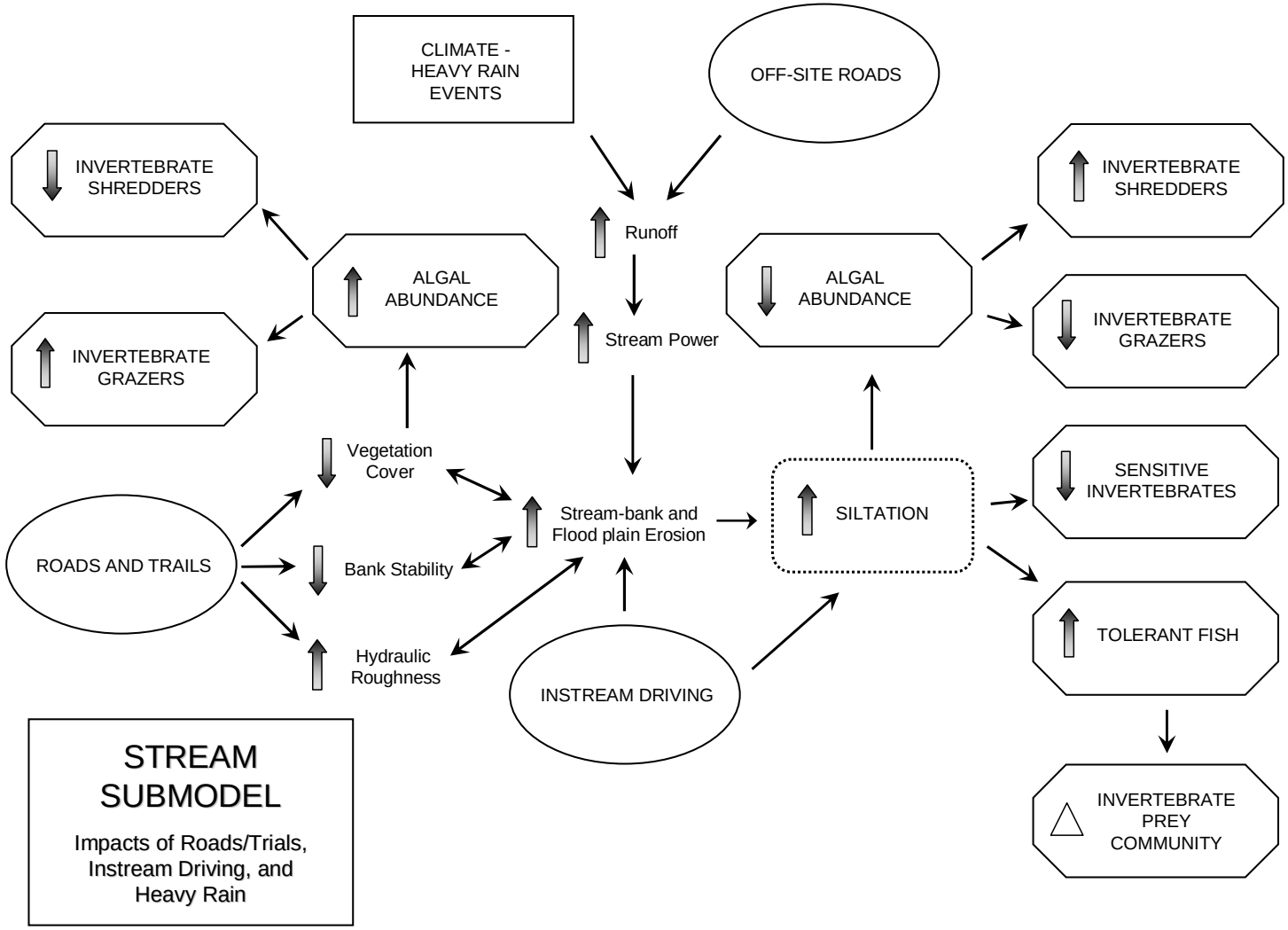


Figure 11. Stream grazing submodel.

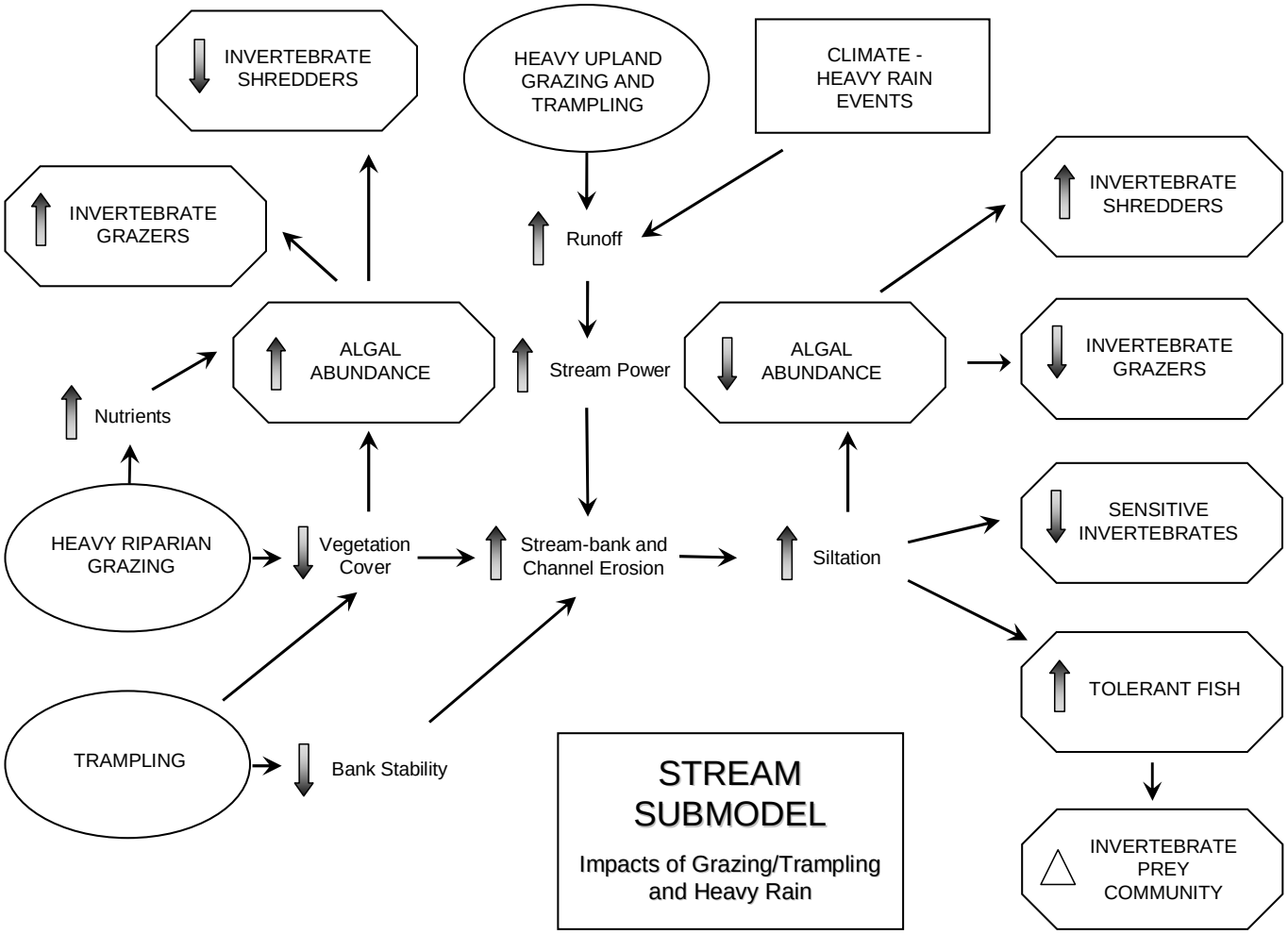


Figure 12. Stream fire and logging submodel.

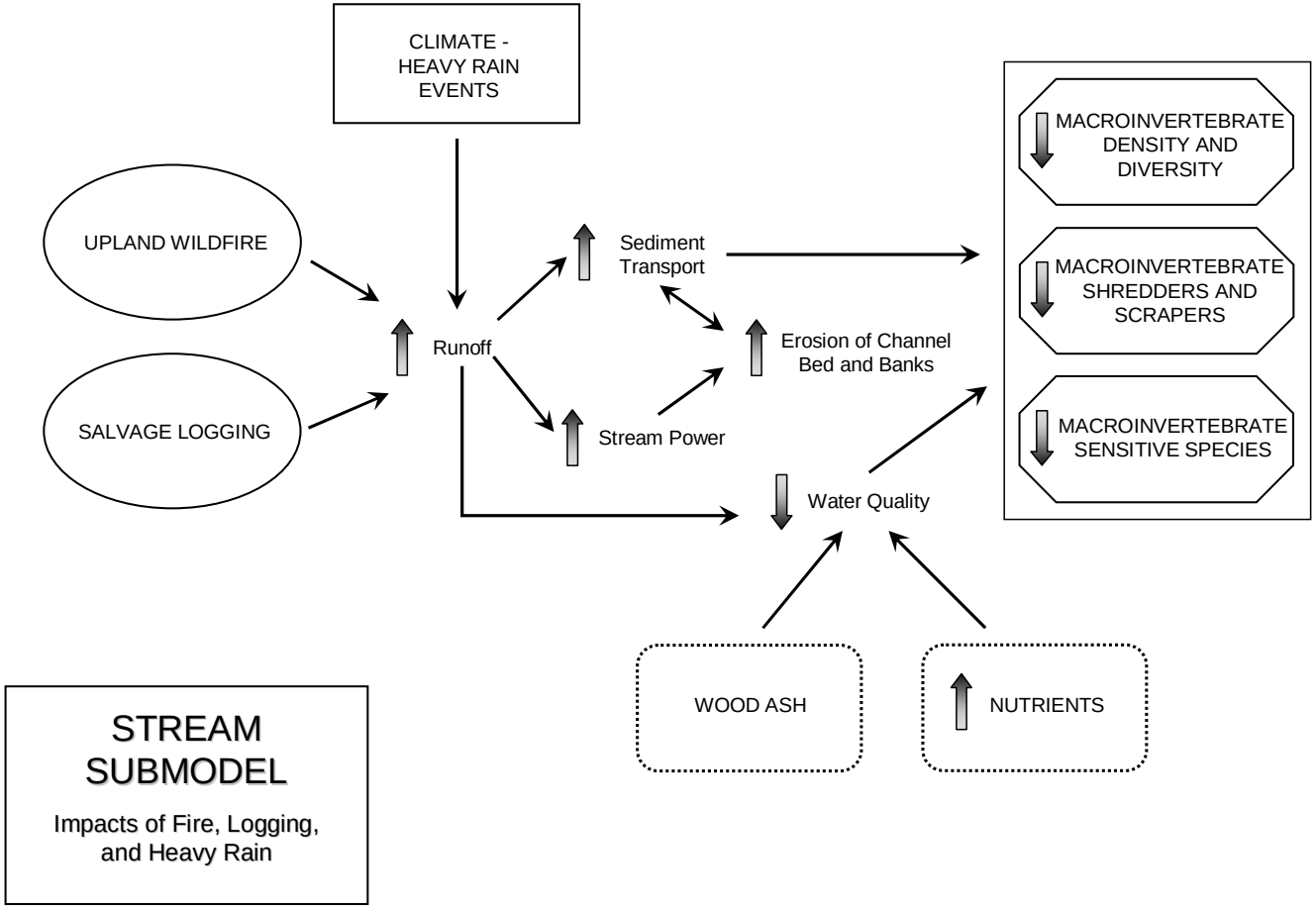


Figure 13. Reservoir overarching model.

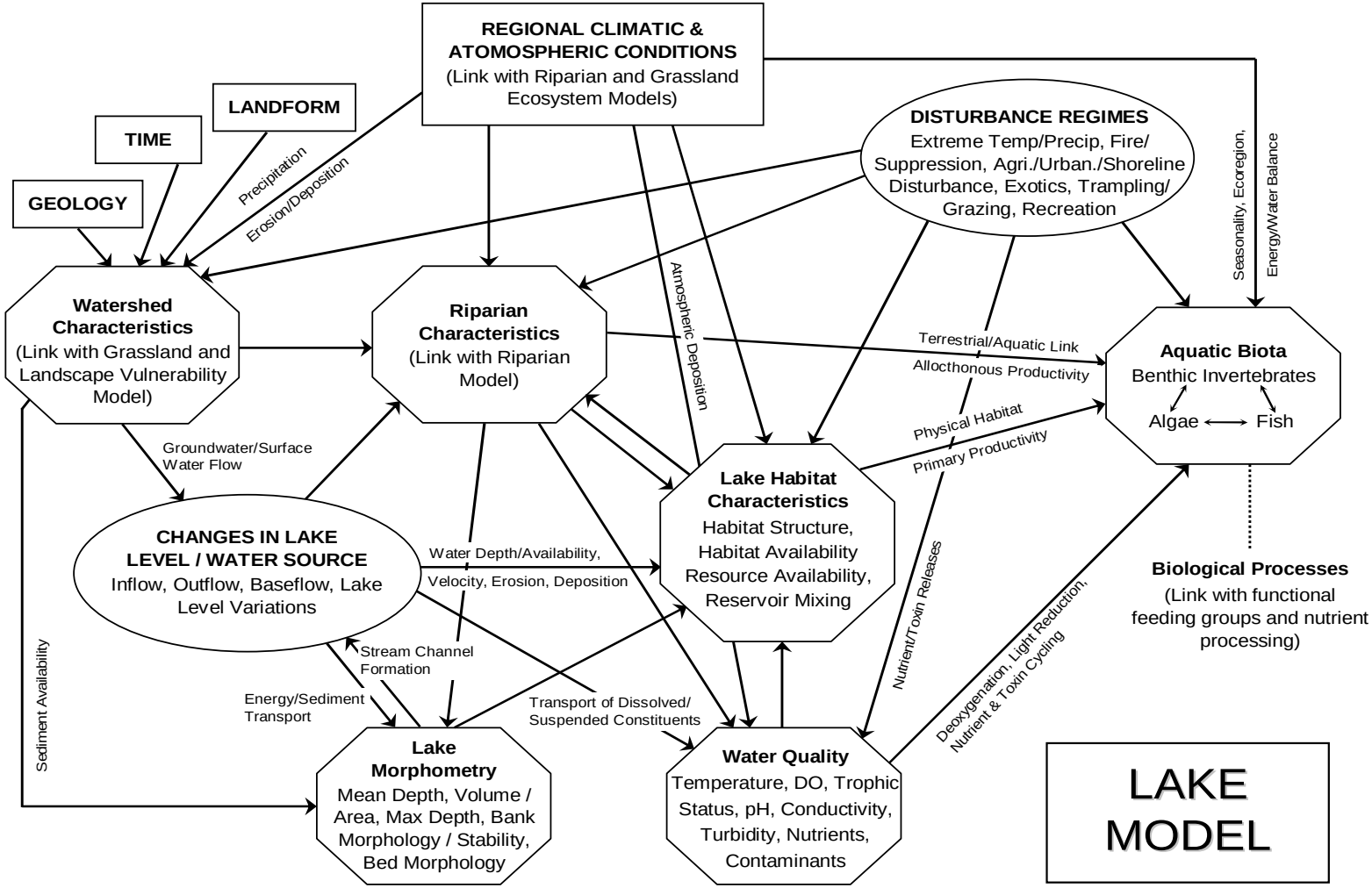
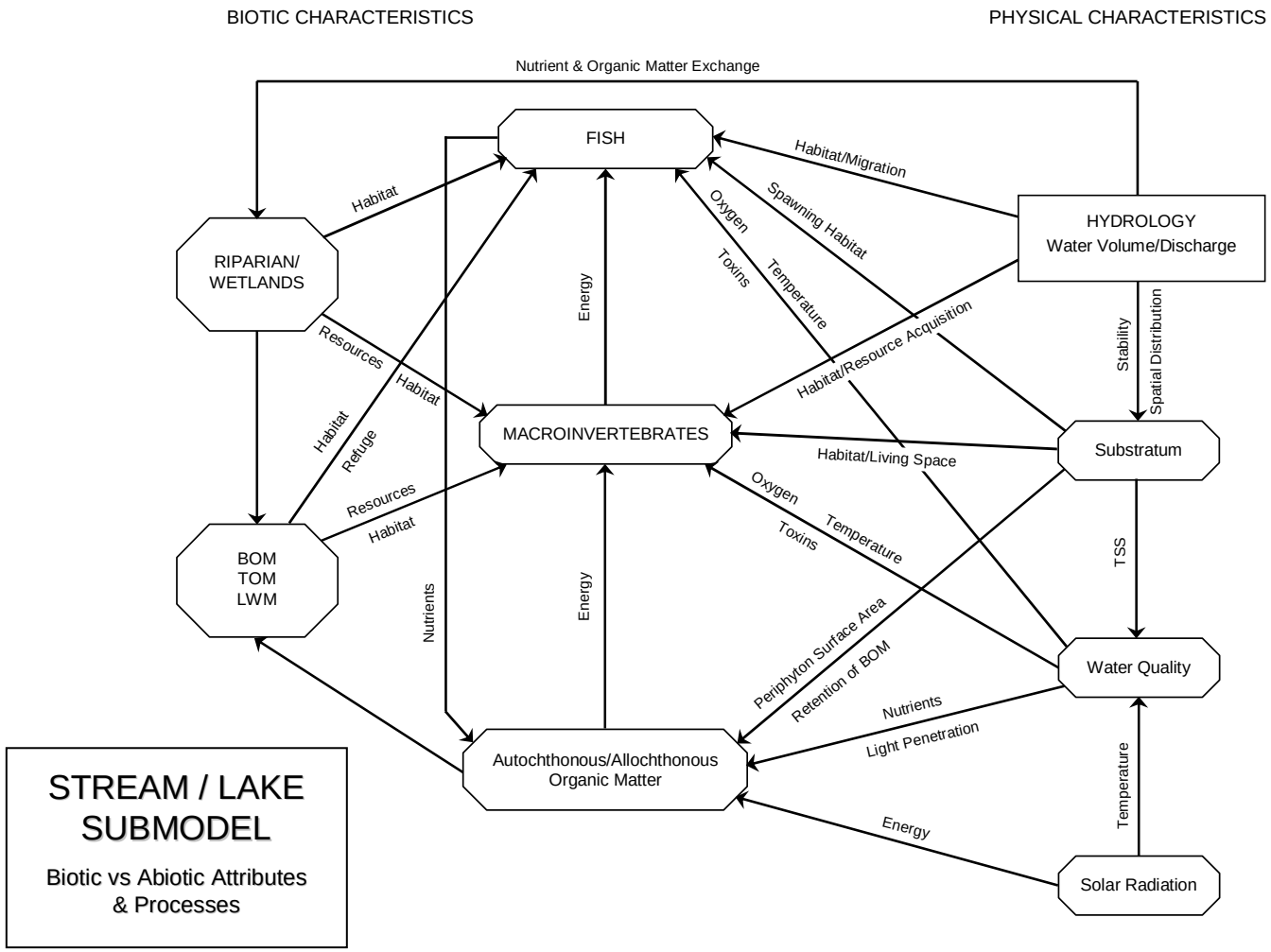


Figure 14. Biotic versus abiotic attributes submodel.



## APPENDIX Q MONITORING PROJECTS OCCURING WITHIN OR IN THE VICINITY OF SOPN PARKS

MONITORING WITHIN SOPN PARKS

*Alibates Flint Quarries National Monument*

Landscapes – Fire – Fire and Fuel Dynamics – Effects of Large Fire
A large wild fire burned 5,200 acres (2,104 ha) including the majority of the monument in 1998. This fire was extremely hot due to fuel buildup, dry weather and high temperatures. The extent and vegetation response from this fire was monitored from 1998-2003.

*Bent's Old Fort National Historic Site*

Biological Integrity – Focal Species or Communities – Vegetation Communities – Vegetation Transects
The park has monitored vegetation transects from 1993 to 2002. Surveys are conducted 1-2 times per year. In 2002, it was determined that these would be monitored every five years. The goals of this monitoring are to asses changes in grassland communities.

Biological Integrity – Focal Species or Communities – Mammals – White-tailed Deer
Colorado Division of Wildlife conducts aerial flights for white-tailed deer (*Odocoileus virginianus*) by reach. Two of these reaches include the park.

Biological Integrity – At-Risk Biota – T&E Species and Communities – Prairie Dog Town Extent
The park monitors the extent and population levels of a black-tailed prairie dog (*Cynomys ludovicianus*) town in the southeastern portion of the park. Extent is based on active burrows and the clip line. A 656 X 656 ft (200 m) plot is used to estimate total population. Protocols follow Plumb et al. (2001).

Biological Integrity – Invasive Species – Invasive / Exotic Plants
Locations of exotic plants are detected through annual walks through the entire park. Locations and metadata are recorded with a GPS unit.

Water – Hydrology – Ground Water Dynamics – Water Table
The water table has been monitored for the last three years. There are 18 wells and 2 water gauges in the river. Groundwater is a major concern for the park's wetlands and the Arkansas River due to increased development upstream of the park.

Landscapes – Fire – Fire and Fuel Dynamics – Fire Plots
Fire plots monitoring are conducted by BEOL staff according to the NPS Fire Monitoring Handbook. This park was formerly in the Colorado Front Range Cluster. In 2005, this park moved under the Southern Plains Fire Cluster. These plots are monitored to provide information to evaluate whether the objectives of the fire management office are met.

*Capulin Volcano National Monument*

Air and Climate – Air Quality – Wet and Dry Deposition
The National Atmospheric Deposition Program (NADP) has maintained an air quality site at the park since 1984. Deposition measurements are useful because they give an indication of the total annual pollutant loading at the site. However, deposition varies with the amount of annual precipitation. Concentration measurements are independent of precipitation amount; therefore, concentration provides a better indication of whether ambient pollutant levels are increasing or decreasing over time, despite rainfall fluctuations. The purpose of this project is to collect data on the chemistry of precipitation for monitoring of geographical and temporal long-term trends. The precipitation at each station is collected weekly according to strict clean-handling procedures. It is

then sent to the Central Analytical Laboratory where it is analyzed for hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium).

Air and Climate – Weather and Climate – Weather and Climate
Weather data including temperature and precipitation has been continuously collected from the park since 1939.

Biological Integrity – Infestations and Disease – Insect Pests – Gypsy Moth
The park has operated 2 traps per year since for at least the past five years. US Forest Service loans the traps to the park. The traps are put out for 4 months near visitor parking. No data or summary is provided to the park. The objective is to detect the spread of exotic gypsy moths (*Lymantria dispar*).

Biological Integrity – Focal Species or Communities – Grassland Vegetation – Grassland Monitoring
Dr. Genarro from Eastern New Mexico University conducted grassland monitoring at the monument from 1974 to 1979. The objective was to monitor woody encroachment on the park grasslands.

Landscapes – Fire – Fire and Fuel Dynamics – Fire Effects
Fire effects monitoring is being conducted by the Pueblo Fire Cluster according to the NPS Fire Monitoring Handbook. Monitoring began in 2004 and includes fire extent and species composition before and after prescribed fires. Provide information to evaluate whether the objectives of the fire management office are met.

*Chickasaw National Recreation Area*

Air and Climate – Weather and Climate – Weather and Climate
Weather data including temperature and precipitation has been continuously collected from the park since 1978. Precipitation data goes back to approximately 1915. The weather data from the 1970's forward has been collected by the Oklahoma climatological survey. There is also a Mesonet realtime weather station just north of Sulhpur, OK.

Landscapes – Fire – Fire and Fuel Dynamics – Fire Effects
Fire effects monitoring is being conducted by the Southern Plains Fire Cluster according to the NPS Fire Monitoring Handbook. Monitoring initially began in 1999 and was then suspended. Monitoring began again in 2004 with some of the original plots and some new plots. This information includes fire extent and species composition before and after prescribed fires. Provide information to evaluate whether the objectives of the fire management office are met.

Water – Water Quality – Water Chemistry
The park collects water quality data including dissolved oxygen, pH, conductivity, turbidity, temperature and nitrates. This data set began in 2001.

Water – Water Quality – Microorganisms – E. Coli
In the park swimming areas, the park collects data on E. coli. The protocol is based on Director's Order 83 that was further developed into a park monitoring plan.

Water – Hydrology – Surface Water Dynamics – Reservoir Level
The US Geological Survey monitors reservoir level and sediment deposition. Together these two parameters can provide estimates for reservoir capacity.

Biological Integrity – Focal Species or Communities – Mammals – White-tailed Deer
The park conducts night-time spotlight surveys for deer throughout the park since 1999. Hunting is a major reason for visitation at this park unit.

Biological Integrity – Invasive Species – Invasive / Exotic Animals – Fire Ants
As part of the park's integrated pest management plan, the park collects data on fire ant (*Solenopsis invicta*) infestations and treatments. This project was initiated in 1999.

Water – Hydrology – Surface Water Dynamics – Stream Flow
There is a USGS stream gaging station on Rock Creek that has been active since

Water – Hydrology – Ground Water Dynamics – Spring Flow
There is a gage for spring flow at Antelope Springs. This was in operation until the early 1990's, when monitoring stopped, but then was re-initiated in 2003. This work is conducted by the park.

*Fort Larned National Historic Site*

No current or historic monitoring projects.

*Fort Union National Monument*

Landscapes – Fire – Fire and Fuel Dynamics – Fire Effects
Fire effects monitoring is being conducted by the Southern Plains Fire Cluster according to the NPS Fire Monitoring Handbook. Monitoring initially began in 1999. This information includes fire extent and species composition before and after prescribed fires. Provide information to evaluate whether the objectives of the fire management office are met.

*Lake Meredith National Recreation Area*

Water – Hydrology – Surface Water Dynamics – Stream Flow
Four stream gages are operated by the United States Geological Survey (USGS) along the Canadian River and its tributaries. These gages include the Canadian River near Amarillo, TX (07227500), Canadian River near Canadian, TX (07228000), Palo Duro Creek near Spearman, TX (07233500), and Wolf Creek at Lipscomb, TX (07235000). The period of record for these gages ranges from 43 to 75 years. Peak flows generally occur in June, while low flow periods take place in December and January.

Water – Hydrology – Surface Water Dynamics – Reservoir Level
Since 1965, the Bureau of Reclamation has monitored reservoir level and sediment deposition. Together these two parameters can provide estimates for reservoir capacity.

Water – Water Quality – Microorganisms – E. Coli
E. coli levels are measured at the Stillings Basin for swimming purposes at LAMR. Monitoring follows Director's Order 83. Canadian River Municipal Water Authority also monitors E. coli in the Lake and the River.

Water – Water Quality – Water Chemistry
Since 1965, water quality has been routinely monitored by the Texas Natural Resources Conservation Commission (TNRCC), USGS, and the Canadian River Municipal Water Authority (CRMWA) with the primary purpose of assuring that domestic water attains state drinking water standards. Between these three entities, a total of 29 water quality monitoring stations exist in the vicinity of Lake Meredith. There are currently three active stations in the lake and approximately 10 active tributary stations. The CRMWA also collects fecal coliform data from 12 additional sites on the lake. The USGS also manages four additional sites that are scattered across the Canadian River Basin. These water quality stations include the Canadian River near Sanchez, NM, the Canadian River at Logan, NM, the Canadian River above the New Mexico-Texas State Line, and the Canadian River near Canadian, Texas.

Biological Integrity – Focal Species or Communities – Birds – Christmas Bird Counts
Audubon conducts a bird count in December every year at the park since at least 1994. The Christmas Bird Count (CBC) began over a century ago in order to determine winter distributions of various bird species. CBC is used to monitor the status of resident and migratory birds across the Western Hemisphere. Volunteer birders of all skill levels count and record every individual bird and bird species seen during one 24-hour calendar day in late December. Each group has a designated circle 15 miles (24 km) in diameter - about 177 square miles (285 km) - where they try to census as much ground as possible within a day. This count has been conducted continuously since 1971. Count results are available at http://www.audubon.org/bird/cbc.

Biological Integrity – Focal Species or Communities – Mammals – White-tailed Deer
Texas Parks and Wildlife conducts an aerial deer survey every winter that includes LAMR. LAMR began to supplement these surveys with spotlights in 2004.

Biological Integrity – Focal Species or Communities – Fishes – Game Fish
Texas Parks and Wildlife conducts semi-annual surveys with gill-nets of the condition of game fish present at LAMR. Health department monitors the mercury level in walleye (*Stizostedion vitreum*).

Biological Integrity – At-Risk Biota – T&E Species and Communities – Bald Eagle Winter Survey
The Texas Panhandle Audubon Society conducts a winter bald eagle (*Haliaeetus lecocephalus*) survey on an annual basis.

Landscapes – Fire – Fire and Fuel Dynamics – Fire Effects
Fire effects monitoring is being conducted by the Southern Plains Fire Cluster according to the NPS Fire Monitoring Handbook. Plots were established in 1999 by the Pueblo Fire Cluster, but they have never been monitored. This information will provide information to evaluate whether the objectives of the fire management office are met.

*Lyndon B. Johnson National Historical Park*

Air and Climate – Weather and Climate – Weather and Climate
Weather data including temperature and precipitation has been continuously collected in real time from the park since 2002 at a Mesowest weather station.

Water – Water Quality – Water Chemistry
The park has collected data from two sites along the Pedernales River in the LBJ Ranch District as part of Lower Colorado River Authority's Riverwatch Program since 1996. A third site was added along Town Creek in the Johnson City District in 2004. Monitoring is done once a month and parameters include dissolved oxygen, temperature, turbidity, fecal coliform, pH, nitrates, visibility and conductivity.

Biological Integrity – Infestations and Disease – Plant Diseases – Oak Wilt
Oak wilt is a disease that has a high mortality rate and may have increased in frequency due to higher oak densities from lack of fire in the region. LYJO conducts an annual survey of the park oak trees with the Texas Forest Service on an annual basis.

*Pecos National Historical Park*

Air and Climate – Weather and Climate – Weather and Climate
Temperature and precipitation has been collected at the park since 1989.

Biological Integrity – Focal Species or Communities – Birds – Christmas Bird Counts
Audubon conducts a bird count every year at the park since 2002. Birders count and record every individual bird and bird species seen during one 24-hour calendar day in late December. Each group has a designated circle 15 miles (24 km) in diameter - about 177 square miles (285

km) - where they try to census as much ground as possible within a day. The count was started in 2002. Count results are available at http://www.audubon.org/bird/cbc.

*Sand Creek Massacre National Historic Site*

Water – Hydrology – Surface Water Dynamics – Stream Flow
Stream flow is monitored at SAND by the town of Eads Public Works Division.

*Washita Battlefield National Historic Site*

No current or historic monitoring projects.

MONITORING OUTSIDE THE PARK

*Several Parks*

Air and Climate – Air Quality –Wet and Dry Deposition – CASTNet
(CASTNet) is a national dry deposition monitoring network. There is only one dry deposition CASTNet sampler near the SOPN (CHE185 [Cherokee Nation] Adair County, OK), and it is located close to the eastern border of Oklahoma and may not be representative of SOPN units.

Air and Climate – Air Quality – Wet and Dry Deposition – NADP
The National Atmospheric Deposition Program (NADP) is a national monitoring program for dry deposition. Deposition measurements are useful because they give an indication of the total annual pollutant loading at the site. However, deposition varies with the amount of annual precipitation. Concentration measurements are independent of precipitation amount; therefore, concentration provides a better indication of whether ambient pollutant levels are increasing or decreasing over time, despite rainfall fluctuations. In general, wet deposition and concentration of sulfate, nitrate, and ammonium are low in the western U.S. relative to the Midwest and East. Pollutant deposition in the SOPN is consistent with this pattern. NADP sites within SOPN are: CO00 (Alamosa); CO00 (Alamosa), Alamosa, CO; CO01 (Las Animas Fish Hatchery), Bent County, CO; KS32 (Lake Scott State Park), Scott County, KS; NM07 (Bandelier National Monument), Los Alamos County, NM; OK29 (Goodwell Research Station), Texas County, OK; OK00 (Salt Plains National Wildlife Refuge), Alfalfa County, OK; OK17 (Great Plains Apiaries), McClain County, OK; TX02 (Muleshoe National Wildlife Refuge), Bailey County, TX; TX56 (LBJ National Grasslands), Wise County, TX; TX21 (Longview), Gregg County, TX; TX16 (Sonora), Edwards County, TX; AR27 (Fayetteville) Washington County, AR.

Air and Climate – Air Quality – Air Contaminants – MDN
Monitoring of toxic air pollutants, including organic chemicals (e.g., pesticides, herbicides, PCBs, dioxin) and heavy metals, has been done in some areas of the country on an ad hoc basis, but has not been done as part of a long-term nationwide network. An exception is the Mercury Deposition Network (MDN) , which collects rainfall for mercury analysis at over 60 sites nationwide (http://nadp.sws.uiuc.edu/mdn/). Sources of mercury include atmospheric deposition, mining activities, and natural sources. Coal contains mercury and large coal-burning power plants are major sources of mercury to the atmosphere and, eventually, terrestrial and aquatic ecosystems. Bioaccumulation of mercury in fish and wildlife has resulted in fish consumption advisories, and neurological and reproductive effects to wildlife and humans. MDN monitors near SOPN units are TX50 (Fort Worth) Tarrant County, TX; TX21 (Longview), Gregg County, TX; OK15 (Newkirk) Kay County, OK.

Air and Climate – Air Quality – Visibility and Particulate Matter – IMPROVE
Visibility-impairing particles and gases are monitored nationwide through the IMPROVE program. Most IMPROVE monitors are located in or near Class I air quality areas in order to characterize visibility conditions and assess progress towards visibility improvement under the Regional Haze Program. Each IMPROVE site has a fine particle sampler that measures the types and amounts

of particles that obscure visibility. Data are available from the Visibility Information Exchange Web System (VIEWS) at http://vista.cira.colostate.edu/views/. Visibility is not monitored in any of the SOPN park units. However, visibility impairment is regional in nature and nearby IMPROVE samplers indicate that visibility is degraded to some extent throughout the SOPN area. IMPROVE sites within SOPN are: CEBL1 (Cedar Bluff), Trego County, KS; CHER1 (Cherokee Nation) Kay County; OK, ELLI1 (Ellis), Ellis County, OK; WIMO1 (Wichita Mountains NWR), Comanche County, OK; BAND1 (Bandelier National Monument), Los Alamos County, NM; SACR1 (Salt Creek NWR), Grant County, NM; WHPE1 (Wheeler Peak), Taos County, NM; ELDO1 (El Dorado Springs), Cedar County, MO.

Air and Climate – Air Quality – Ozone

There are no ozone monitors in any SOPN units; however, State and local air quality agencies operate a number of ozone monitors near SOPN park units. Most of these monitors are placed to characterize ozone concentrations in urban areas, including Tulsa, Oklahoma City, Dallas/Ft. Worth, Austin, and San Antonio. Data from these monitors has been used by the States and EPA to determine compliance with the EPA ozone health standard (based on an 8-hr averaging period). Part or all of 474 counties nationwide are designated as nonattainment for either failing to meet the 8-hour ozone standard or for causing a downwind county to fail (Figure 4). Nonattainment areas include the Dallas/Ft. Worth metropolitan area and San Antonio. Ozone affects human health, causing acute respiratory problems, aggravation of asthma, temporary decreases in lung capacity in some adults, inflammation of lung tissue, and impairment of the body's immune system. Chamber studies have shown ozone effects to birds and other wildlife. However, these effects to birds and wildlife have not been demonstrated in the wild. Effects to vegetation have been widely documented and ozone is one of the most widespread pollutants affecting vegetation in the U.S. Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. Long-term exposures can result in shifts in species composition, with ozone tolerant species replacing intolerant species.

Air and Climate – Weather and Climate – Weather and Climate

Temperature and precipitation are recorded by a variety of state and federal agencies near SOPN parks. Locations are: BEOL – Mesowest, La Junta (1997 - Present); CAVO – Clayton, 58 miles southeast (1908 - present), Raton 32 northwest (1952 - Present), and Des Moines 13 miles east (1925 - Present), Mesowest Raton (1999 - Present); CHIC – Mesowest Station in Murray County (2001 - Present); FOLS – Precipitation record in Larned, closest National Weather Service weather station is Great Bend, 43 miles east; FOUN – Mesowest, Las Vegas (1997 - Present); LAMR – Mesowest, Borger (2004 - Present); LYJO – Mesowest Johnson City (2004 - Present) and (2002 - Present); PECO – Mesowest, Pecos (2000 - Present); WABA – Black Kettle National Grasslands.

Biological Integrity – Focal Species or Communities – Long Term Ecological Research Sites

The Konza Prairie Long-term Ecological Research (LTER) Program in eastern Kansas lies to the north and east of SOPN and is in a tall-grass ecosystem (see Knapp et al. 1998). The Short-grass Steppe Long-term Ecological Research Program in eastern Colorado is also outside of the SOPN.

Biological Integrity – Focal Species or Communities – Birds – Christmas Bird Counts

The Christmas Bird Count (CBC) began over a century ago in order to determine winter distributions of various bird species. CBC is used to monitor the status of resident and migratory birds across the Western Hemisphere. Volunteer birders of all skill levels count and record every individual bird and bird species seen during one 24-hour calendar day in late December. Each group has a designated circle 15 miles (24 km) in diameter - about 177 square miles (285 km) - where they try to census as much ground as possible within a day. Count results are available at http://www.audubon.org/bird/cbc. Historic and current count circles cover all or a portion of the

following SOPN sites: BEOL – Cimarron National Grassland, John Martin Resevoir, Pueblo, Rocky Ford; CAVO – Union and Colfax County; CHIC – Murray County; FOLS – Quivira NWR, Dodge City; FOUN – Mora County; LAMR – Canadian River, Amarillo, Lake Meredith East, Lake Meredith West; LYJO – Burnet County, Boerne, Balcones Canyonlands NWR, Austin; PECO – Santa Fe and San Miguel Counties; SAND – John Martin Reservoir; WABA – Washita NWR

Biological Integrity – Focal Species or Communities – Birds – Breeding Bird Surveys
The North American Breeding Bird Survey (BBS), which is coordinated by the National Biological Service and Canadian Wildlife Service, is a primary source of population trend and distribution information for most species of North American birds. Several recent summaries of the BBS have been published (e.g., Peterjohn and Sauer 1993, Droege and Sauer 1989, 1990). The survey unit is a roadside route, which is 39.4 km (24.5 miles) long. An observer surveys the route once each year during the peak of the breeding season, primarily during June although routes in desert regions and some southern states are surveyed during May. The observer stops at 0.5 m (0.8 km) intervals, and records all birds seen or heard within a 0.25 mile (0.4 km) radius circle of each stop during a 3-min sampling period. The starting point and direction of each route was randomly located within a degree block of latitude and longitude (Robbins et al. 1989, Droege and Sauer 1990). Routes near SOPN parks are: BEOL – Route 327 Otero County, Route 68 Crowley County; CAVO – Routes 5 and 135, Western Colfax and Union County; CHIC – Route 5 Western Pontotoc County; FOLS – Routes 314, 9 Pawnee County; FOUN – Routes 11, 84, Wagon Mound; LAMR – Route 101, Pantex; LYJO – Route 328, Northeast Gillespie County; PECO – Routes 16, 60 San Miguel County; SAND – Routes 321, 221, 21, Kiowa County; WABA – Route 20, Grimes.

Biological Integrity – Focal Species or Communities – Birds – Grassland Birds
Rocky Mountain Bird Observatory conducts grassland bird surveys throughout the state of Colorado. The goals of the project are to determine trends in population and distribution, and determine local densities of birds which will ultimately help identify priority areas for conservation, and provide data that tells us how management can be used or changed to positively influence habitat. Currently, the monitoring project focuses on two areas, all-bird surveys in eastern Colorado, western Nebraska, western Kansas, and western Oklahoma, and monitoring of five U.S. Forest Service National Grasslands.

Water – Hydrology – Surface Water Dynamics – Stream Flow
USGS monitors stream flow gages at places throughout the country. Locations near SOPN parks are: BEOL – Arkansas River, Las Animas (USGS 07124000, 1940 - Present), and Arkansas River, Swink (USGS 07121500 1922-Present); FOLS – Pawnee River (USGS 07141200, 1925 - Present); LAMR – Canadian River, nr Amarillo (USGS 07227500, 1939 - Present); LYJO – Pedernales River, Johnson City (USGS 08153500, 1940 – Present) and Pedernales River, Fredericksburg (USGS 08152900, 1980 - Present); PECO – Pecos River, Pecos (USGS 8378500, 1930 - Present); SAND – Big Sandy Creek (USGS 07134100, 1969 -1981, 1996 - Present); WABA – Washita River, Cheyenne (USGS 07316500, 1938 - Present)

*Capulin Volcano National Monument*

Biological Communities – Focal Species or Communities – Birds
The Breeding Biology Research and Monitoring Database (BBIRD) program is a national, cooperative program that uses standardized field methodologies for studies of nesting success and habitat requirements of breeding birds. BBIRD is comprised of independent investigators from throughout North America who work with and make their results available to local managers, disseminate results through articles in peer-reviewed journals and who meet annually to discuss results and issues. BBIRD participants contribute their data to the national BBIRD database to allow examination of large-scale patterns and trends. The national database includes data through 2002 on nearly 60,000 nests and associated vegetation, representing more than 210 species of birds. BBIRD monitors nesting success and habitat of nongame birds by finding and monitoring nests at replicate plots across North America. Studies at each local site generally

include plots within large blocks of relatively unfragmented habitat and plots within another treatment to examine land use issues, such as fragmentation, habitat loss, or silvicultural treatments. Standardized vegetation sampling is conducted at nest sites, non-use plots, and point counts to allow detailed analysis of microhabitat requirements for successful nesting. The BBIRD program is managed under the Biological Resources Division, U.S. Geological Survey and is supported in part by this program and by the USDA Forest Service. There is a historical BBIRD site in North central NM, that was monitored from 1992-1996

*Lyndon B. Johnson National Historical Park*

Biological Integrity – Focal Species or Communities – Birds – Bird Counts
Bird counts are conducted three times a year at the Bamberger Ranch, 7 miles south of the Johnson City District. Methods are loosely based on the Christmas Bird Count methods.

Biological Integrity – Focal Species or Communities – Freshwater Communities
Routine Biological Monitoring: 10 locations along the Colorado River and its major tributaries are sampled twice per year. Each visit to a site involves intensive fish and aquatic insect collections, as well as aquatic habitat analysis. Preliminary data analysis indicates the water quality of the Colorado River and its tributary streams supports a diverse community of fish and aquatic insects.

Water – Water Quality – Water Chemistry
The Lower Colorado River Authority's Riverwatch Program has 16 stations on the Pedernales River or its tributaries.

*Pecos National Historical Park*

Biological Integrity – At-Risk Biota – T&E Species and Communities – Spotted Owl
The US Forest Service conducts spotted owl (*Strix occidentalis lucida*) monitoring on in the Santa Fe National Forest, 8 miles north of PECO.

## LITERATURE CITED


Droege, S., and J. R. Sauer 1989. North American Breeding Bird Survey annual summary 1988. U. S. Fish. Wildl. Serv., Biol. Rept. 89(13):1-16.

Droege, S., and J. R. Sauer 1990. North American Breeding Bird Survey annual summary 1989. U. S. Fish. Wildl. Serv., Biol. Rept. 90(8):1-22.

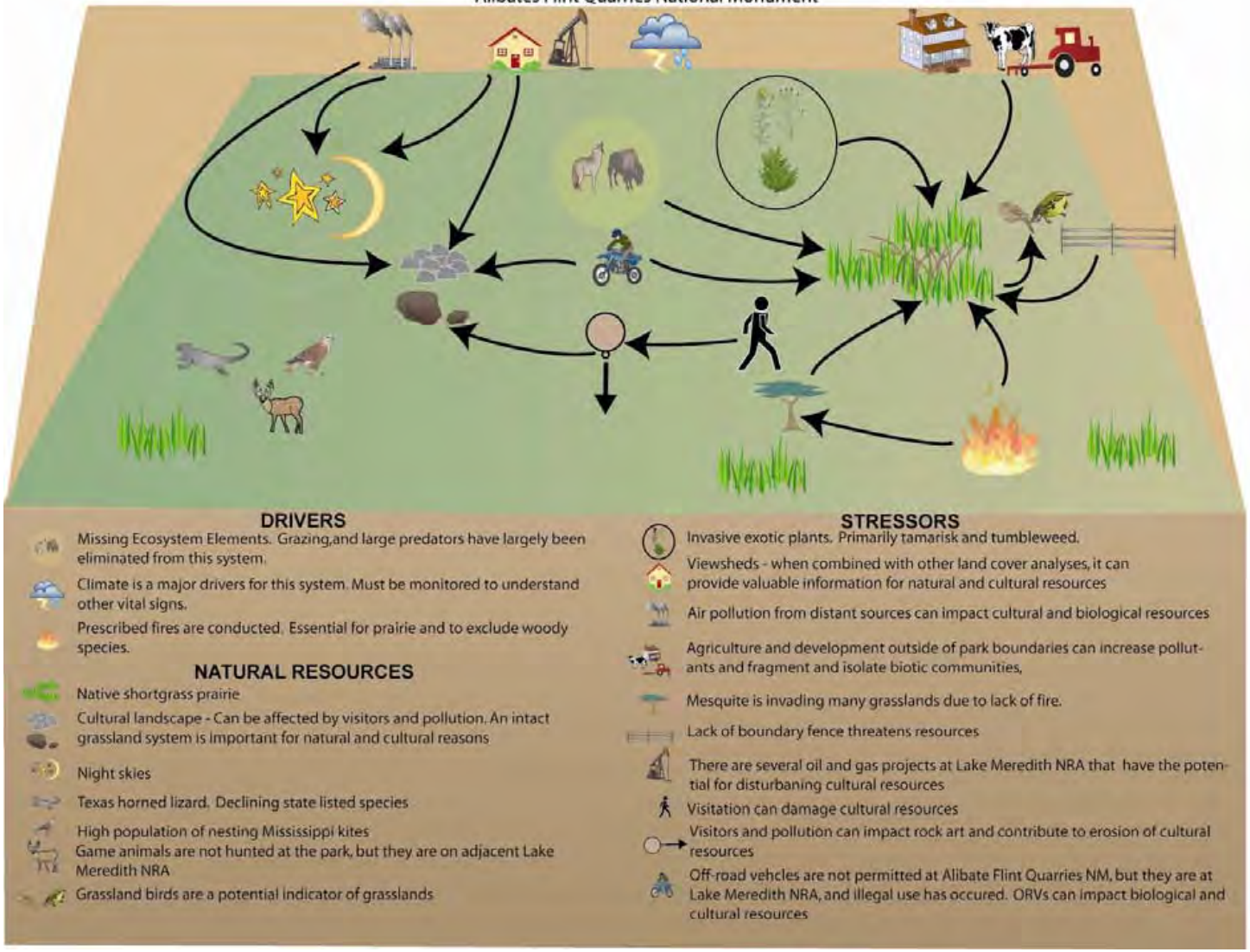
Knapp, A. K., J. M. Briggs, D. C. Hartnett, and S. L. Collins, editors. 1998. Grassland dynamics: long-term ecological research in tallgrass prairie. Oxford U. Press, Oxford. 364pp.

Peterjohn, B. G., and J. R. Sauer. 1993. North American Breeding Bird Survey annual summary 1990-1991.Bird Populations 1:52-67.

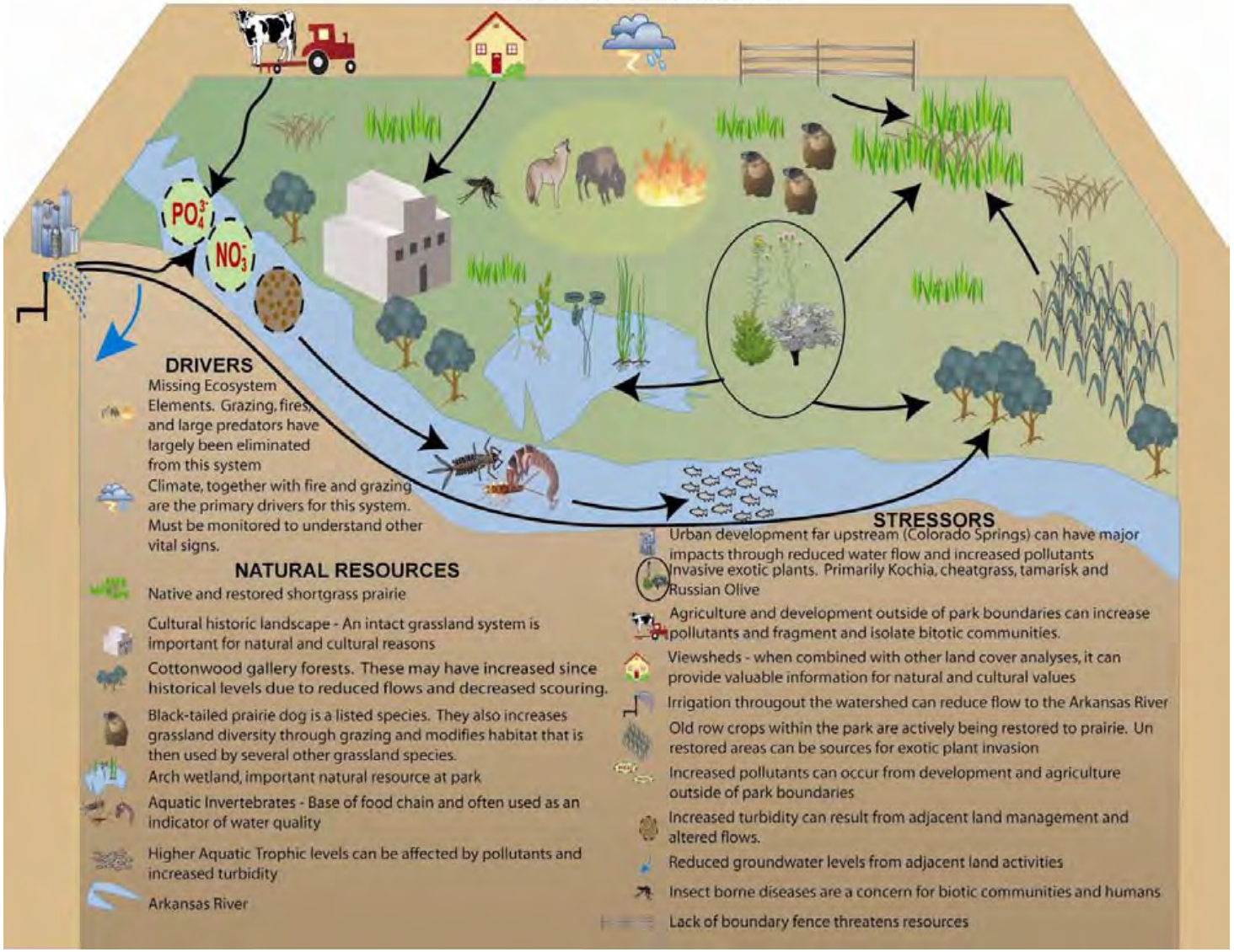
Plumb, G.E., G.D. Willson, K. Kalin, K. Shinn, and W.M. Rizzo. 2001. Black-tailed prairie dog monitoring protocol for seven prairie parks. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Missouri Field Station, Columbia, MO. 27 p.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. Proc. Natl. Acad. Sci, USA 86:7658-7662.

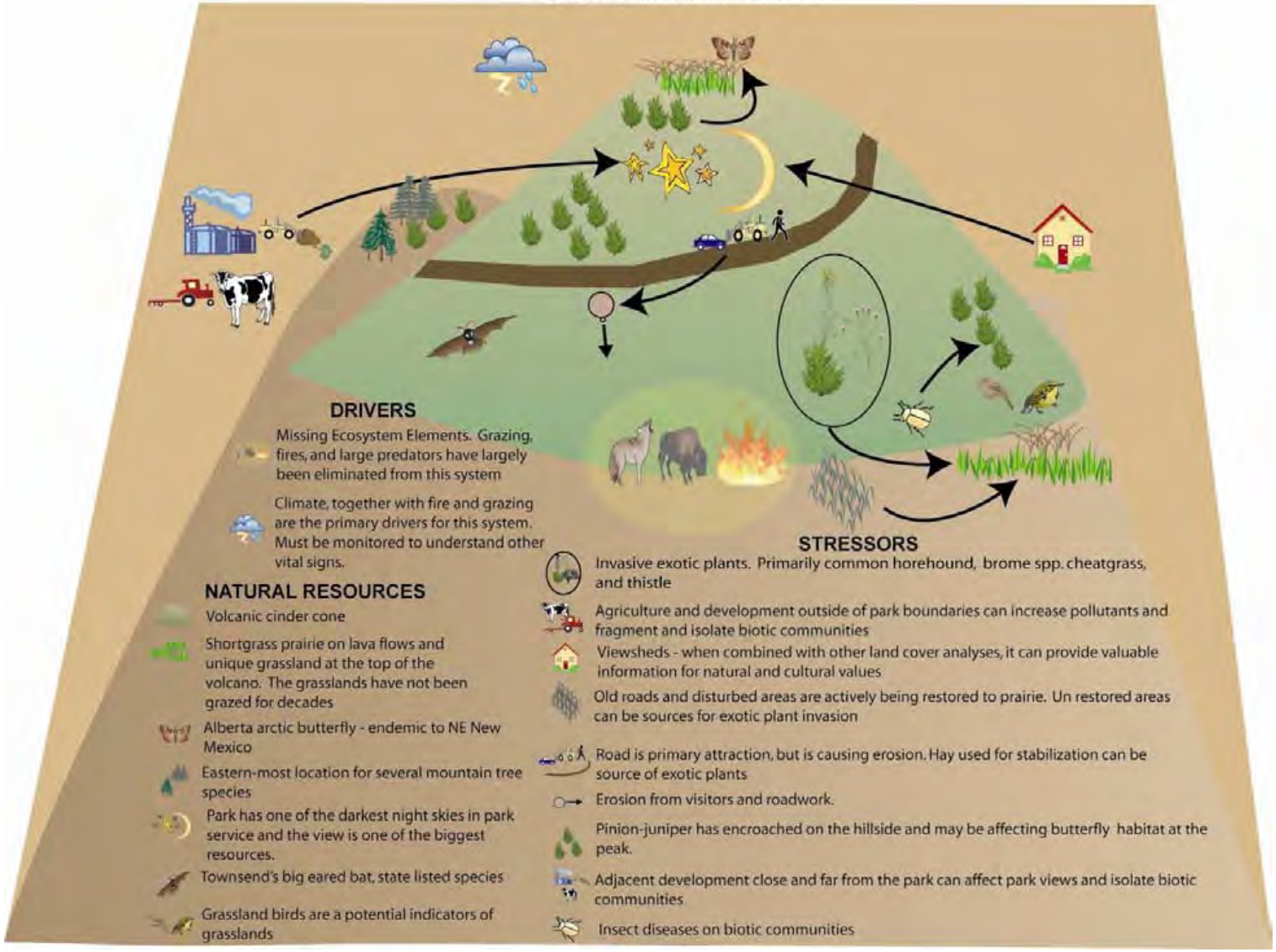
Alibates Flint Quarries National Monument



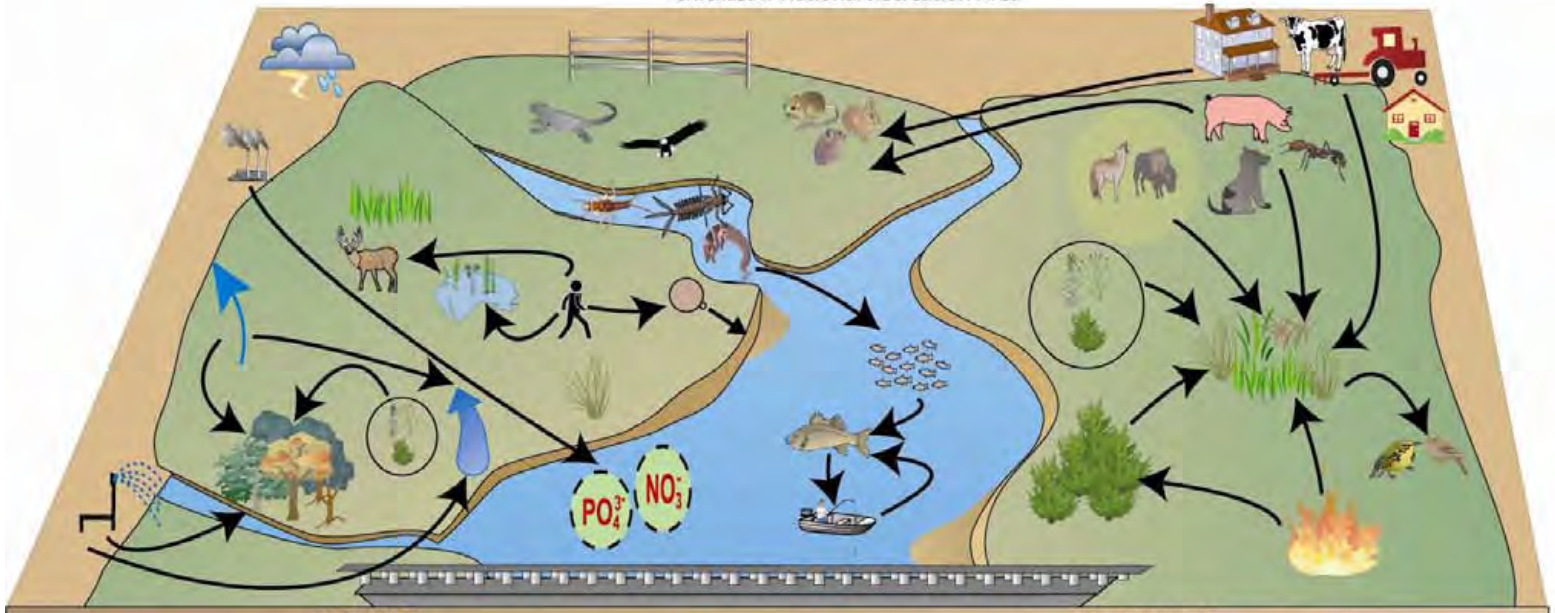
Bent's Old Fort National Historic Site



Capulin Volcano National Monument



Chickasaw National Recreation Area




## DRIVERS

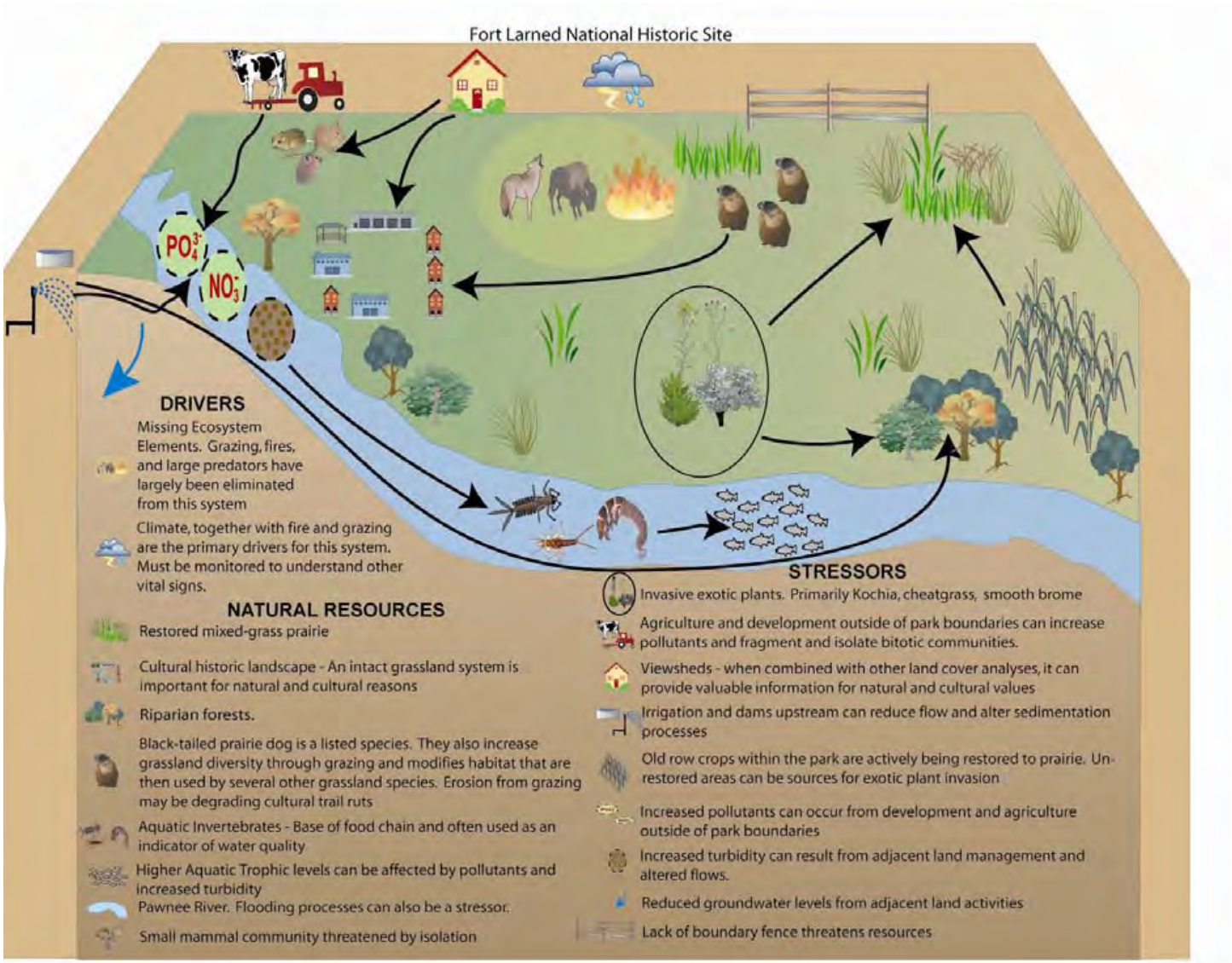
- Missing Ecosystem Elements. Grazing,and large predators have largely been eliminated from this system.
- Climate is a major driver for this system. Must be monitored to understand other vital signs
- Prescribed fires are conducted. Essential for prairie and to exclude woody species

## NATURAL RESOURCES

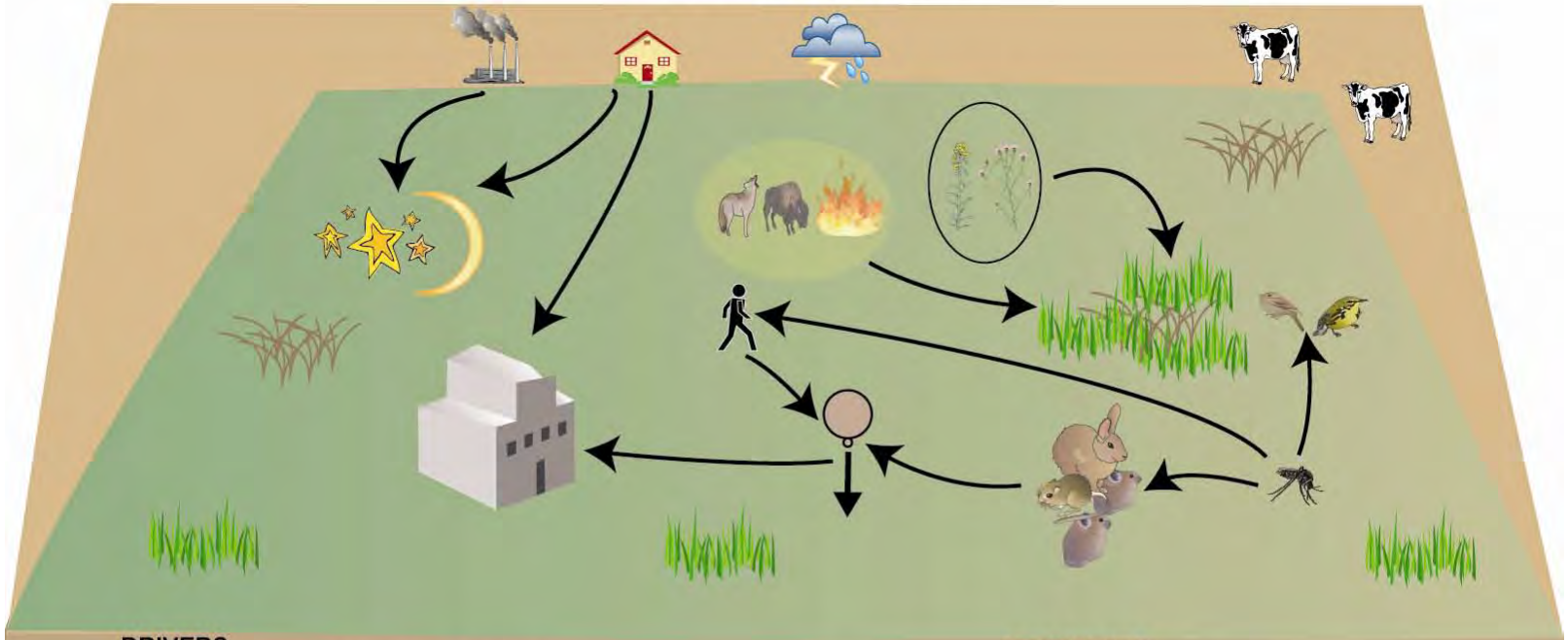
- Restored and native mixed-grass prairie
- Lake of the Arbuckles, Veteran's Lake and several streams
- Bottomland riparian forests.
- Upland springs are a major natural resource and reason for park's existence
- Wetland communities
- Aquatic invertebrates - Base of food chain and often used as an indicator of water quality
- Higher aquatic trophic levels can be affected by pollutants
- Largemouth bass and game animals are a primary reason for visitation
- Grassland birds are a potential indicators of grasslands
- Small mammal community threatened by isolation
- Texas horned lizard and bald eagle, listed species

## STRESSORS

- Woody encroachment by eastern red cedar due to lack of fire threatens grass-lands communities
- Viewsheds - when combined with other land cover analyses, it can provide valuable information for natural and cultural values
- Invasive exotic plants. Primarily Johnson grass, brome spp.
- Agriculture and development outside of park boundaries can increase pollutants and fragment and isolate bitotic communities.
- Air pollution from distant sources
- Park visitors can be a stressor to natural resources, but can also be affected by pollutants at the park
- Lack of boundary fence and boundary encroachments threatens resources
- Reduced groundwater levels from adjacent land activities
- Visitation can damage cultural and natural resources
- Increased pollutants can occur from development and agriculture outside of park boundaries
- Feral animals threaten native communities (hogs, dogs, cats, fire ants)
- Erosion is a major stressor to the lakes and streams.


Fort Larned National Historic Site
$PO_4^{3-}$
$NO_3^-$
DRIVERS
Missing Ecosystem Elements. Grazing, fires, and large predators have largely been eliminated from this system
Climate, together with fire and grazing are the primary drivers for this system. Must be monitored to understand other vital signs.
NATURAL RESOURCES
Restored mixed-grass prairie
Cultural historic landscape - An intact grassland system is important for natural and cultural reasons
Riparian forests.
Black-tailed prairie dog is a listed species. They also increase grassland diversity through grazing and modifies habitat that are then used by several other grassland species. Erosion from grazing may be degrading cultural trail ruts
Aquatic Invertebrates - Base of food chain and often used as an indicator of water quality
Higher Aquatic Trophic levels can be affected by pollutants and increased turbidity
Pawnee River. Flooding processes can also be a stressor.
Small mammal community threatened by isolation
STRESSORS
Invasive exotic plants. Primarily Kochia, cheatgrass, smooth brome
Agriculture and development outside of park boundaries can increase pollutants and fragment and isolate bitotic communities.
Viewsheds - when combined with other land cover analyses, it can provide valuable information for natural and cultural values
Irrigation and dams upstream can reduce flow and alter sedimentation processes
Old row crops within the park are actively being restored to prairie. Un-restored areas can be sources for exotic plant invasion
Increased pollutants can occur from development and agriculture outside of park boundaries
Increased turbidity can result from adjacent land management and altered flows.
Reduced groundwater levels from adjacent land activities
Lack of boundary fence threatens resources

Fort Union National Monument



## DRIVERS

Missing Ecosystem Elements. Grazing, fires, and large predators have largely been eliminated from this system. There has been no grazing for 50 years.

Climate, together with fire and grazing are the primary drivers for this system. Must be monitored to understand other vital signs.

## NATURAL RESOURCES

Native shortgrass prairie

Cultural historic landscape - An intact grassland system is important for natural and cultural reasons

Grassland birds are a potential indicators of grasslands

## STRESSORS

Small mammal may be high due to presence of ruins

Burrowing mammals have potential to destroy ruins and affect erosion of Santa Fe Trail ruts

Viewsheds - when combined with other land cover analyses, it can provide valuable information for natural and cultural values

Invasive exotic plants. Primarily field bindweed and common mullein

Park entirely surrounded by contiguous ranch. If ranch changed ownership, park could change dramatically

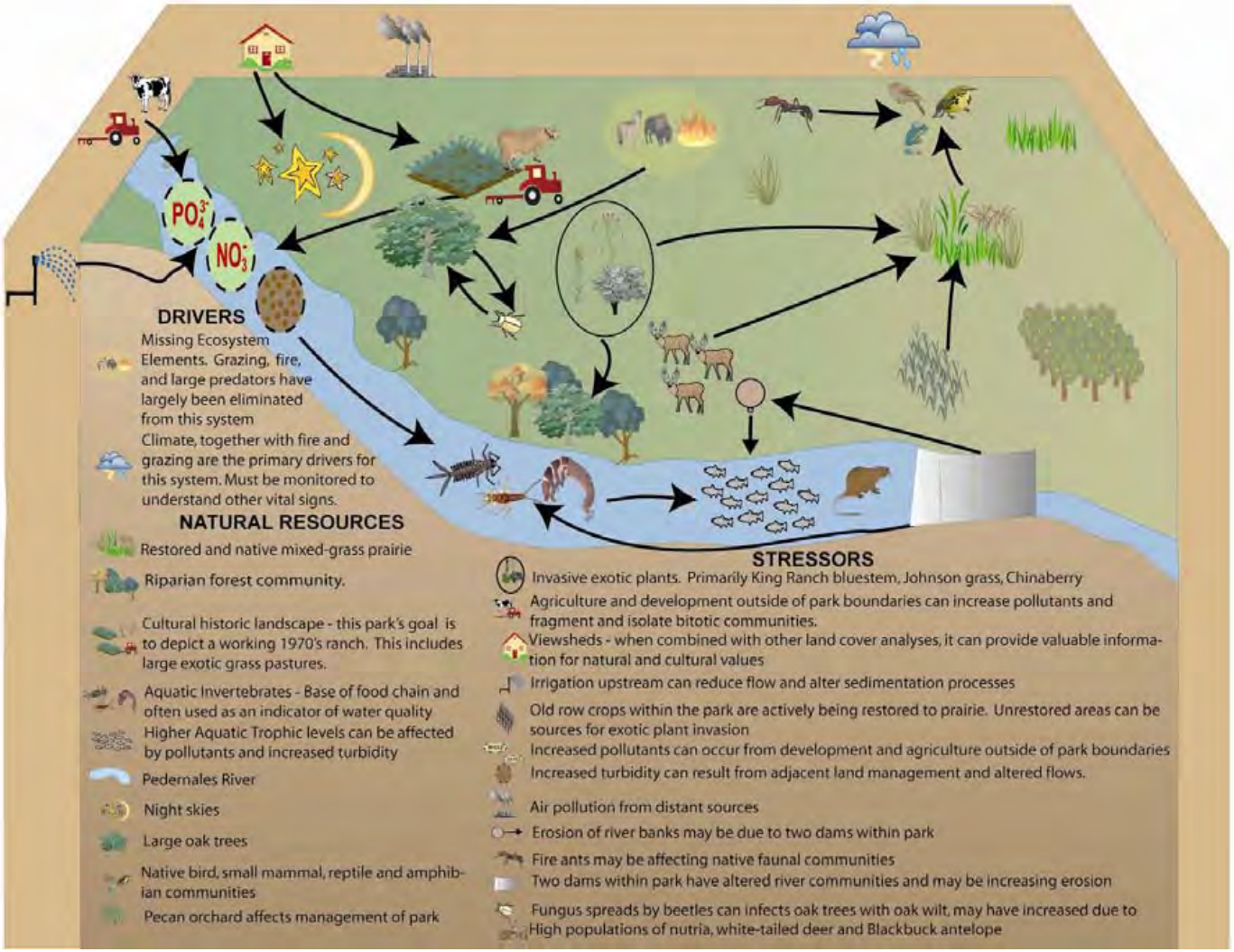
Visitors can impact ruins and natural resources

Insect and mammal borne diseases are a concern for biotic community and humans

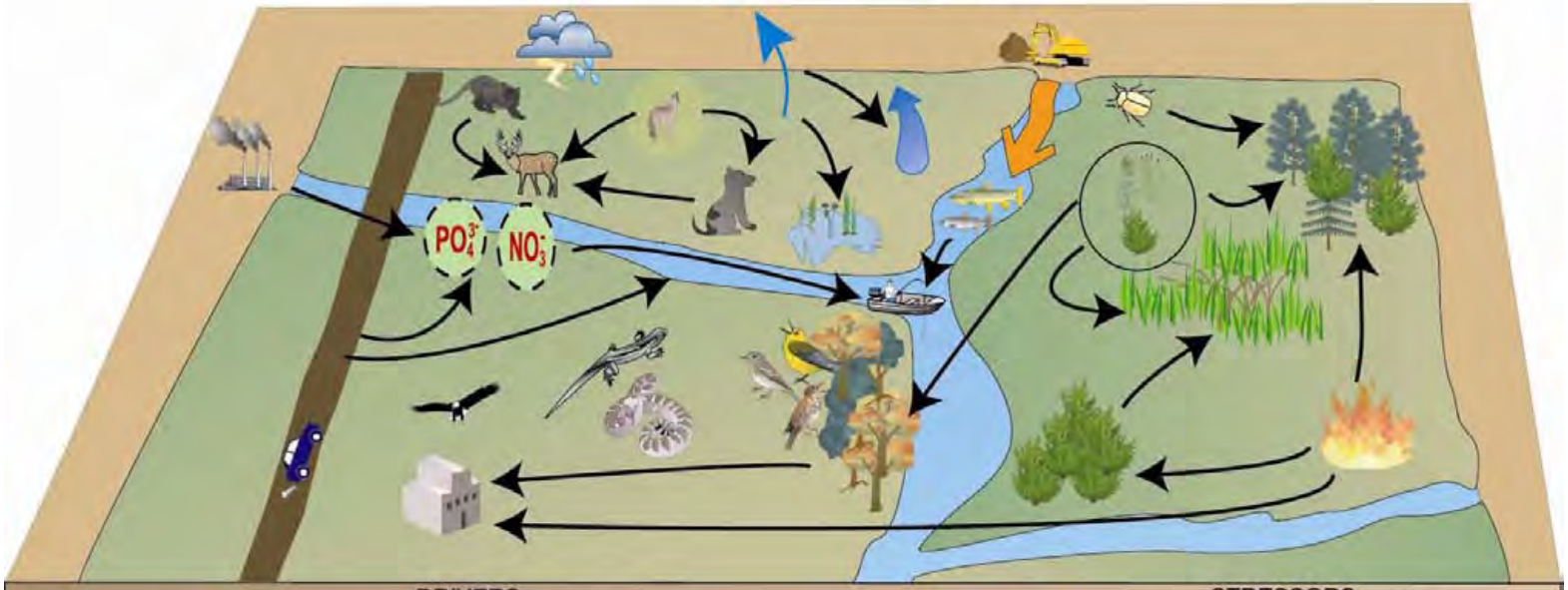
Air pollution from distant sources

Lake Meredith National
Recreation Area
DRIVERS
Missing Ecosystem Elements:
Grazing, and large predators
have largely been eliminated
Climate is a major driver for this system. Must be
monitored to understand other vital signs.
Prescribed fires are conducted. Essential for prairie
and to exclude woody species.
NATURAL RESOURCES
Native and restored shortgrass prairie
Lake Meredith, Canadian River and several tributaries
Cottonwood gallery forests. These may have increased since historic times due to
reduced flows and decreased scouring
Black-tailed prairie dog is a listed species. They also increases grassland diversity
through grazing and modifies habitat that are used by several other grassland species.
Texas horned lizard, declining state listed species
Aquatic Invertebrates - Base of food chain and often used as an indicator of water quality
Higher Aquatic Trophic levels can be affected by pollutants and increased turbidity
Arkansas River Shiner and bald eagle, federally listed species
NATURAL
RESOURCES
Night skies
High population of nesting Mississippi kites
Grassland birds are a potential indicators of
grasslands
Largemouth bass, walleye and game animals are
a primary reason for visitation
STRESSORS
Invasive exotic plants. Primarily tamarisk and tumbleweed
Mesquite is invading many grasslands due to lack of fire.
Off road vehicle use has a major impact on terrestrial and aquatic communities
Agriculture and development outside of park boundaries can increase pollut-
ants, affecting higher trophic levels, and fragment/isolate biotic communities
Viewsheds - when combined with other land cover analyses, it can provide valuable
information for natural and cultural values
Old roads and disturbed areas are actively being restored to prairie. Un-restored
areas can be sources for exotic plant invasion
Erosion occurs due to off-road vehicles and along steep slopes
There are several oil and gas projects within the park that have the potential for
disturbances
Air pollution from distant sources
Park visitors can be a stressor to natural resources, but can also be affected by
pollutants at the park
E. Coli levels can impact aquatic communities and park visitation.
Lack of boundary fence threatens resources

Lyndon B. Johnson National Historical Park



Pecos National Historical Park




**DRIVERS**

- Missing Ecosystem Element. Large predators have largely been eliminated from this system.
- Prescribed fires are conducted. Essential to maintain grasslands and natural processes of pinion-juniper forests
- Climate, together with fire are the primary drivers for this system. Must be monitoried to understand other vital signs.

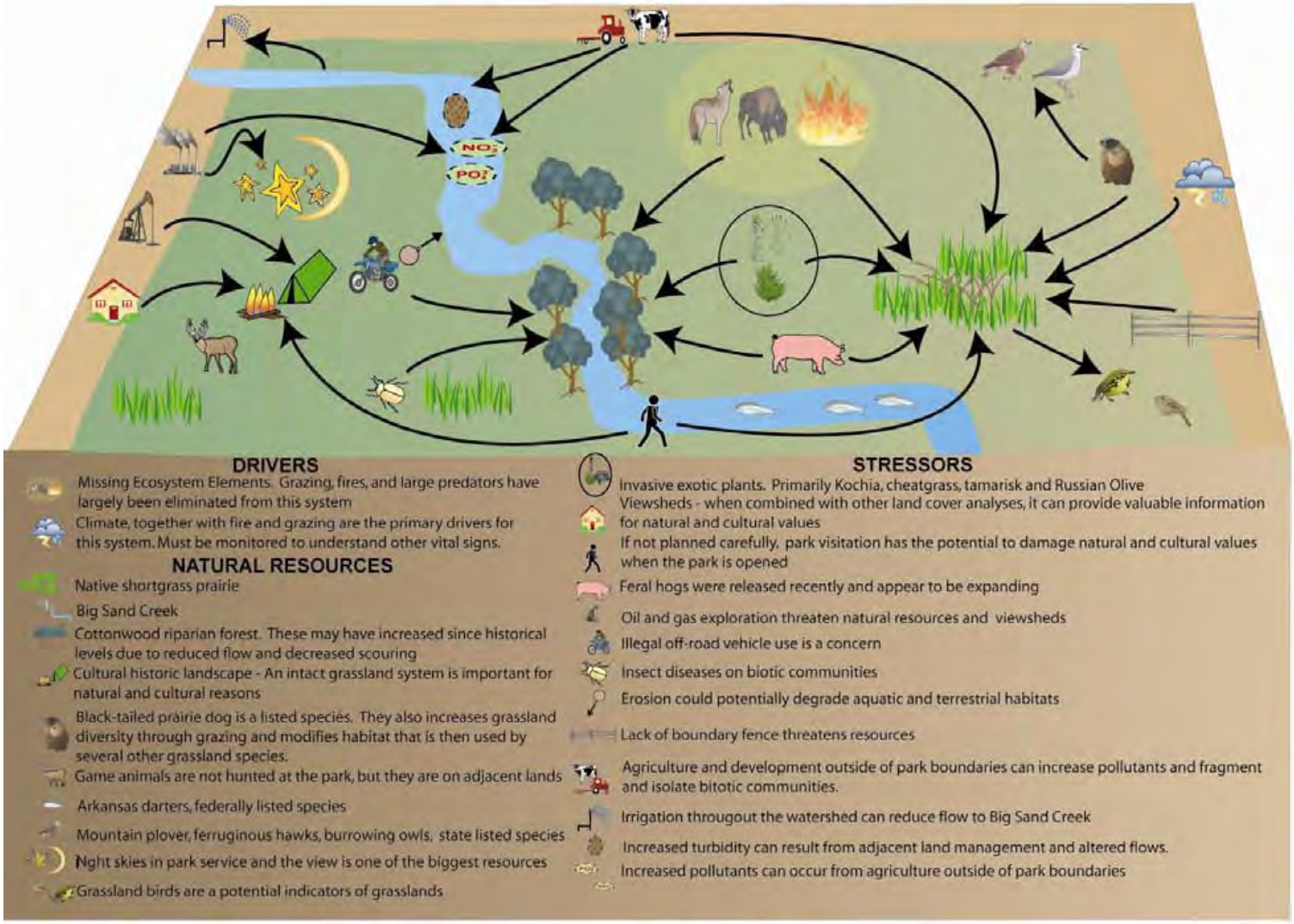
**NATURAL RESOURCES**

- Pinion pine-juniper forest with ponderosa pine and Douglas fir
- Pecos River, Glorietta Creek, Galisteo Creek and and other tributaries
- Riparian forest community
- Restored wetland along Glorietta Creek
- Native and cultural grasslands
- Upland springs are important for biological and cultural resources
- Cultural historic landscape - Grasslands and forests are important for natural and cultural reasons
- Mountain lions are a top predator and the big game community is an important resource
- When park is made more acessible to public, game fishery will likely be a big reason for visitation
- Reptile community is an important park natural resource
- Bald eagle, listed species
- Migratory songbird stopover area along the riparian area

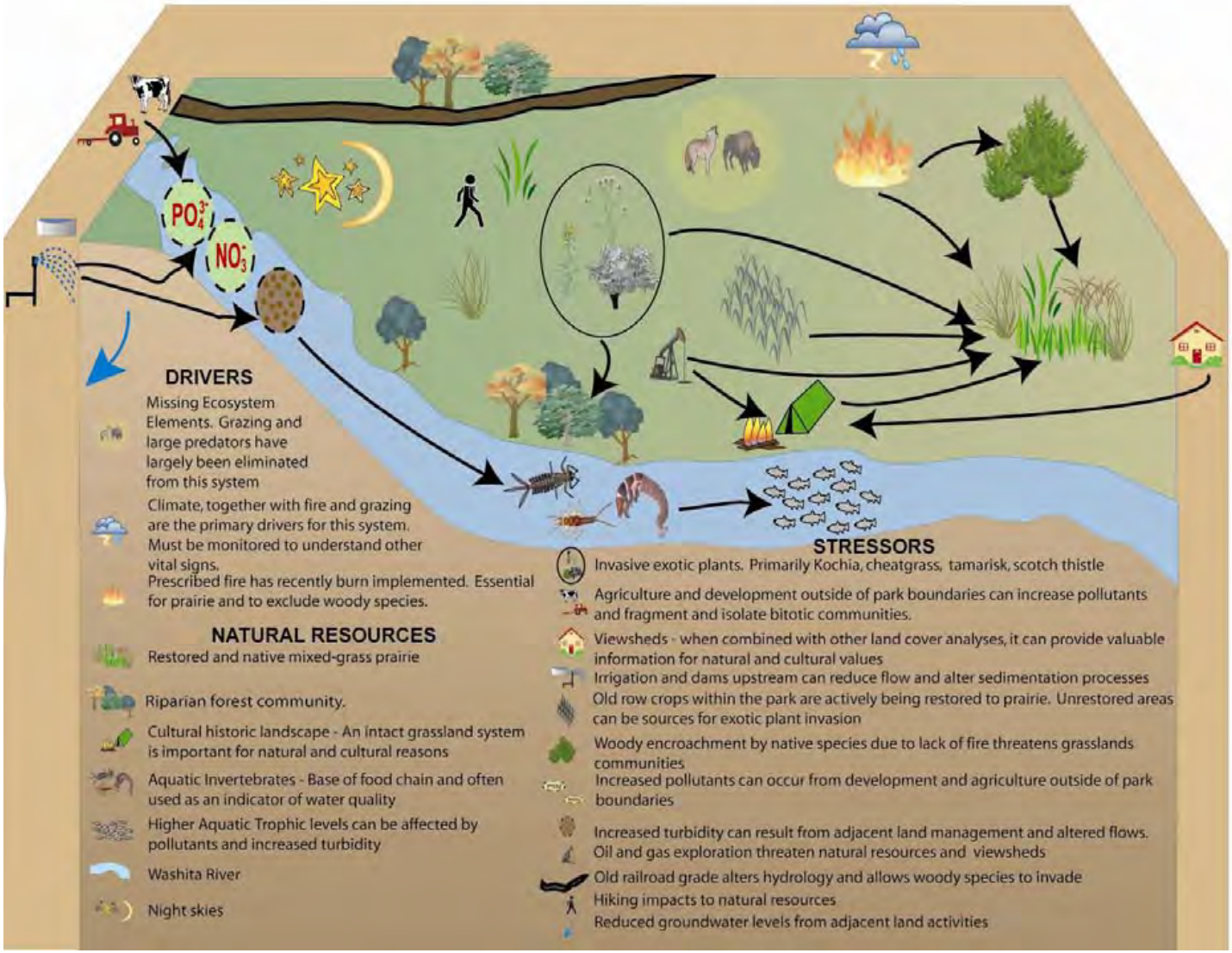
**STRESSORS**

- Invasive exotic plants. Primarily russian thistle, kochia, siberian elm, and tamarisk
- Route 63 bisects the park and Interstate 25 is the western edge of park, alters natural processes
- Gold and silver mining upstream contaminates river
- Heavy metals in fisheries, likely from upstream mining operations
- Woody encroachment by juniper due to lack of fire threatens grasslands communities
- Feral dogs threaten native communities
- Reduced groundwater levels from adjacent land activities
- Insect diseases on biotic communities
- Contaminated fishery and decreased water quality could diminish potential visitation
- Increased pollutants can occur from roads and development outside of park boundaries
- Air pollution from distant sources can impact cultural and biological resources

Sand Creek Massacre National Historic Site



Washita Battlefield National Historic Site



## APPENDIX S. GRASSLAND CONCEPTUAL MODELS

# Short-grass and Mixed-grass Ecosystems in the Southern Plains, U.S.A.: Conceptual Ecosystem Models

**Prepared by Daniel Tinker and Ann Hild**
**Departments of Botany and Renewable Resources**
**University of Wyoming**
**Laramie, Wyoming**

**for**

**The Great Plains Cooperative Ecosystem Studies Unit**
**And the National Park Service and**
**Southern Plains Inventory and Monitoring Program**

**September, 2005**

## OVERVIEW OF MODEL DEVELOPMENT AND MODEL TYPES

The National Park Service (NPS) Inventory and Monitoring (I & M) program plans to initiate long-term monitoring of natural resources within its parks. In the Southern Plains Network (SOPN), mixed- and short-grass prairies are the dominant ecosystem. However, due to the relatively small size of Southern Plains parks, many of the prairies within the parks are isolated fragments and no longer function as did historical grasslands. Land management within and outside the parks can have a major impact on the ecological processes and functions on these prairie fragments. Understanding how these prairie systems have functioned historically, as well as how they currently function, is critical for identification of ecological indicators, or ecological vital signs, that represent the condition of a variety of natural resources. Conceptual models that describe the structure and function of these prairie fragments will aid land managers in the identification and selection of appropriate vital signs for long-term monitoring.

Various forms of conceptual models, including Jenny-Chapin, conceptual diagrams, State-Transition models, and Driver-Stressor schematic models were developed for SOPN, and are described separately in the following sections. We first provide some general background information for short-grass and mixed-grass prairie communities.

### *Introduction to Grassland Communities*

Grasslands were historically the largest vegetation type in North America, covering more than 300 million ha (Küchler 1964), yet still occupy over 125 million ha in the United States (U.S. Forest Service 1980). However, due to widespread changes in land use and conversion to agricultural lands, short-grass and mixed-grass prairie grasslands are currently some of the most endangered ecosystems in North America (Rickletts et al. 1999). Short-grass prairies are dominated by two species of grass, blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloë dactyloides*), but other species such as needle and thread grass (*Stipa comata*), prairie june grass (*Koeleria macrantha*), and sand dropseed (*Sporobolus cryptandus*) are also important components. These ecosystems are found primarily east of the Rocky Mountains, from Nebraska and Wyoming southward through the High Plains (Sims and Risser 2000). Mixed-grass prairies, which extend from south-central Canadian provinces to central Texas, are more floristically rich, and are characterized by vegetation intermediate to tallgrass and short-grass prairies. Dominant species vary across a latitudinal gradient, and include species of *Elymus*, *Pseudoroegneria*, *Bouteloua*, along with various species of sedges (*Carex* sp.) (Barbour et al. 1987).

## CONCEPTUAL MODEL DEVELOPMENT AND DESCRIPTIONS

### *General Ecosystem Model – Jenny-Chapin Model*

Jenny (1941) developed a simple model containing five state variables, including global climate, topography, parent material, potential biota, and time that control the formation of soils, as well as control many ecosystem processes. Chapin et al. (1996) expanded the state variable approach to include four interactive controls (regional climate, disturbance regime, soil processes, and functional groups) that not only help to control ecosystem structure and function, but also respond to ecosystem characteristics. We have modified each of these models slightly to better represent the state variables and interactive controls of the grassland systems in the Southern Plains, resulting in a general grassland model that describes at a very basic level the important feedbacks and drivers of grassland ecosystems (Figure 1). While time, as included in Jenny's original model for explaining soil formation, is certainly important in grassland ecosystems, we have substituted Land Use Legacies as a much more direct and potentially important constraint on grasslands of the Southern Plains. Land use legacies pertain to the past history of the land, (grazing, fire, agriculture) which can dramatically affect future grassland conditions.

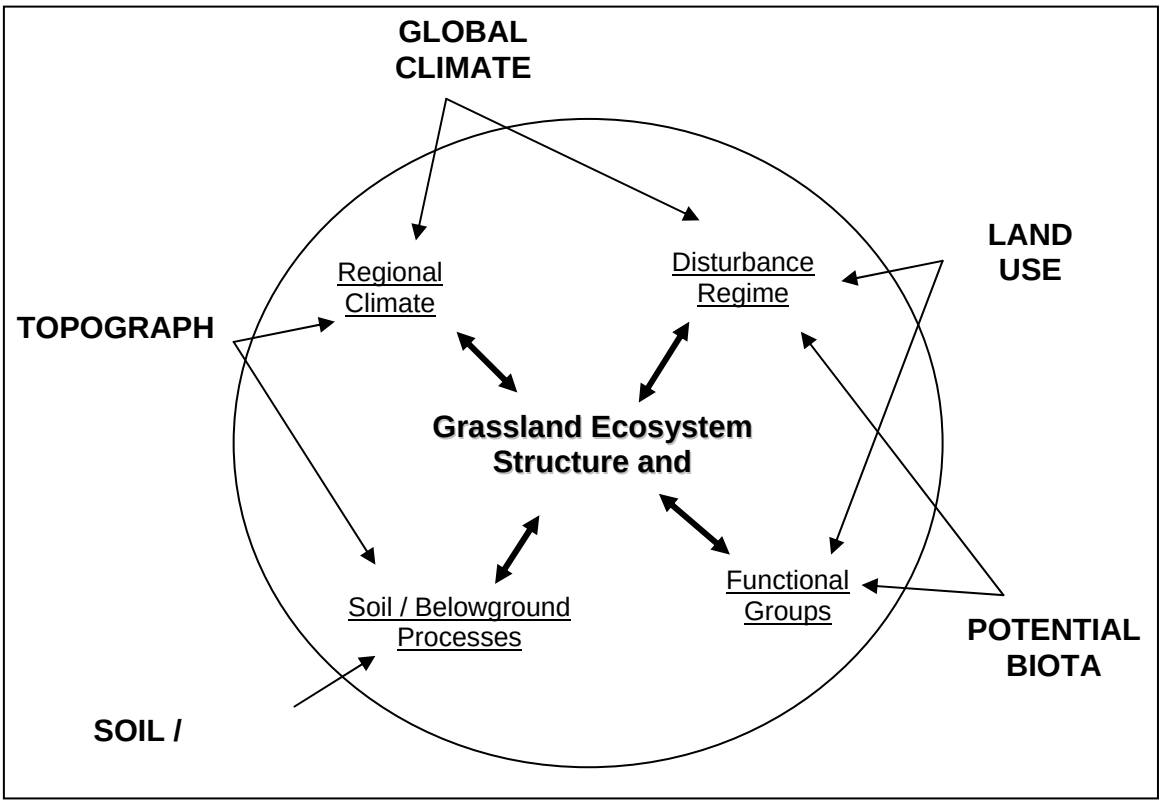



**Figure 1. Generalized Jenny-Chapin Grassland Ecosystem Model**

*Short-grass and Mixed-grass Prairie Pictorial Model Overview*

The various environmental variables, along with critical ecosystem drivers, stressors, and responses are depicted here in a non-hierarchical, general grassland pictorial model, included as Figure 2. This pictorial drawing also depicts many of the important interactions among various biotic and abiotic components of grassland ecosystems, and suggests ways that management and/or human activities may affect these interactions and outcomes.

The climate found in short-grass and mixed-grass ecosystems is quite variable across central North America. Notably, in the majority of these systems, approximately two-thirds of the annual rainfall in central grasslands occurs during the growing season. The usual rainfall deficiency that occurs late in the growing seasons provides conditions more favorable for the maintenance of grasslands than to deciduous forests (Sims and Risser 2000). In particular, grasslands of the Great Plains are strongly influenced by north-south and east-west climatic patterns, with precipitation decreasing from east to west, and air temperature increasing from north to south (Singh et al. 1983). Precipitation also acts as a strong driver of grassland ecosystem processes, and the relationship between rainfall and productivity is generally linear (Lauenroth 1979). The distribution of grasslands within the central U.S., as well as their vegetative composition, is further related to the interactions of a variety of other environmental and edaphic factors, including physiographic and topographic conditions, elevation, and herbivory (McNaughton et al. 1982). With respect to bedrock geology and soils, Mollisols are typically associated with cool, wet grasslands of the central plains, while more arid sites are most often characterized by Aridisols (Sims and Risser 2000). In the southern plains, soil texture varies from fine sandy soils to clay soils. There is a swath of relatively fertile Alfisols that stretches from southeastern Kansas into central Texas, following the general distribution of the cross timbers vegetation, as mapped by Küchler (1984), while Mollisols are most abundant throughout the rest of the southern plains (Sims and Risser 2000). Finally, land use change, primarily brought about by human uses and

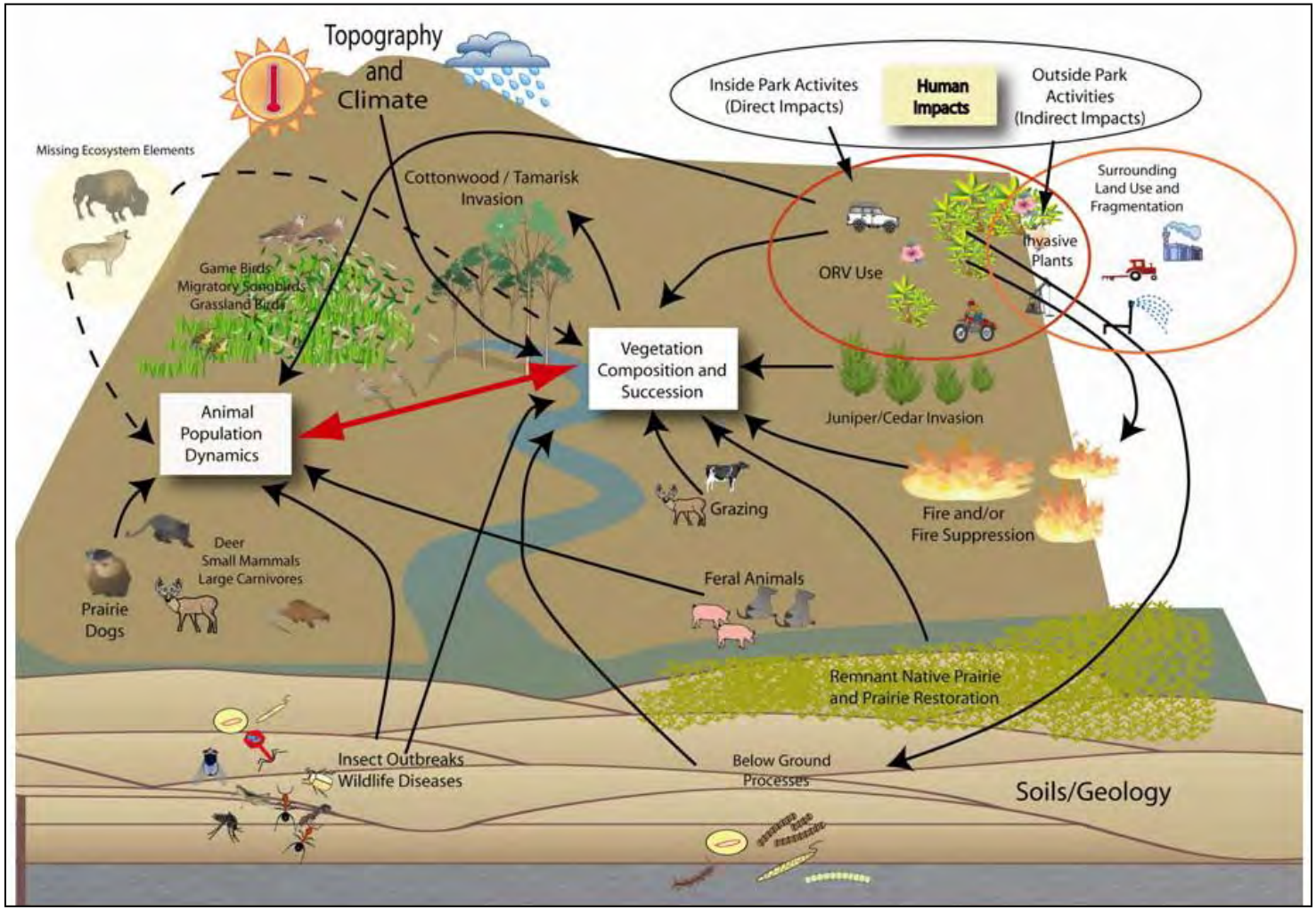



**Figure 2. Grassland pictorial model.**

impacts such as agriculture and urban development, may cause dramatic impacts on grassland ecosystems, including the loss of soil fertility and biological diversity, as well as hydrologic changes and increases in soil erosion (Paruelo et al. 2001).

Wet and dry cycles, along with periodic drought in short-grass systems, may be both harmful and beneficial, depending on the timing and intensity of the cycles. Dickinson and Dodd (1976) found that increases in water may affect the phenology of some grass species, e.g., blue grama, and flowering may occur earlier than in drier periods. Soil water, along with nitrogen, is thought to be the most important resources for determining community structure and plant growth in semiarid grasslands (Sala et al. 1992; Lauenroth et al. 1978). Notably, some grassland systems have developed adaptations to aridity, which may manifest themselves as morphological changes such as small stature and basal meristems (Coughenour 1985). These adaptations may also be advantageous for recovery from herbivore grazing. In general, grassland ecosystem responses to herbivory and defoliation are quite variable, and many systems have evolved grazing resistance to herbivory (e.g., Milchunas and Lauenroth 1993). However, grazing may be detrimental to many short-grass and mixed-grass ecosystems, depending on the intensity and duration of the grazing activity. Grazing impacts also vary along gradients of interaction with fire, and these interactions are more fully discussed later in the Grazing-Fire Submodel section of this narrative (Figure 3).

Erosion of surficial soils may occur as a result of intense, episodic rainfall events, or from road building, agricultural activities, and other human land uses. Stream bank erosion may also occur from land use practices such as grazing. For example, excessive grazing, which can cause increases in bare ground, may be positively correlated with increases in runoff following precipitation events (Hart et al. 1988; Hart and Frasier 2003). Similarly, flooding of rivers and streams can occur in arid areas where human activities have rerouted water courses and where soil texture prevents rapid infiltration.

Fire may also be a stressor, although most grassland systems have evolved with relatively frequent recurring fires (Sauer 1950; Curtis 1962; Axelrod 1985). Consequently, the suppression and removal of fire as an ecological process could actually act as a more direct stressor than fire itself, although fire may be detrimental in some short-grass prairie ecosystems (Wright and Bailey 1980). The impacts of fire on grassland systems and of the absence of fire, along with its interaction with grazing practices are more fully discussed in the Grazing-Fire Submodel section (Figure 3).

Invasive exotic plant species may colonize disturbed areas in and around NPS lands, and can be transported into parks via humans, vehicles, or other biotic vectors. These plants may outcompete some native vegetation, may persist for decades, and may even exert greater effects on community composition than other factors such as water availability (Clarke et al. 2005). Exotic animal species and feral domestic species can also compete with native species for limited resources. Along with invasive species, insect outbreaks and both natural and exotic wildlife diseases may infest native populations of plants and animals. While they may not be exotic, black-tailed prairie dogs (*Cynomys ludovicianus*) and their colonies play a significant role as a stressor in avian community structure and composition in some areas of short-grass plains (Smith and Lomolino 2004); however, their presence may be either beneficial or detrimental to other fauna and flora. This important dynamic is considered more fully later in this report in a prairie dog gradient model (Figure 5).

An interrelated set of critical factors in grassland systems of the Southern Plains are human impacts, along with adjacent land use and land use change. The many different ways that humans use the land is an important contributor to landscape pattern and process (Turner et al. 2001). For example, residential, commercial, and industrial development on adjacent lands are the direct result of human use (Meyer 1995), and may create hard boundaries around parks that can interrupt natural flows and fluxes of ecosystem processes and services, including recycling of nutrients and maintenance of clean air and water – this may be particularly problematic for some

of the smaller parks in the Southern Plains Network. Many of the historically intact landscapes are rapidly becoming fragmented, largely through human land uses (Harris 1984). Unfortunately, these human "footprints" on the landscape are usually one-directional and are long-lasting legacies on the landscape (Turner et al. 1988). Species-area relationships are important for identifying biodiversity hotspots (Myers et al. 2000), and for helping predict reductions in populations or species in areas subjected to habitat fragmentation (Pimm and Askins 1995). This increases the difficulty in managing small areas, as are common for some parks within SOPN. Closely related to human land uses is the issue of non-park source pollution, which may include a variety of unwanted materials such as fertilizers and airborne pollutants.

Based on the ecosystem components and relationships identified and described in this pictorial model, as well as specific concerns of many of the SOPN parks, we developed three additional submodels that were deemed critical for understanding ecosystem function within SOPN grasslands. The following submodels focus on three key areas of grassland structure and function: fire and grazing; soil carbon and nutrients; and prairie dogs.

## SUBMODEL DESCRIPTIONS

### *State-and-Transition Submodels*

In contrast to basic succession-retrogression models for grasslands and rangelands, resource managers recognize that most semiarid grasslands may be transformed into shrub- or tree-dominated woodlands that may not return to typical grassland communities using grazing management techniques (Laycock 1991). Rather, multi-equilibrial states may exist in space and time, driven by a variety of mechanisms that cause often rapid and unanticipated shifts among the various states (Westoby et al. 1989). Conceptual models that use the state-and-transition approach to non-equilibrium conditions in grassland ecosystems provide more desirable means by which to anticipate such changes and, through monitoring and assessment, mitigate or restore grassland community structure and function (Allen-Diaz and Bartolome 1998; Rodriguez et al. 1997). We have included three such models, or variations thereof, in this report and they are described below and in Figures 3-5.

### *Fire and Grazing State-Transition Submodel*

This submodel (Figure 3) describes the various grassland community types that may occur, along with the mechanisms that cause transitioning, such as the presence or absence of fire and grazing. In addition, the direct conversion of native grassland to agricultural lands such as croplands or hayfields, and the potential for restoration of the grassland community to a condition approaching that of the native composition is also considered. Grassland prairie communities in the central and western US have evolved over millennia with both fire and grazing (Collins 1992; Stebbins 1981). Both of these processes directly and strongly influence community composition, and much of the research on these two important variables has focused on the main effects of each independently. Yet, the interaction of fire and grazing may be more important in determining grassland community composition and condition than the sum of the individual processes. Indeed, fires often concentrate grazing in recently burned areas, where forage quality and quantity is higher (Fuhlendorf and Engle 2004).

The Fire-Grazing submodel (Figure 3) depicts three potential pathways for community composition changes that result from interactions of fire and grazing, as well as a fourth pathway that results in the conversion of any grassland community to agricultural lands.

The first pathway emphasizes intensive, heavy grazing regimes, along with the absence of fire, either through fire suppression, or the inability of managers to apply prescribed fire. These transitions will likely result in a reduction in native plant species, an increase in annuals and other invasives such as prickly pear cactus (*Opuntia sp.*), and a higher abundance of bare soil (e.g., Sims and Risser 2000; Belsky 1992; Albertson 1937). Intermediate vegetative states may be

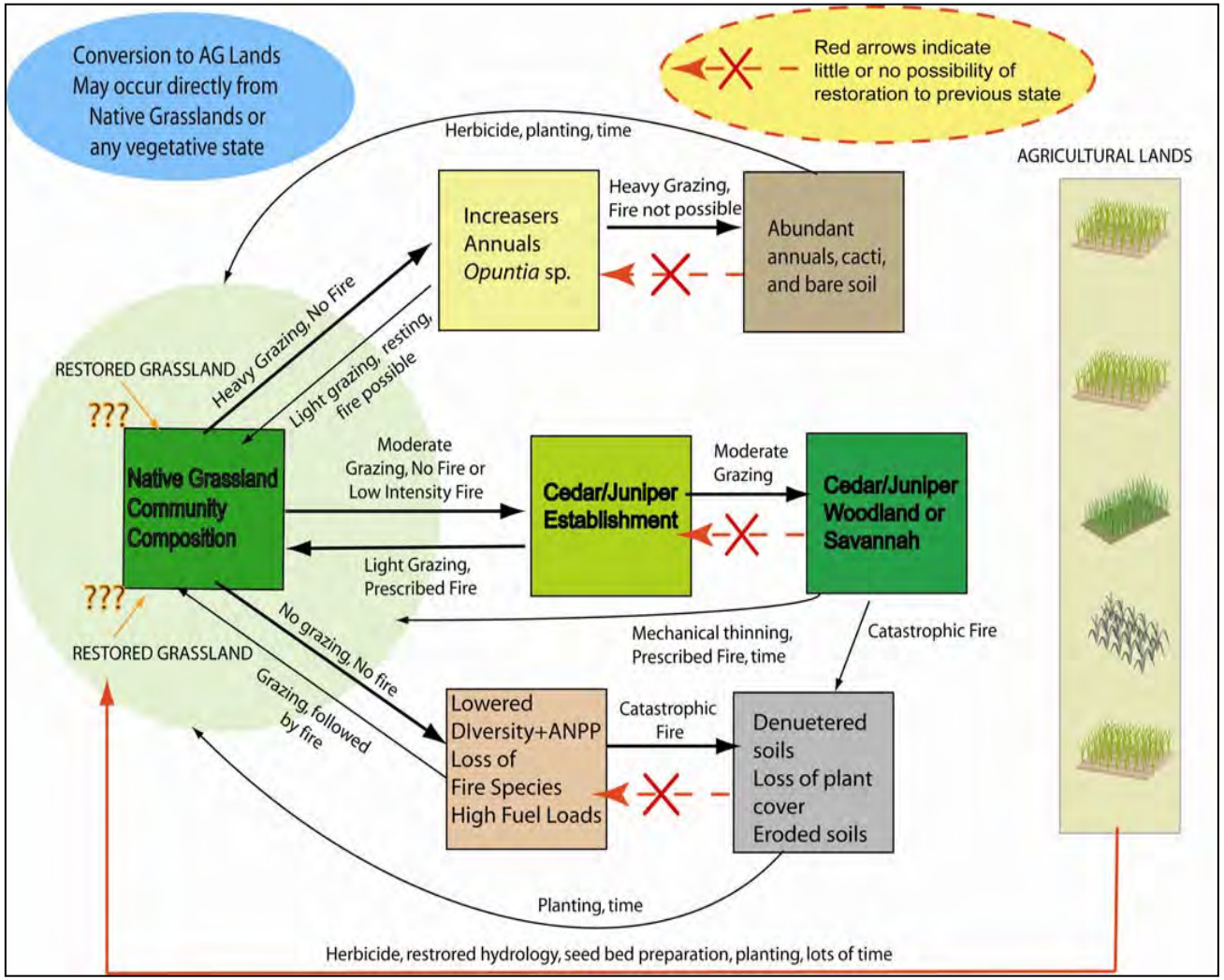



**Figure 3. Fire-grazing state and transition model.**

restored to native communities through a reduction in grazing and occasional fire use; however, highly degraded sites may require much more intensive restoration efforts, including herbicide application, reseeding, and considerable time.

A second transitional pathway that includes more moderate levels of grazing, with fire being absent or very infrequent and low intensity, will likely allow for the establishment of cedar or juniper (*Juniperus spp.*) shrubs and trees, with this establishment resulting in the conversion of grasslands to cedar/juniper woodland or savannahs, given sufficient time (Bragg and Hulbert 1976; Briggs et al. 2002; Hoch et al. 2002). As described above, restoration to an approximation of native grassland community would again require intensive management actions such as mechanical thinning, prescribed fire, and long time periods.

However, a third pathway exists that can result from the complete absence of both fire and grazing. Such a trajectory could initially lead to lower plant species diversity, including fire-adapted species, and would likely increase fine fuel loadings considerably (Belsky 1992; Collins 1987). Such conditions could result in higher frequency of catastrophic fire (e.g., Stinson and Wright 1969), which leads to short-term decreases in plant cover and concomitant increases in runoff and erosion (Hart et al. 1988).

Finally, as mentioned previously, conversion of grassland ecosystems, regardless of condition, to agricultural land is always possible, resulting in the immediate conversion of vegetative composition. It is believed that it would be extremely difficult to restore such land to native grassland, or perhaps even to an approximation of native grassland, and only then if intensive restoration efforts that include herbicide, reseeding, restoration of hydrology, and long periods of time are implemented.

*Soil Carbon and Nutrient Submodel*

This submodel (Figure 4) is a bit different from more traditional state-and-transition models in that, in addition to suggesting possible pathways for vegetative change, it also represents, in a very simplified manner, basic pools and processes associated with carbon and nutrients in a grassland ecosystem.

Soil carbon and nutrient dynamics for grasslands and other ecosystem types have been thoroughly described in literally hundreds of books and scientific journals (sensu Aber and Melillo 2001). Aboveground net primary productivity (ANPP) by grassland plants contributes to the processes of litterfall, decomposition, and mineralization, which, in turn, provide the release of nutrients for uptake by the microbial and plant communities. Because fire, grazing, and human land use most directly impact ANPP in grassland ecosystems, it is these transitions and resulting conditions that are discussed in this submodel. Indeed, the transitional pathways described here are quite similar to those discussed in the Fire-Grazing submodel, and focus on fire, grazing, their interactions, and the conversion of grassland to agricultural lands.

When fire is present, along with moderate grazing, accumulated fuels and litter are combusted and many important nutrients are released. Although some of these nutrients are lost during volatization, those that remain are often in forms more available to plants, which may result in higher ANPP (Aber and Melillo 2001). Some of the microbial community may be lost, especially in the upper organic layers of the soil, but soil heating in mineral soil, which could further reduce the abundance of microbes, is rare (Whelan 1995).

When both fire and grazing are removed from these systems, the effect is less dramatic than when both are present. For example, without periodic releases of available nutrients as provided by fires, ANPP may actually decrease slightly in the long-term, which also somewhat reduces inputs to litter and fine fuels. Consequently, there is minimal short- or long-term effect on the belowground community structure.

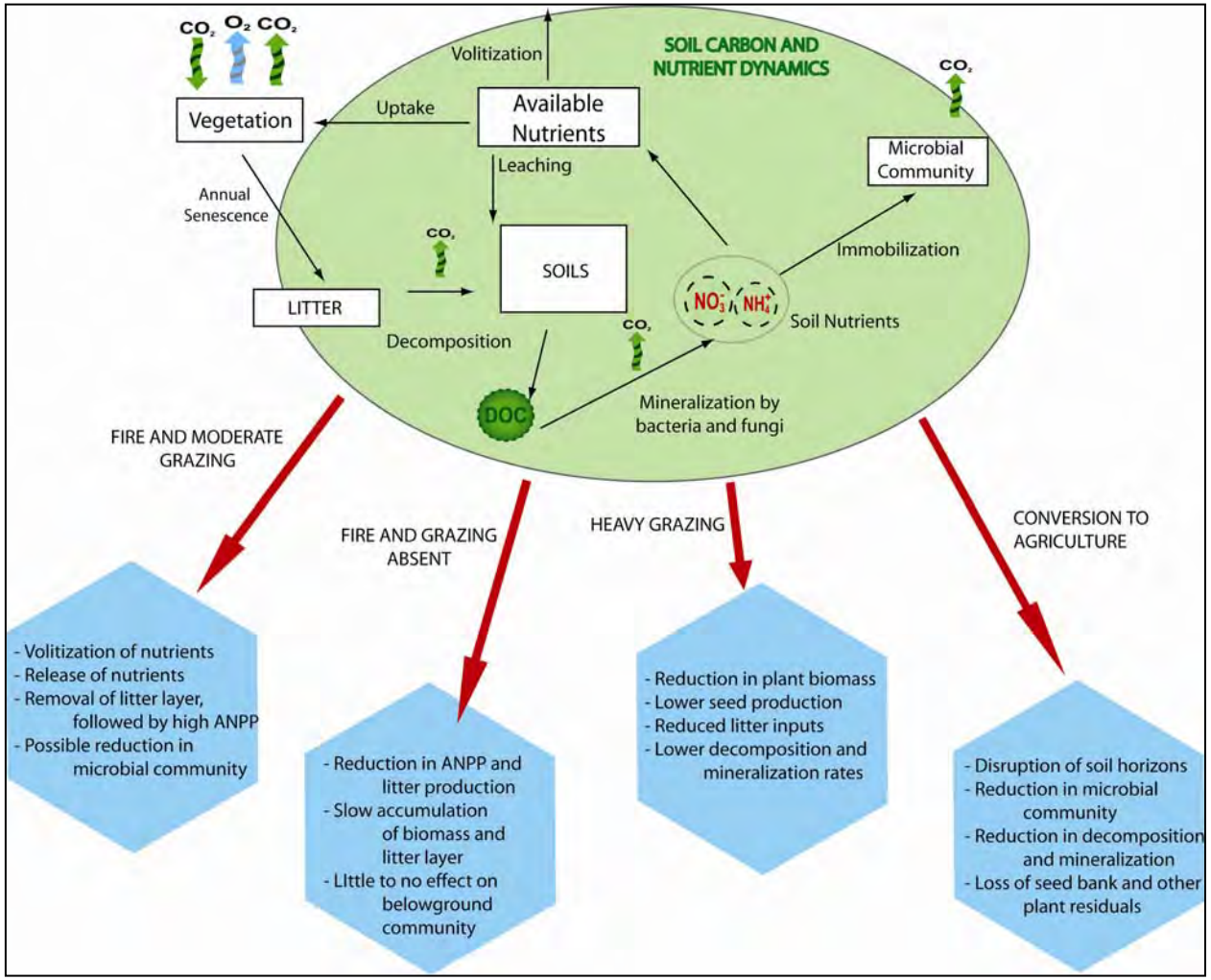



**Figure 4. Soil carbon and nutrient dynamic submodel.**

In contrast, under intensive grazing practices, the chronic reduction in plant biomass may result in dramatic decreases in plant litter inputs. This, in turn, will cause a reduction in decomposition and mineralization rates and, potential reductions in available nutrients. Notably, heavy grazing will also result in lower seed production and, therefore, lower dispersal and recruitment of new individual plants.

Conversion of grassland sod-forming plants to agriculture will disrupt belowground structure and function dramatically compared to the other three pathways described above. The disruption of surficial soil horizons increases evaporation and water loss, which can reduce decomposition and mineralization of soil organic matter. Perhaps most importantly, the loss of plant residuals and other forms of the seed bank may preclude restoration to native grassland community composition without very intensive and extended reclamation treatments.

*Prairie Dog Submodel*

The black-tailed prairie dog is usually considered to be a keystone species in grassland and prairie ecosystems (Kotilar et al. 1999). The influences and roles of prairie dogs in short-grass and mixed-grass systems will be examined in the following submodel (Figure 5) in the context of a gradient of prairie dog abundance, from absent to high, and under various stressors that may affect prairie dog populations, regardless of density.

Over the past century, prairie dogs have been subjected to widespread eradication efforts, yet still persist, albeit in much reduced numbers when compared to historical population densities (Clark 1989). In addition, other stressors to population numbers include the destruction of habitat, mostly through land use change, extended drought, epidemics of Sylvatic plague, and, indirectly, the removal of wolves (*Canis lupus*) from most grassland and prairie ecosystems, which results in an increase of a primary prairie dog predator, the coyote (Miller et al. 1994; Cully 1993). This increase in coyote abundance may negate any increases in swift fox and ferret abundance, as described below (Laliberte and Ripple 2004).

In the absence of prairie dogs and their burrows from grassland and prairie ecosystems, structural changes to the landscape occur, including a shift to a more static landscape pattern (Kotilar et al. 1999). Additionally, the vertical structure of vegetation is higher, resulting in an increase of fine fuels. This increase may eventually lead to a higher frequency of intense fires (Whelan 1995), which may create large patches of bare ground and increase the likelihood of exotic plant invasion. Many of these consequences are important management considerations in many, if not most, of the parks in the SOPN.

At high population densities, many benefits of prairie dogs and their burrows have been documented. One of the many roles they serve is that of prey for a variety of predators, including swift fox (*Vulpes velox*), coyote (*Canis latrans*), and black-footed ferrets (*Mustella nigripes*). Their presence also creates a decrease in vertical structure of vegetation. While perhaps not intuitive, this reduction in vertical structure may have important implications for many other species. For example, visibility for swift foxes is increased (Agnew et al. 1986), mountain plovers (*Charadrius montanus*) are more likely to nest in such landscapes (Knowles et al. 1982), and there is a greater likelihood that ferruginous hawks (*Buteo regalis*) and burrowing owls (*Athene cunicularia*) will occupy these lands (Cook et al. 2003; Desmond et al. 1995). Notably, the decrease in vertical structure may also increase habitat for relatively rare species such as the lesser prairie chicken (*Tympanuchus pallidicnctus*) (Barko et al. 1999).

Finally, at lower densities, populations may become isolated, resulting in genetic isolation, reduced gene flow, and reduced genetic diversity, all critical factors in maintenance of persistent and adaptable populations of organisms (Dobzhansky 1970).

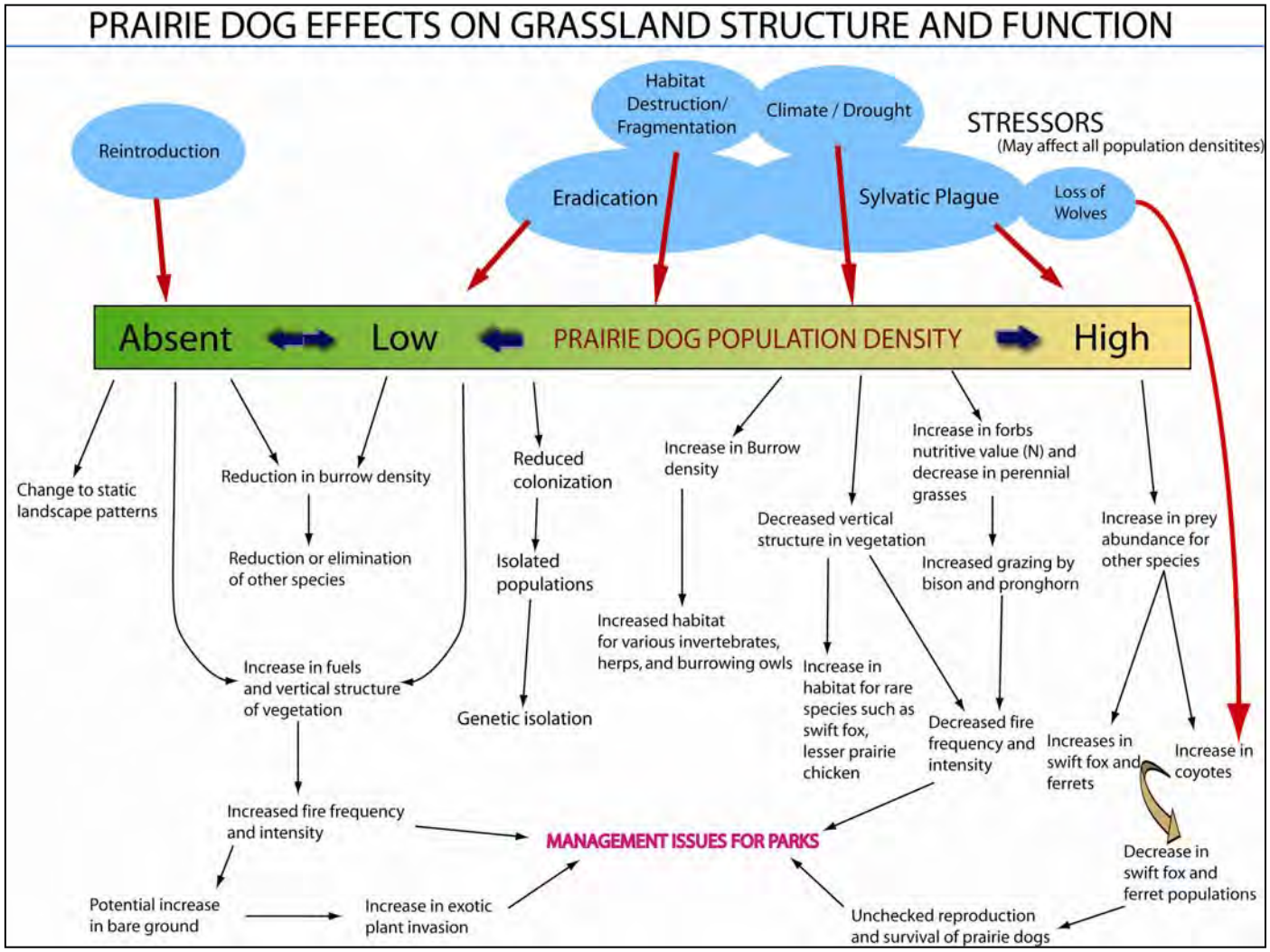



**Figure 5. Prairie dog effects submodel.**

*Driver-Stressor Schematic Models for Short-grass and Mixed-grass Prairie*

Driver-stressor models are often useful for identifying linkages among various state variables and ecosystem properties and responses (e.g., Gentile et al. 2001), but are also useful for identifying important ecosystem indicators, or "vital signs" along with appropriate means of measurement of the indicators. Most of the forcing factors depicted in the following two schematic models have been discussed above in the section describing the grassland pictorial model, but the following figures may serve as summaries of the various components and linkages, as well as serve to identify critical ecological indicators. Although separate models were developed for short-grass and mixed-grass prairie, differences between the two systems and, therefore, between the two models are minimal. For Figures 6 and 7, the hierarchy of organization for the models includes: drivers (boxes), which are major external factors or forcings that have large-scale influences; stressors (ovals) that represent physical, chemical, or biological agents that cause significant changes in ecological components, patterns, or relationships in natural systems; ecological outcomes or processes (diamonds), defined as physical, chemical, or biological responses to drivers or stressors, and which may be either positive or negative (these processes are more fully described in the submodels section); indicators (hexagons) that represent living or nonliving, information-rich features of an ecosystem that can be measured or estimated, and that are somehow indicative of the quality or integrity of the larger ecological system; and measurements (parallelograms) of the above described indicators.

## INDICATORS

The following section will focus only on the Indicators depicted in the schematic models. Suggested measurements for each indicator are included in Figures 6 and 7, but are not specifically discussed in this report.

**Bird and other wildlife populations** are directly and indirectly affected by many of the stressors contained in the pictorial submodel (Figure 2), including direct and indirect human impacts such as land use change, and the invasion of exotic and feral species. Inventories of big game, ungulates and other small mammals may serve as important indicators of ecosystem function. The interactions of temperature, precipitation, and soil type, along with annual and decadal wet and dry cycles can determine the structure and activity of **wetland areas and upland springs**.

Regeneration of **Cottonwood (*Populus deltoides*) riparian woods** relies heavily on episodic flooding events. Regulation of water flows, through impoundments and irrigation, may reduce the likelihood of such events and, consequently inhibit natural regeneration of new individuals along these important corridors. Tamarisk (*Tamarix spp.*) and other non-native plants may encroach on cottonwood habitat in the absence of cottonwood regeneration, altering the community composition in such areas. In mixed-grass ecosystems in particular, small patches of **deciduous hardwood forests** are quite sensitive to many stressors such as human impacts, grazing, fire, and invasive plant species.

**Grassland community composition** is perhaps the best indicator of the condition of these ecosystems. Changes in the natural fire regimes, along with varying intensities of domestic livestock grazing, can shift community composition to a range of conditions that may or may not resemble native grasslands (Figure 3). Also, dramatic alterations in community structure and composition, such as those that occur with the conversion of native grasslands to agricultural areas, require substantial restoration efforts to recreate grassland communities that even remotely resemble original, native ecosystems. Such restoration is rarely, if ever successful in completely restoring converted agricultural land to native grassland communities. Resource islands in these temperate grasslands, which develop from spatially heterogeneous plant cover, can be areas of accumulated soil materials. These islands may take decades to create, but can disappear within three years of the death of an individual plant, and may be good indicators of ecosystem condition (Burke et al. 1998). Further, the **habitat quality** of the grassland ecosystems responds to a variety of drivers and stressors, most notably human impacts, grazing,

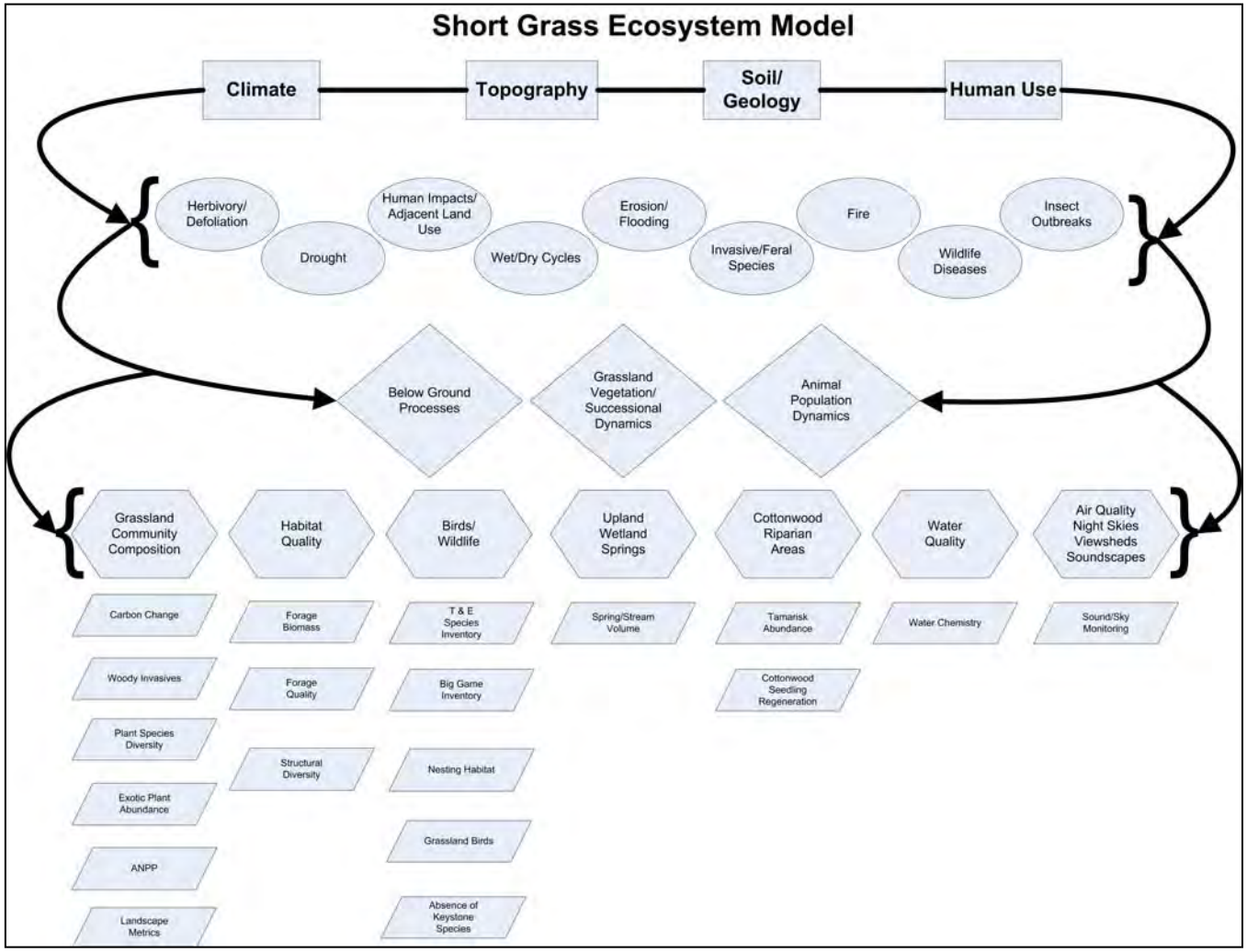



**Figure 6. Short-grass ecosystem driver-stressor schematic model.**

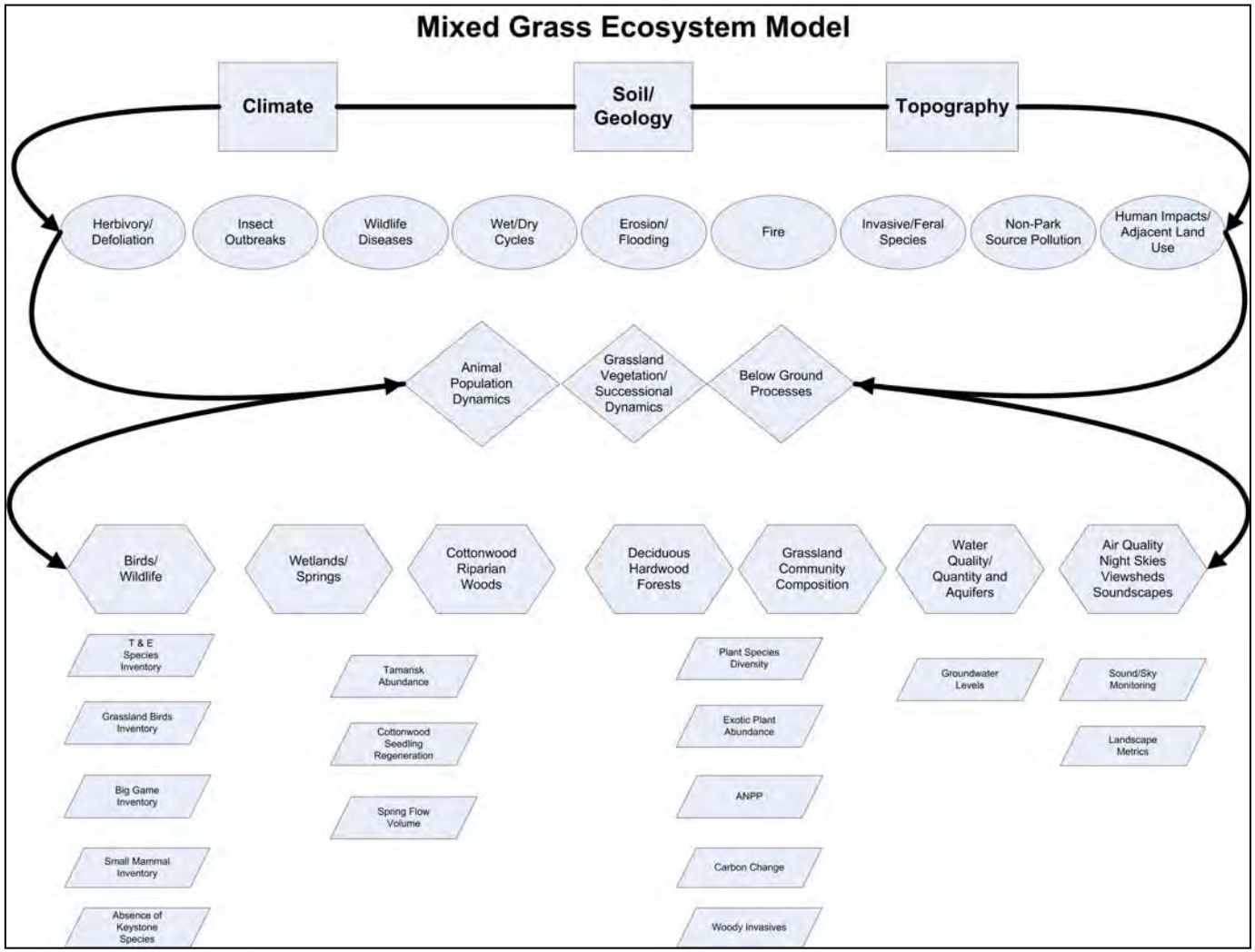



**Figure 7. Mixed-grass ecosystem driver-stressor schematic model.**

and periodic drought. Also, fire, or the absence of fire, can either adversely affect or benefit habitat conditions for many ungulates, small mammals, and birds (Figures 2 and 3). As discussed in an earlier section of this report (See Prairie Dog Submodel; Figure 5), prairie dogs exert a disproportionate influence on habitat quality and quantity for a variety of organisms, including burrowing owls, swift fox, and lesser prairie chicken. Further, changes in land use and, therefore, community composition, can alter many soil processes such as decomposition and mineralization, which may result in reduced productivity and lower habitat quality for herbivores and obligate carnivores.

Water quality and quantity respond to a myriad of drivers and stressors. **Water quantity** is directly affected by annual precipitation and periodic drought, along with water allocation by human uses. **Water quality** may be impacted by specific non-park source pollution, and also by non-point source pollution such as atmospheric deposition. More detail on aquatic systems is included in a separate report prepared elsewhere for the SOPN grasslands. **Night skies and soundscapes**, arguably some of the most desired resources in national parks and recreation areas, are primarily affected by human impacts and adjacent land uses, including construction of roads and buildings. Other impacts to soundscapes can include fire suppression efforts and direct impacts of intense fires, such as smoke and haze. However, night skies may also be impacted by other natural causes such as dust, which may be caused by extended periods of drought.

REFERENCES


Aber, J.D., and J.M. Melillo. 2001. Terrestrial Ecosystems. Harcourt Academic Press. San Diego, CA. Second Edition.

Agnew, W. D., W. Ursek, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. J. Range Management 39:135-139.

Albertson, F.W. 1937. Ecology of mixed prairie in west central Kansas. Ecological Monographs 7: 481-547.

Allen-Diaz, B., and J.W. Bartolome. 1998. Sagebrush-grass vegetation dynamics: comparing classical and state-transition models. Ecological Applications 8: 795-804.

Axelrod, D.I. 1985. Rise of the grassland biome, central North America. Bio. Rev. 51: 163-201.

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial Plant Ecology. Second Edition. Benjamin/Cummings Publishing, Menlo Park, CA.

Barko, V.A., J.H. Shaw, and D.M Leslie, Jr. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwest Naturalist 44: 484-489.

Belsky, A.J. 1992. Effects of grazing, competition, disturbance and fire on species composition and diversity in grassland communities. J. Vegetation Science 3: 187-200.

Bragg, T.B., and L.C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Management 29: 19-24.

Briggs, J.M., A.K. Knapp, and B.L. Brock. 2002. Expansion of woody plants in tallgrass prairie: a 15 year study of fire and fire-grazing interactions. Am. Midland Naturalist 147: 287-294.

Burke, I.C., W.K. Lauenroth, M.A. Vinton, P.B. Hook, R.H. Kelly, H.E. Epstein, M.R. Aguiar, M.D. Robles, M.O. Aguilera, K.L. Murphy, and R.A. Gill. 1998. Plant-soil interactions in temperate grasslands. Biogeochemistry 42: 121-143.

Chapin, F.S., III, M.S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. American Midland Naturalist. 148: 1016-1037.

Clark, T.W. 1989. Conservation biology of the black-footed ferret. Wildlife Preservation Trust International, Special Scientific Report No. 3.

Clarke, P.J., P.K. Latz, and D.E. Albrecht. 2005. Long-term changes in semi-arid vegetation: invasion of an exotic perennial grass has larger effects than rainfall variability. J. Vegetation Science 16: 237-248.

Collins, S.L. 1992. Fire frequency and community heterogeneity in tallgrass prairie: a field experiment. Ecology 73: 2001-2006.

Collins, S.L. 1987. Interactions of disturbances in tallgrass prairie: a field experiment. Ecology 68: 1243-1250.

Cook, R. R., J. E. Cartron, and P. J. Plocheta, Jr. 2003. The importance of prairie dogs to nesting ferruginous hawks in grassland ecosystems. Wildlife Society Bulletin 31:1073-1082.

Coughenour, M.B. 1985. Graminoid responses to grazing by large herbivores: adaptations, exaptations and interacting processes. Annals of the Missouri Botanical Garden 72: 852-863.

Cully, J.F. 1993. Plague, prairie dogs and black-footed ferrets. Pages 38-48 in J.L. Oldemeyer, D.E. Biggins, B.J. Miller, and R. Crete, eds.: Management of prairie dog complexes for the reintroduction of the black-footed ferret. Biological report 13. US Department of the Interior, US Fish and Wildlife Service.

Curtis, J.T. 1962. the modification of mid-latitude grasslands and forests by man, pp. 721-736 in W.L. Thomas, Jr., ed., Man's role in changing the face of the earth. University of Chicago Press, Chicago.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. Can. J. of Zoology 73:1375-1379.

Dickinson, C.E., and J.L. Dodd. 1976. Phenological pattern in the shortgrass prairie. American Midland Naturalist 96: 367-378.

Dobzhansky, T. 1970. Genetics of the evolutionary process. Columbia University Press. New York, NY.

Fuhlendorf, S.D., and D.M. Engle. 2004. Application of the fire-grazing interaction to restore a shirting mosaic on tallgrass prairie. Journal of Applied Ecology 41: 604-614.

Gentile, J.H., M.A. Harwell, W. Cropper, Jr., C.C. Harwell, D. DeAngelis, S. Davis, J.C. Ogden, and D. Lirman. 2001. Ecological conceptual models: a framework and case study on ecosystem management for South Florida sustainability. The Science of the Total Environment 274: 231-253.
Harris, L.D. 1984. The Fragmented Forest. University of Chicago Press, Chicago, Illinois, USA.
Hart, R.H., M.J. Samuel, P.S. Tewst, and M.A. Smith. 1988. Cattle, vegetation and economic responses to grazing systems and grazing pressure. J. Range Management 41: 282-286.
Hart, R.H., and G.W. Frasier. 2003. Bare ground and litter as estimators of runoff on short- and mixed-grass prairie. Arid Land Research and Management. 17: 485-490.
Hoch, J.A., J.M. Briggs, and L.C. Johnson. 2002. Assessing the rate, mechanisms, and consequences of the conversion of tallgrass prairie to *Juniperus virginiana* forest. Ecosystems 5: 578-586.
Jenny, H. 1941. Factors of soil formation. McGraw-Hill. New York.
Knowles, C.J., C.J. Stoner, and S.P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.
Kotilar, N.B., B.W. Baker, A.D. Whicker, and G. Plumb. 1999. A critical review of assumptions about the prairie dog as a keystone species. Environmental Management 24: 177-192.
Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society special publication 36, New York.
Laliberte, A. S., and W. J. Ripple. 2004. Range contractions of North American carnivores and ungulates. BioScience 54(2): 123-138.
Lauenroth, W.K. 1979. Grassland primary production: North American grasslands in perspective, pp. 3-24 in N.R. French, ed., Perspectives in grassland ecology. Springer-Verlag, New York.
Lauenroth, W.K., J.L. Dodd, and P.L. Sims. 1978. The effects of water- and nitrogen-induced stresses on plant community structure in a semiarid grassland. Oecologia 36: 211-222.
Laycock, W.A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. J. Range Management 44: 427-733.
McNaughton, S.J., M.B. Coughenhour, and L.L. Wallace. 1982. Interactive processes in grassland ecosystems, pp. 167-193 n J.R. Estes, R.J. Tyrl, and J.N. Brunken (eds.), Grasses and grasslands, systematics and ecology. University of Oklahoma Press, Norman, OK.
Meyer, W.B. 1995. Past and present land use and land cover in the USA. Consequences, Spring 1995: 25-33.
Milchunas, D.G., and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63: 327-366.
Miller, B., G. Ceballos, and R. Reading. 1994. The prairie dog and biotic diversity. Conservation Biology 8: 677-681.
Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.
Paruelo, J.M., I.C. Burke, and W.K. Lauenroth. 2001. Land-use impact on ecosystem functioning in eastern Colorado, USA. Global Change Biology 7: 631-639.
Pimm, S.L., and R.A. Askins. 1995. Forest losses predict bird extinctions in eastern North America. Proceedings of the National Academy of Sciences (USA) 92: 9343-9347.
Ricketts, T.H., E. Dinerstein, D.M. Olsen, C.J. Loucks, W. Eichbaum, D. DellaSala, K. Kavanagh, P. Hedao, P.T. Hurley, K.M. Carney, R. Abel, and S. Waiters. 1999. Terrestrial ecoregions of North America. Island Press, Washington, D.C.
Rodriguez Iglesias, R.M., and M.M. Kothman. 1997. Structure and causes of vegetation change in state and transition model applications. J. Range Management 50: 399-408.
Sala, O.E., W.K. Lauenroth, and W.J. Parton. 1992. Long-term soil water dynamics in the shortgrass steppe. Ecology 73: 1175-1181.
Sauer, C.O. 1950. Grassland, climax, fire, and man. J. Range Mgt. 3: 16-22.
Sims, P.L., and P.G. Risser. 2000. Grasslands. *In*: Barbour, M.G., and W.D. Billings, eds., North American Terrestrial Vegetation, Second Edition. Cambridge University Press, New York, pp. 323-356.
Singh, J.S., W.K. Lauenroth, R.K. Heitschmidt, and J.L. Dodd. 1983. Structural and functional attributes of the vegetation of the mixed prairie of North America. Bot. Rev. 489: 117-149.

Smith, G.A., and M.V. Lomolino. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass plains. Oecologia 138: 592-602.
Stebbins, G.L. 1981. Coevolution of grasses and large herbivores. Annals of the Missouri Botanical Garden 68: 75-86.
Stinson, K.J. and H.A. Wright. 1969. Temperature and headfires in the southern mixed prairie of Texas. J. Rangeland Management 22: 169-174.
Turner, M.G., S.R. Carpenter, E.J. Gustafson, R.J. Naiman, and S.M. Pearson. 1988. Land use. *In*: M.J. Mac, P.A. Opler, P. Doran, and C. Haecker, eds. Status and Trends of Our Nation's biological Resources, volume 1, pp. 37-61. National Biological Service, Washington, DC, USA.
Turner, M.G., R.H. Gardner, and R.V. O'Neill. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer-Verlag, New York.
U.S. Forest Service. 1980. An assessment of the forest and range land situation in the United States. USDA publication FS-345. Forest Service, Washington, D.C.
Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. J. Range Management 42: 266-274.
Whelan, R.J. 1995. The Ecology of Fire. Cambridge University Press. Cambridge, UK.
Wright, H.A., and A.W. Bailey. 1980. Fire ecology and prescribed burning in the Great Plains – a research review. USDA Forest Service general technical report INT-77. Intermountain Forest and Range Experiment Station, Ogden, Utah.

# APPENDIX T. LANDSCAPE LEVEL ISSUES FACING THE SOPN - CONCEPTUAL MODELS

**Todd M. Swannack and Dustin W. Perkins**

## INTRODUCTION

In order to achieve a sustainable ecosystem within the parks of the Southern Plains Network (SOPN), management strategies will require not only an understanding of the natural resources available within each park, but also knowledge of the ecological and human-mediated processes occurring within the landscapes surrounding the parks. Neighboring land-use practices such as cattle grazing, row cropping, and development can severely alter the connection between the ecosystem inside and outside of the park (Turner et al. 2001). Managers must be aware of the possible ecological influences the surrounding landscape can have on the natural processes occurring in the park in order to make the management decisions that will perpetuate the ecological integrity (or desired condition, in the case of a cultural / historical site) of the park. A suite of conceptual models was created in order to address the landscape-level issues facing the parks of the SOPN. These models will be used to develop a set of vital signs that can be used to monitor land use changes occurring outside of the park and the influence of those changes on the park.

## JENNY–CHAPIN MODELS (FIGURE 1)

Historically, the spatial configuration and species composition of a landscape (the *landscape pattern*) was created by the interaction of ecosystem processes (energy flow, trophic dynamics, etc…) acting upon a landscape over a long period of time (Turner et al. 2001). At global scale, these ecosystem processes are controlled by the interaction of five driving variables (termed *state factors*): climate, topography, parent material (geology), the potential biota, and time (Jenny 1941) (Figure 1A). Chapin et al. (1996) further modified the Jenny (1941) model to include four *interactive controls*: regional climate, soil resources, the major functional groups of organisms, and disturbance regime (Figure 1B). Interactive controls occur at a much more localized spatial and more recent temporal scale (e.g., the state factor climate refers to changes in global climates between a glacial and interglacial period (10,000 years), whereas regional climate could be the climate for a specific area (last 30 years), or a change in temperature or precipitation in a pasture before and after grazing (1 day). Interactive controls not only regulate ecosystem processes, but respond to these processes as well. This dynamic relationship between interactive controls and the landscape is what must be maintained in order to have a sustainable ecosystem (Chapin et al. 1996). Specific systems will react more strongly to some interactive controls (Chapin et al. 1996), for example, a grassland ecosystem / landscape is highly dependent on a frequent disturbance regime consisting of fire, migratory grazing, and drought (Krebs 2001).

Developing conceptual models for monitoring any ecological process requires precise definitions for spatial and temporal scales (Levin 1992). Different processes occur at very different spatial and temporal scales, for example a single fire event may occur in a 328 foot (100 m) area over a 2 day period, but the fire regime for the ecotype may occur in the same area over several hundred years (Delcourt et al. 1983). The spatial scale for these models included the lands surrounding the park and any processes, ecological or anthropogenic, which can affect those lands. The temporal scale of these models includes the next 50 – 100 years, as that time-frame is the most realistic for the monitoring goals of the SOPN.

## CURRENT PROCESSES AFFECTING THE LANDSCAPE PATTERN (FIGURE 2)

Over the past 150 years, the ecological processes of the Southern Plains were disrupted by increased anthropogenic activity, which led to replacing the migratory bison (*Bison bison*) with non-migratory cattle, and large-scale fire suppression. As a result, the current landscape pattern of the SOPN is not only influenced by natural processes, but also heavily affected by human-

mediated processes, and as the landscape pattern changes, it also influences both the natural and human processes.

## HUMAN PROCESSES SUBMODEL (FIGURE 3)

Land cover patterns in the United States are mainly altered by direct human use (Meyer 1995). Four factors appear to be the major ecological stressors facing the SOPN (based on discussions with park managers, regional experts, surrounding land use and satellite imagery):

1) Residential development, which introduces housing developments, infrastructure (roads, sewers, power line easements, etc…)
2) Industrial / commercial developments, which introduces industrial and / or commercial buildings (along with the associated infrastructure)
3) Agricultural developments (e.g., cattle grazing, row cropping, and feedlots)
4) Management techniques of neighboring lands

These four stressors can affect the landscape pattern by altering the ecological process operating within the park, either by disrupting the natural disturbance regime or by modifying the habitat. These two variables are further explained in figures 5 and 8 below.

## NATURAL DISTURBANCE REGIME (FIGURE 4)

Disturbance is an important part of many ecosystems and landscapes – disturbances create spatial heterogeneity and help maintain community structure (Turner et al. 2001). A disturbance is simply a discreet event, occurring over a short period of time, that disrupts the ecosystem and changes resource availability or the physical environment (White 1979). A disturbance regime refers to the spatial and temporal dynamics of disturbances over a longer time period (Turner et al. 2001).

## EFFECTS OF CHANGING THE NATURAL DISTURBANCE REGIME (FIGURE 5)

Grassland ecosystems were maintained by a disturbance regime of grazing, fire, drought, and stochastic events like tornadoes, floods, and episodic infestations. Historically, the landscape was composed of a shifting mosaic of disturbed and undisturbed lands, however, as anthropogenic activity increased, this disturbance regime changed. Currently, the landscapes in the SOPN are less likely to undergo dramatic shifts in landscape pattern as a result of catastrophic events and global climate change and more likely to be affected by changes in the fire regime and grazing patterns. Therefore, these processes are shown in greater detail in figures 6 and 7.

### *Fire Submodel (Figure 6)*

Fire is an important part of the disturbance regime of a grassland ecosystem (Smith and Smith 2001), and when it occurred naturally, it created a mosaic of burned and unburned patches across the landscape. Several land-managers have recognized the importance of fire and conducted prescribed fire on their lands, but these fires generally do not mimic historic conditions as burning occurs only on a pasture by pasture basis with a predictable frequency and often with different seasonality that would have historically occurred. Fire suppression has essentially removed fire as a regular disturbance in human-dominated landscapes, and as a result the landscape is dominated by competitively dominant plant species, which out compete the small-leafed and Nitrogen-fixing plants that colonize an area after a disturbance (Chapin et al. 1996). Fire suppression also increases the probability of woody encroachment, and also increases the fuel load of a landscape and both of which can contribute to a higher probability of a catastrophic fire.

Whenever a fire event does occur, there is an increased probability of colonization of invasive species (and woody encroachment if there is a long time period between fires). Once invasives

have been established, the landscape can be exposed to edge effects (refer to fragmentation submodel for a detailed description of edge effects) between the burned and unburned lands, and the grassland may eventually be converted to a scrubland. If a catastrophic fire (a fire event at a large spatial scale) does occur, the dynamics of the native communities will be disrupted for a significant time (e.g., the Yellowstone fire).

The lack of fire within the grasslands of the SOPN can eventually affect the ecosystems of the parks and several indicators could be used to monitor these affects. Monitoring land-use / land-cover changes, in addition to the human population density in the surrounding areas, could be a good indicator of fire supression (e.g, the more people in an area, especially an urbanized region, the higher the probability of fire suppression). Also, as exotic species become more prevalent (due to fire supression), monitoring native grassland bird species (diversity and abundance) could indicate how fire suppression is affecting the system.

*Grazing Submodel (Figure 7)*

Grazing by migrating herds of bison stimulated primary production of the Plains grasslands by moving among patches of grazed and ungrazed habitat (Smith and Smith 2001). This pattern prevented extended overgrazing in any one area and helped create the shifting mosaic of vegetation historically found in the Southern Plains. Once the bison were replaced by cattle, this pattern changed. Domestic grazers are limited in their movements by fences and stable water sources and are generally kept at high densities, which can result in the overgrazing of the landscape (Figure 6A) (Smith and Smith 2001). This overgrazing can eliminate the beneficial effects the migratory grazing patterns of the bison had on the landscape (McNaughton 1993, Rambo and Faeth 1999).

Rotating cattle among pastures to prevent overgrazing of a specific pasture somewhat mimics the effects of migratory grazing by creating a mosaic of grazed and ungrazed pastures, but this only occurs on a small scale and is completely dependent on the management practices, and to some degree the economic conditions, of individual landowners. If cattle are not rotated, pastures become overgrazed and the probability of invasive species colonizing an area increases. Overgrazing can not only change the species composition of a landscape (Sims 1988), but also affect the spatial heterogeneity of the vegetation (Adler et al. 2001). Several grassland species are sensitive to heavy grazing pressures and will disappear from the landscape (Briske 1996). If grazing alters the spatial structure of a landscape, it will affect a wide range of ecosystems functions (Adler et al. 2001). For example, changes in spatial structure caused by grazing can alter the diversity of consumers utilizing the habitat (England and DeVos 1969, Grant et al. 1982). In addition, overgrazed lands have more exposed soil, which increases the amount of runoff. The increased nutrient load carried in the runoff would cause a disruption of the nutrient cycling occurring within the park.

Grazing (along with fire) is essential for maintaining a grassland ecosystem and therefore the effects of the grazing regimes in the lands surrounding the parks should be monitored. Establishing communication with the neighboring land owners and asking them about their herds and grazing rotations could be a good indicator of the processes occurring outside the park. Also, monitoring the land-use / land-cover changes, the number of fences, and change in species diversity along the borders of the park could assist park managers in determining where and how grazing is affecting the landscape.

## HABITAT MODIFICATION (FIGURE 8)

Human mediated activities (stressors from Figure 3) can modify a landscape in myriad ways (Soulé 1986), however, the three major landscape-level issues resulting from habitat modification facing the parks in the SOPN are: 1) change in the ecosystem function, 2) change in the distribution of species, and 3) change in the habitat characteristics of the landscape.

Neighboring land use practices, such as overgrazing and row-cropping, can change the ecosystem processes occurring within the parks. High cattle densities and heavy agricultural use add higher concentrations of usable nitrogen, sulfates, and phosphates into the system, which will runoff into the park and disrupt the normal nutrient cycles. Industrial and residential development can introduce air- and water-borne pollutants, which will change the air and water quality of a park and both can affect ecological processes occurring within the park.

The distribution of species within a park is not only influenced by the management strategies of the park, but also neighboring land-use practices. If the habitat matrix surrounding the park is significantly modified (i.e., developed into neighborhoods, pastoral lands for grazing, row cropping, etc…), the composition of native species, changes (refer to the prairie dog sub-model under the grassland model section for an example of species displacement). Species requiring large expanses of unbroken habitat, like large carnivores, are displaced quickly and this causes a trophic shift within the food web. In the case of rare, threatened, or endangered (RTE) species (which generally have specific habitat requirements), habitat modification can be especially detrimental. If the park is the only area within the surrounding matrix possessing these unique habitat types, managers are faced with the problem of not only conserving this habitat type, but also monitoring the habitat for potential degradation, which can lead to the local extinction of the RTE species.

The landscape of the Southern Plains was traditionally composed of a continuously shifting mosaic of patches in varying stages of ecological succession. As the landscape became more human-dominated, this mosaic became fragmented, creating a matrix of native and non-native habitat types (refer to Figure 9 – Human-mediated fragmentation for a thorough description of fragmentation). As the landscape continued to be modified, the spatial configuration of the landscape changed. Currently, development has introduced patches of non-native pasture grasses for grazing, feedlots, row crops, and residential and commercial developments, all of which can introduce exotic species (refer to fragmentation submodel for a more thorough explanation of exotic species).

The effects of habitat modification are probably the biggest ecological threat facing the parks of the SOPN. However, the ecological effects for each of the three landscape level issues caused by habitat modification can be easily monitored.

The changes in ecosystem function can be monitored by measuring water and air quality within (or near) the parks. Sampling and measuring nutrient loads in the soils in and around the park could be possible indicators for the changes in nutrient cycling. Also, monitoring the human population density in areas surrounding the park (along with the rate of growth) could give park managers an idea of how the ecosystem will continue to change in the future.

Monitoring the changes in species distribution simply requires knowledge of the current distribution / abundance of the species in the park and the ability to monitor those species through time, using the same protocols. Maintaining a continuous inventory of every species in the park is not cost-effective, however, certain groups of species (native bird and amphibian communities) are good indicators of ecosystem integrity. Also, the presence (or disappearance) of populations of RTE species are good indicators of the community structure within an ecosystem.

The change in habitat characteristics can dramatically affect the landscape pattern. There are several indicators which can be used to monitor the change in habitat composistion: land-use / land-cover in areas surrounding the park, the mosaic of natural areas (patch size and arrangement), the amount of wetland within the region, and the density of houses can all be remotely sensed and are relative easy to monitor. As the habitat characteristics change, abundance and composition of exotic species will change across the landscape as well, so monitoring the diversity of exotic species within the park can be a good indicator of the processes occurring outside of the park.

*Human-Mediated Fragmentation (Figure 9)*

Fragmentation caused by human development is the biggest stressor currently occurring at the parks in the SOPN. Fragmentation of a landscape occurs when a large piece of habitat is transformed into a number of smaller patches, isolated from each other by a matrix of foreign habitats which are unlike the original (Wilcove et al. 1986). Fragmentation resulting from anthropogenic activity is generally irreversible and can severely disrupt ecosystem functions. The major effects of fragmentation are a decrease in the functional ecosystem size, a disruption of natural processes, and an increase in the amount of foreign habitat (patches of non-native habitat). These three effects are not independent and each facilitates the others, and any of these can cause more fragmentation (refer to Figures 5, 6, and 7 for a description of the possible effects of disrupting natural processes).

The size of the functional ecosystem decreases as the remaining patches of native habitat become surrounded by human developments (Krebs 2001). Species with large home ranges will become displaced, due to either an increase in human population (Parks and Harcourt 2002), or simply because their resources have decreased significantly (Wilcove et al. 1986). Large predators are especially vulnerable because their trophic position requires small population densities (Woodroffe and Ginsberg 1998) (refer to the prairie dog model for a detailed description of the trophic shifts occurring when a keystone predator is displaced). As the size of the functional ecosystem changes, resource availability changes as well. Species that were once able to forage a continuous piece of habitat will be forced to compete with other species for resources. Eventually, one species will out-compete the other, resulting in the local extinction of the competitively “weaker” species (Lotka 1925, Volterra 1926).

The connectivity among native patches decreases as the number of foreign patches within a habitat increases (Smith and Smith 2001). Essentially, each native patch becomes an island, separated from other native patches by an ocean of untraversable habitat types (Quammen 1996). Organisms generally leave their nascent area by eruptive migration, and patch isolation effectively prevents this exodus (Janzen 1986). Species are then restricted to small patches, and essentially become an isolated, small population, which will eventually lead to a decrease in genetic variability (through inbreeding and genetic drift) which is required to maintain a viable population (Freeman and Herron 1998). Decreased connectivity poses significant problems for species requiring two types of habitats, like amphibians which have both a terrestrial and aquatic stage in their life cycle and migratory birds which utilize multiple habitat types during their breeding and non-breeding seasons. If one of the required habitat types is destroyed or unreachable by migration, then the local extinction of that species is highly likely (Wilcove et al. 1986).

Edge effects are another ecological consequence of fragmentation. The edge is a border between two different habitat types (i.e., grassland and river, piñon-juniper and development). Edge effects are the ecological processes occurring at the margins, and these processes are very different from the processes occurring in the interior of the respective patches (Smith and Smith 2001). The ecological processes occurring at the margins are not limited to point of contact between the two habitat types. If there is a high edge to interior ratio, then the effects will affect the majority of the habitat type (Lovejoy et al. 1986).

Abiotic changes at the borders include a change in temperature and relative humidity, exposure to more wind, and an increase in the amount of solar radiation reaching the soil (Soulé 1986, Chapin et al. 1996). These abiotic factors will eventually change the soil chemistry, facilitating both the invasion of exotic plant species and woody encroachment (Soulé 1986).

The composition of species changes at the border between two habitat types. This area is easily colonized by species (both exotic and native) preferring edge habitat (Woodroffe and Ginsberg 1998). For example, feral cats (*Felis domesticus*) and dogs (*Canis familiarus*) frequent edge

habitat, and these animals can facilitate the spread of zoonotic diseases, introduce parasites into the native vertebrate community, and decimate local population of small mammals, ground nesting birds, and herptiles. Native predators like raccoons (P*rocyon lotor*) also frequent edge habitat, further reducing the abundance of prey animals in the system. These factors change the viability of species residing at the margins – edge species experience an increase in viability and the viability of interior species decreases (Woodroffe and Ginsberg 1998).

Human-mediated fragmentation is often an irreversible and unstoppable process. The three immediate effects (decrease functional ecosystem size, disrupt natural processes, increase foreign habitat) interrupt the flow of energy across an ecosystem and will eventually increase the probability of extinction of species within the park. Monitoring these effects requires knowledge of the processes occurring inside and outside of the park. The mosaic of natural areas (patch size and arrangement) within the landscape surrounding the parks, and the connectivity between the patches can be used to indicate possible source and sink habitats surrounding the park. Land-cover / land-use patterns coupled with human population density can provide park managers with a wealth of knowledge concerning fragmentation outside of the parks. Monitoring the borders of the parks for a change in edge-friendly species (e.g, bird species which utilize edge habitat instead of interior habitat) as well as a change in exotic species composition can assist park managers in determining the edge effects occurring within the parks.

Monitoring the ecological effects of landscape dynamics is a difficult task for natural resource managers. The ecological processes affecting the landscape can occur at different spatial and temporal scales, depending on the process of interest. These conceptual models were developed in order to elucidate several of the major ecological processes affected by the ecosystem changes within SOPN. These models should assist park managers in choosing the appropriate vital signs for the monitoring program.

Human processes appear to be the major stressor on the environment, interrupting several key processes, like fire and grazing, that maintained the grassland ecosystem. Human development has also fragmented the landscape, which decreased the size of the functional ecosystem, reduced connectivity among native habitat patches, isolated species in small patches, and introduced edge effects across the landscape. These disruptive processes lower the fitness of native species residing in the park, which increases the probability of extinction within the park.

## LITERATURE CITED


Adler, P. B., D. A. Raff, and W. K. Laurenroth. 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128:465-479.

Briske, D. D. 1996. Strategies of plant survival in grazed systems: a functional interpretation. Pages 37-68 *in* J. Hodgson and A. W. Illius, editors. The Ecology and Management of Grazing Systems. CAAB International, Wallingford Oxon, UK.

Chapin, F. S., M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. American Naturalist 148:1016-1037.

Delcourt, H. R., P. A. Delcourt, and T. Webb. 1983. Dynamic plant ecology: the spectrum of vegetational change in space and time. Quaternary Science Review 1:153-175.

England, R. E., and A. DeVos. 1969. Influence of animals on pristine conditions on the Canadian grasslands. Journal of Range Management 22:87-94.

Freeman, S., and J. C. Herron. 1998. Evolutionary Analysis. Prentice Hall, Upper Saddle River, New Jersey.

Grant, W. E., E. C. Birney, N. R. French, and D. M. Swift. 1982. Structure and productivity of grassland small mammal communities related to grazing induced changes in vegetative cover. Journal of Mammalogy 63:248-260.

Janzen, D. H. 1986. The eternal external threat. Pages 286-303 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

Krebs, C. J. 2001. Ecology, 5th edition. Benjamin Cummings, San Francisco.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology 73:1943-1983.
Lotka, A. J. 1925. Elements of Physical Biology. Dover Publications, New York.
Lovejoy, T. E., R. O. Bierregaard, A. B. Rylands, J. R. Malcom, C. E. Quintela, L. H. Harper, K. S. Brown, A. H. Powell, G. N. Powell, H. O. Schubart, and M. B. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257-285 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer Associates, Sunderland, MA.
McNaughton, S. J. 1993. Grasses and grazers, science and management. Ecological Applications 3:17-20.
Meyer, W. B. 1995. Past and present land use and land cover in the USA. Consequences 1995:25-33.
Parks, S. A., and A. H. Harcourt. 2002. Reserve size, local human density, and mammalian extinctions in U.S. protected areas. Conservation Biology 16:800-808.
Quammen, D. 1996. The Song of the Dodo: island biogeography in an age of extinction. Scribner, New York.
Rambo, J. L., and S. H. Faeth. 1999. Effect of vertebrate grazing on plant and insect community structure. Conservation Biology 13:1047-1054.
Sims, P. L. 1988. Grasslands. Pages 266-286 *in* M. G. Barbour and W. D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York.
Smith, R. L., and T. M. Smith. 2001. Ecology and Field Biology, 6th edition. Benjamin Cummings, San Fransico.
Soulé, M. E. 1986. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.
Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. Landscape ecology in theory and practice: pattern and process. Springer, New York.
Volterra, V. 1926. Fluctuations in the abundance of a species considered mathematically. Nature 118:558-560.
White, P. S. 1979. Pattern, process, and natural disturbance in vegetation. Botanical Review 45:229-299.
Wilcove, D. S., C. H. McLellan, and A. P. Dobson. 1986. Habitat fragmentation in the temperate zone. Pages 237-256 *in* M. E. Soulé, editor. Conservation Biology: the science and scarcity of diversity. Sinauer, Sunderland, MA.
Woodroffe, R., and J. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126-2128.

**Figure 1 – Jenny-Chapin Model (Chapin et al. 1996). Bold-type font indicates state factors, and italics indicate interactive controls. The circle represents the boundary of the ecosystem**

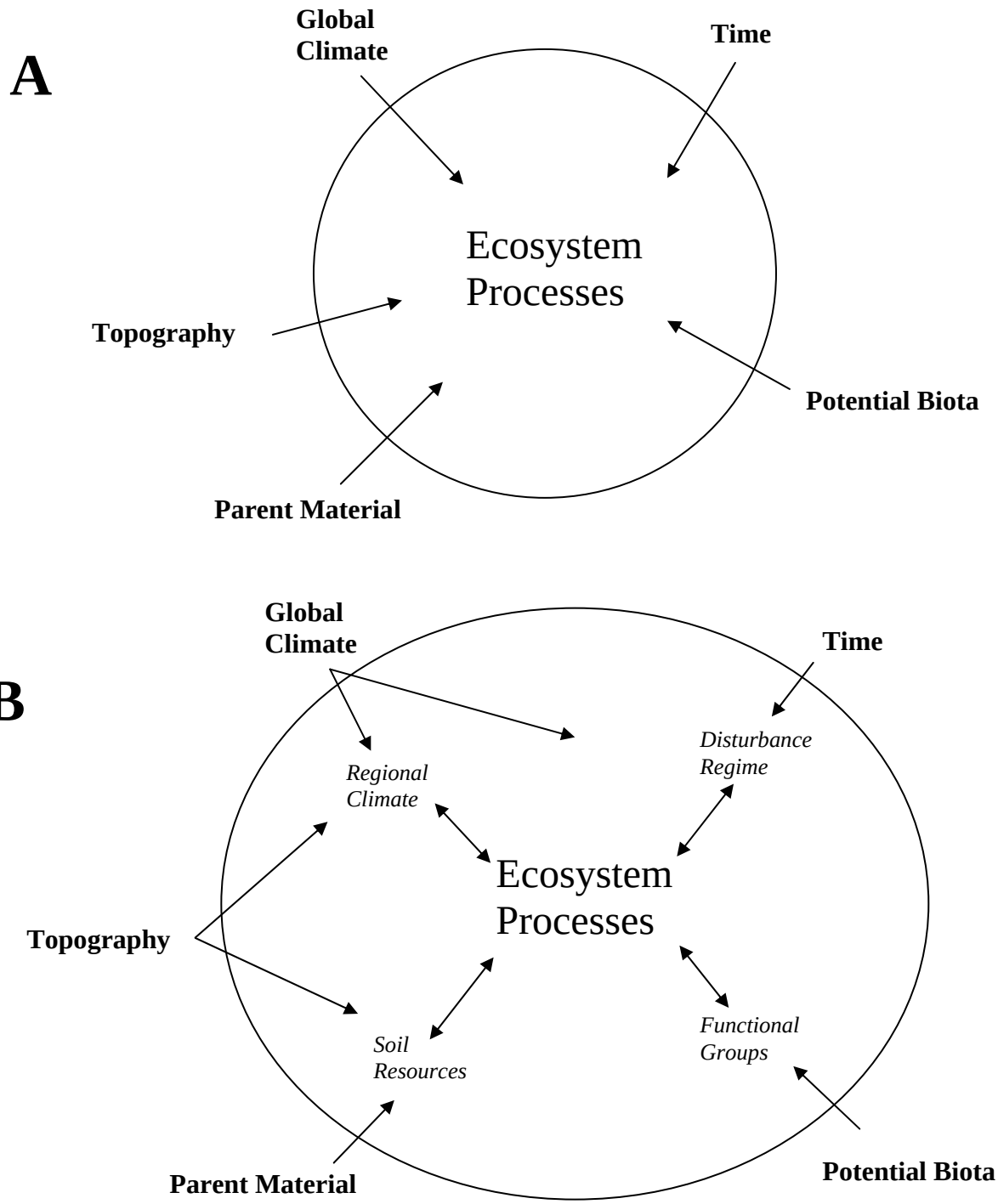


**Figure 2 – Current processes creating landscape pattern. Ovals represent processes and patterns occurring within an ecosystem. Arrows represent the direction of influence – natural and human processes affect the landscape pattern, and as the landscape pattern changes it influences both natural and human processes.**

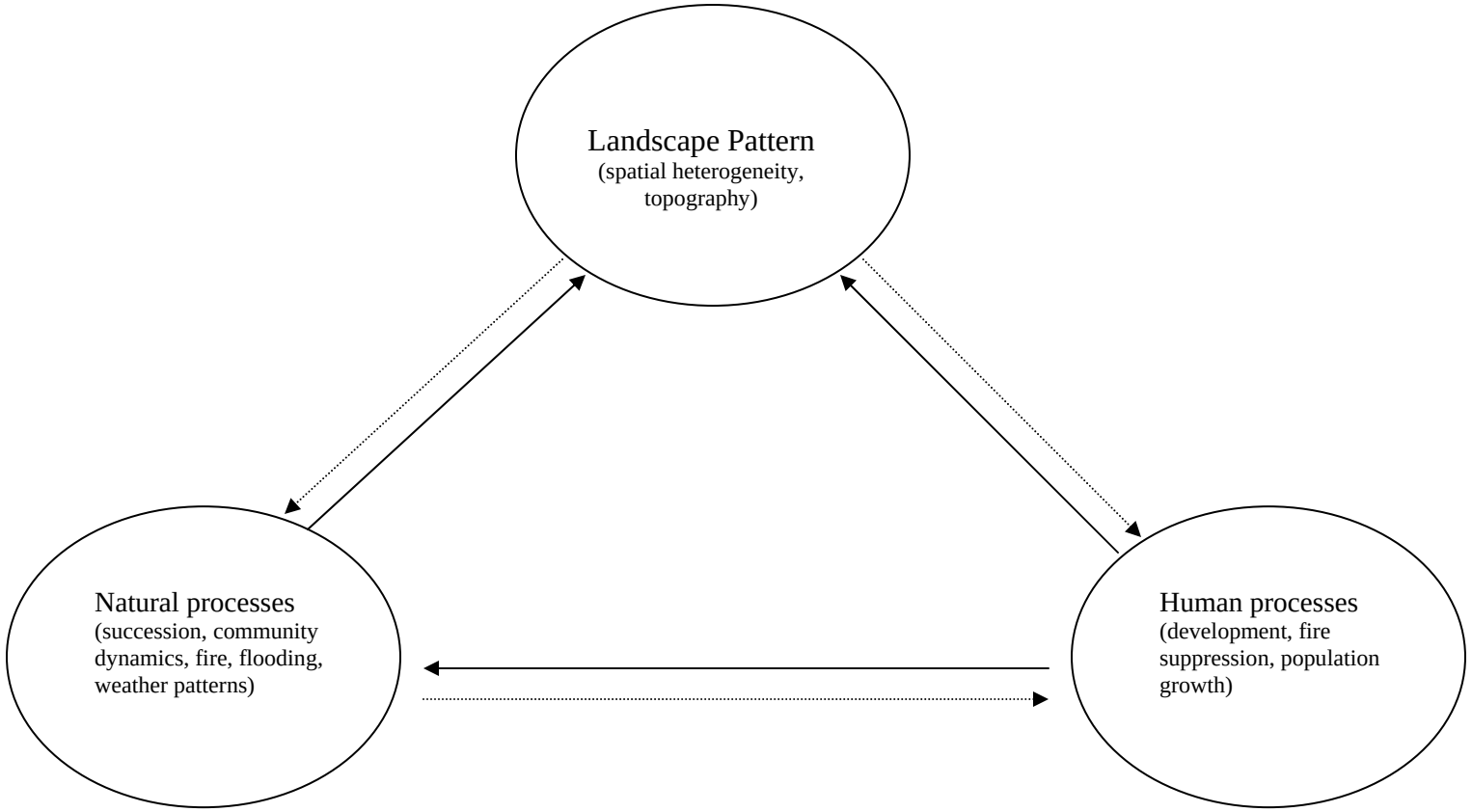


**Figure 3 – Types of anthropogenic processes affecting the ecosystem processes and landscape pattern of the SOPN. Squares represent stressors. Ovals are variables representing ecological effects of development. Each stressor affects both the ecosystem processes and the landscape pattern. Δ represents 'change in.'**

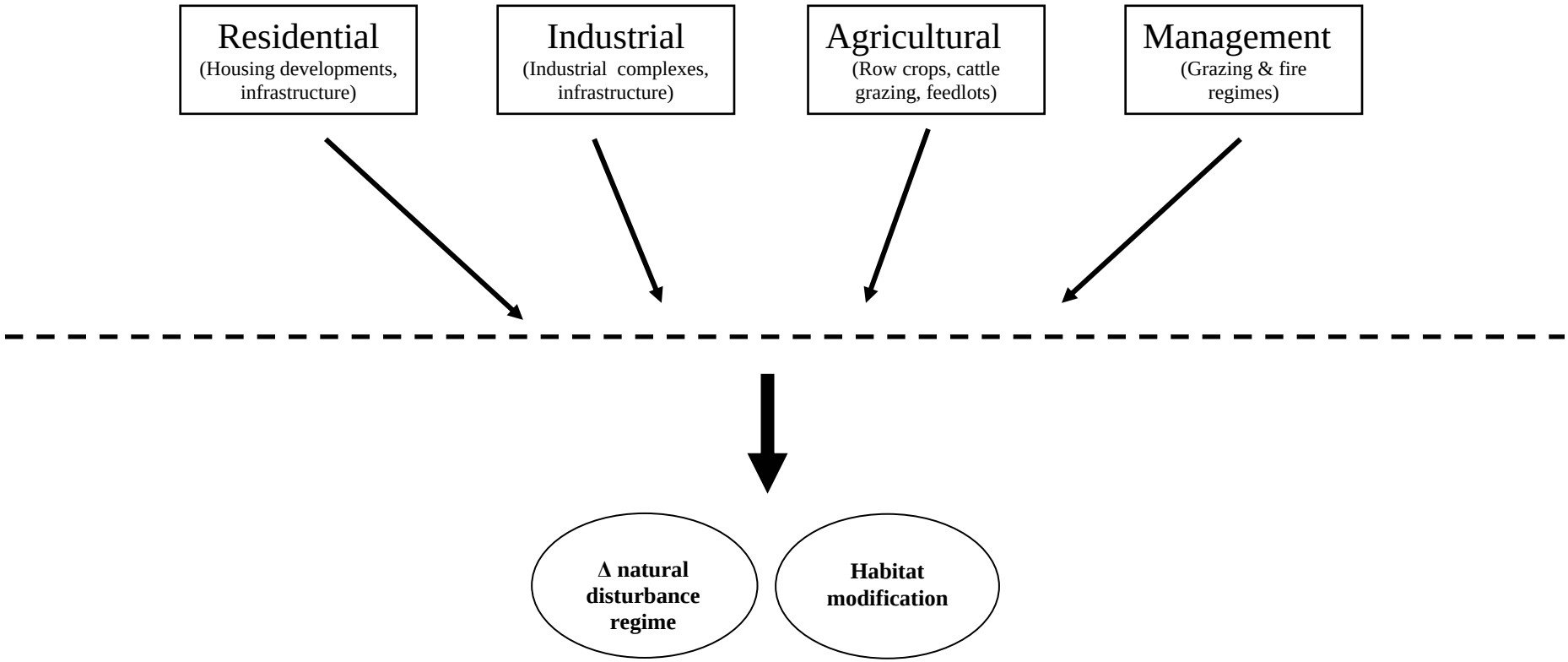


**Figure 4 – Diagrammatic representation of a natural disturbance regime (modified from Chapin et al 1996). The arrows represent time between successive events.**

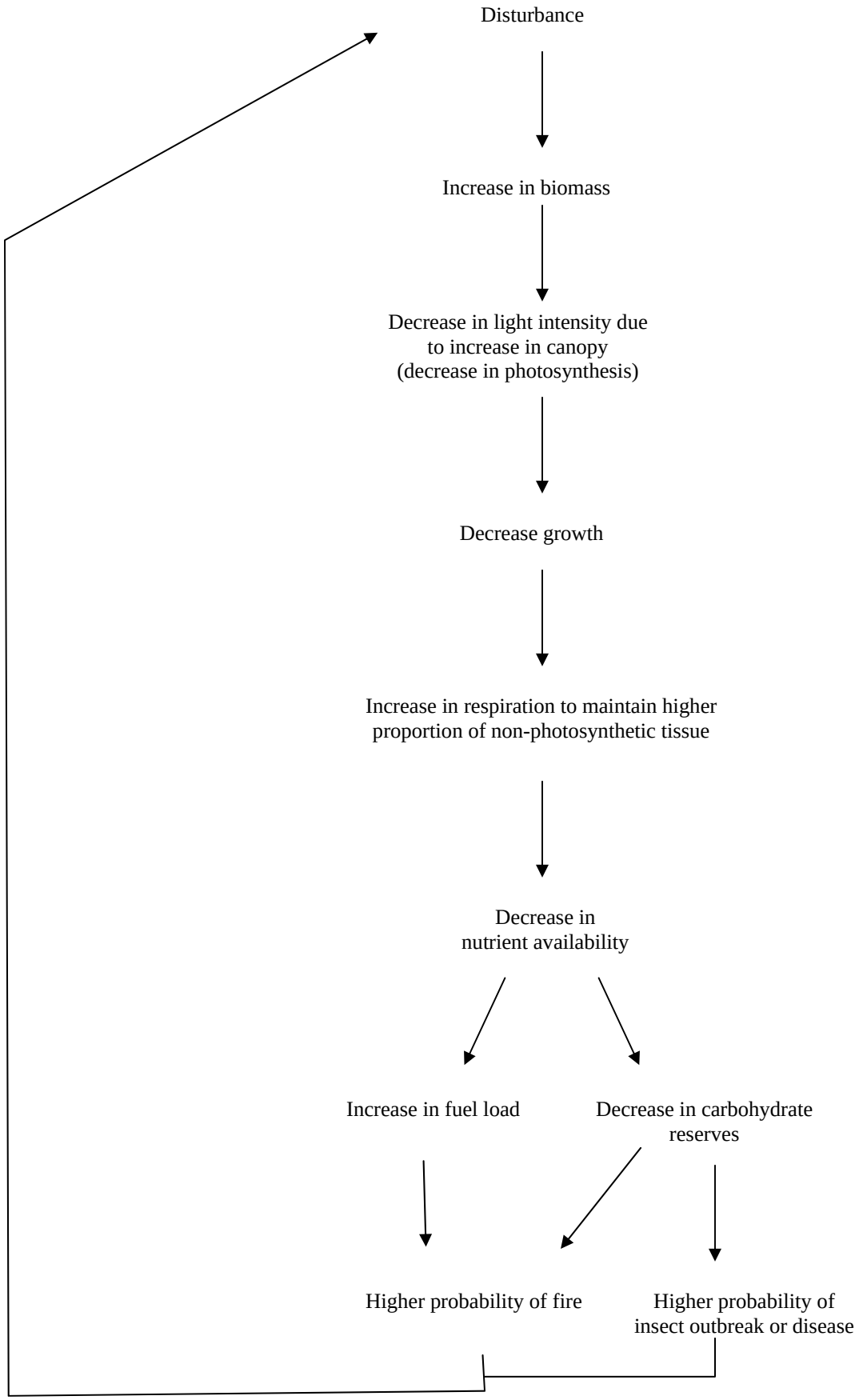


**Figure 5 – Submodel representing the ecological processes affecting the landscape of the parks in the SOPN. Bold-type font indicates the presence of a separate submodel. Δ represents 'change in.'**

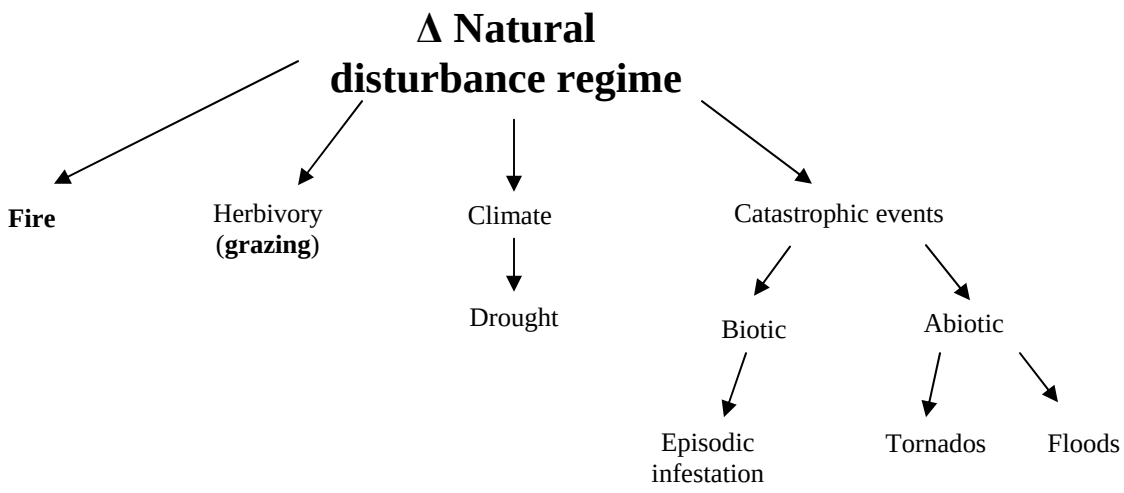


**Figure 6 – A) Submodel representing effects of different fire management strategies on the landscape pattern of the SOPN. B) Submodel representing possible outcomes of a fire event in the SOPN.**

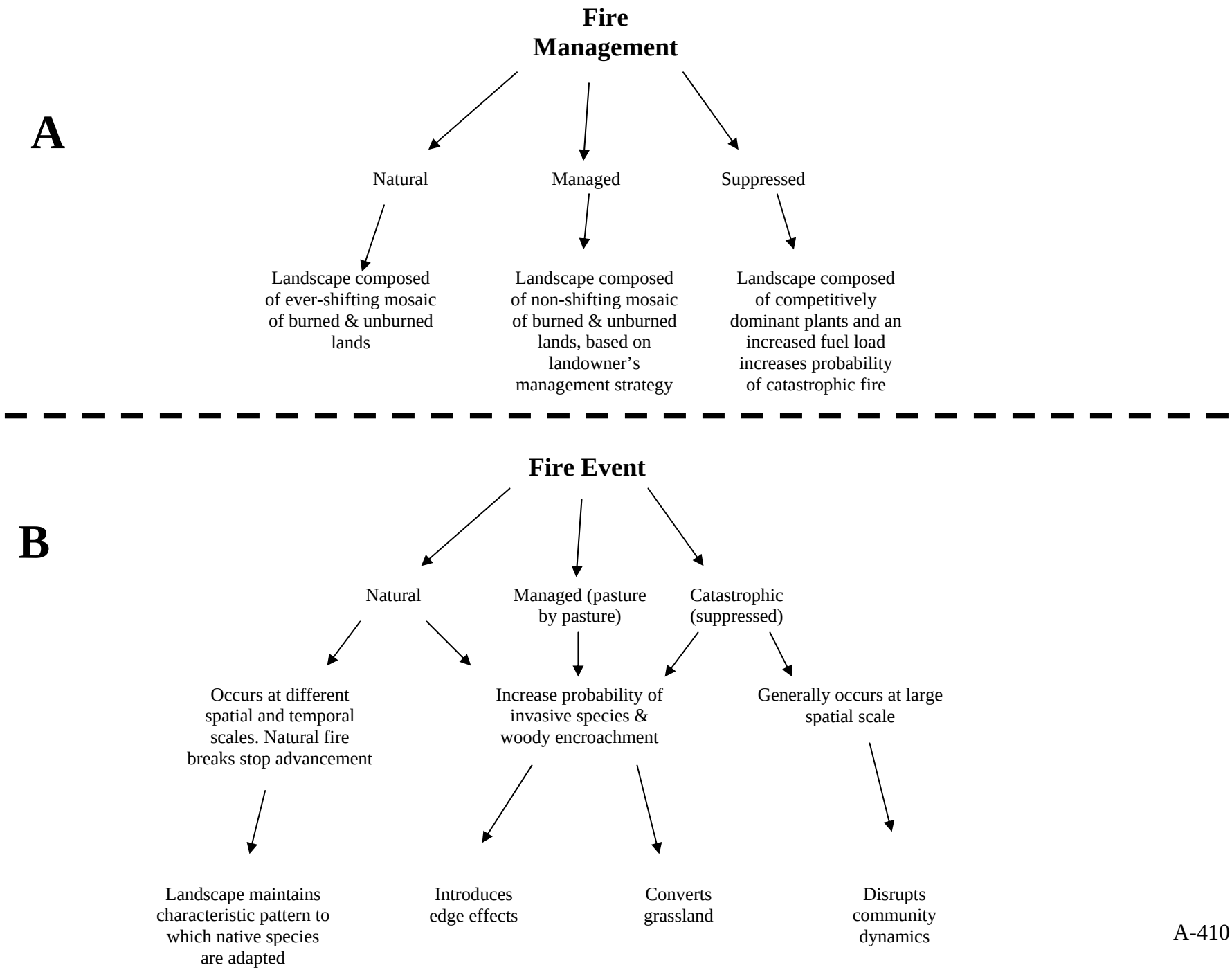


**Figure 7 – A) Submodel contrasting the historical and current grazing regimes in the SOPN. B) Submodel representing possible effects of different grazing strategies used by land owners within the landscape of the SOPN. Δ represents 'change in.'**

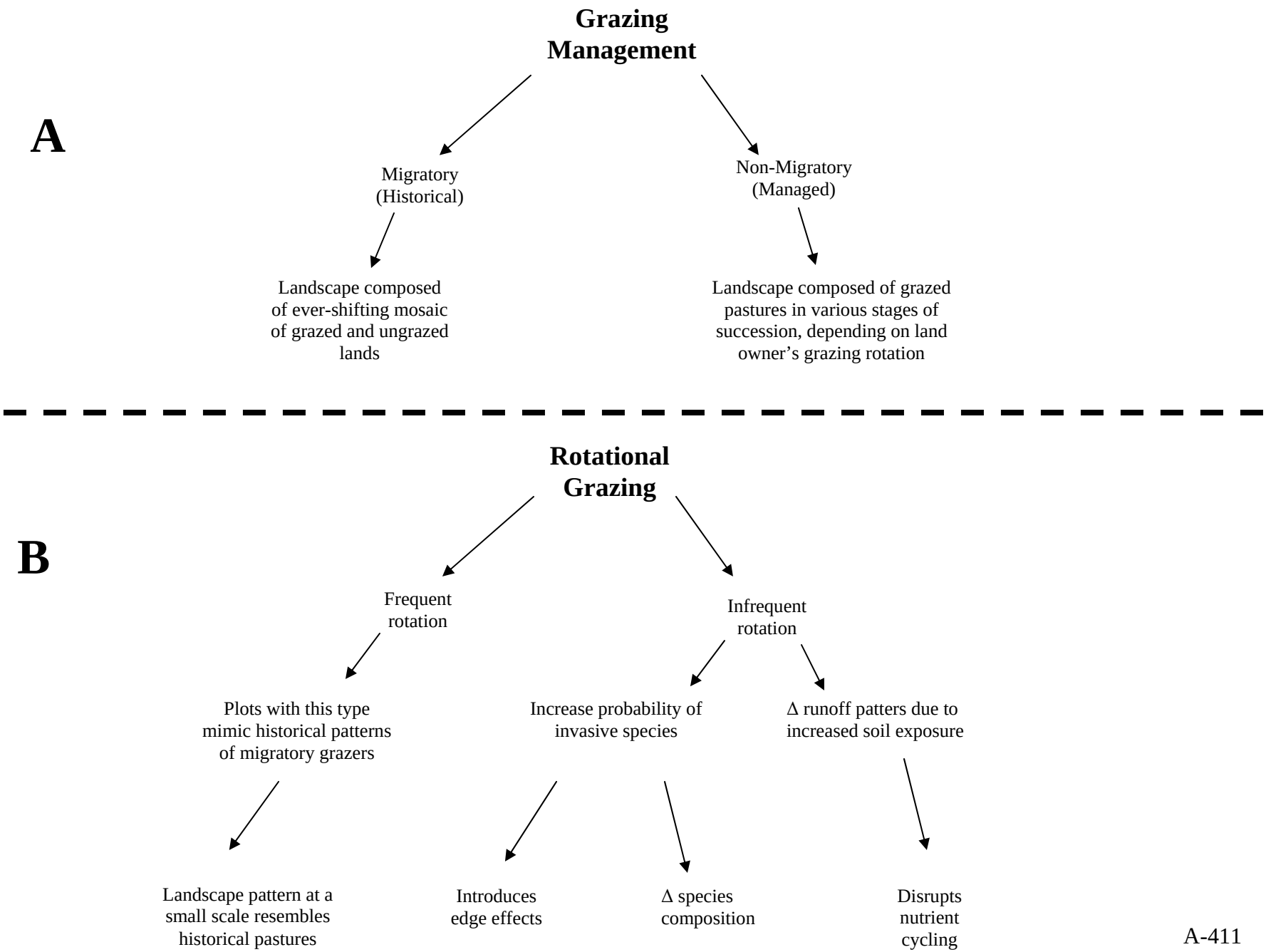


**Figure 8 – Submodel representing the possible effects of human-mediated habitat modification on the landscapes within the SOPN. RTE represents rare, threatened and endangered species. Bold-type font indicates a separate submodel. Topics in italics are thoroughly addressed in the prairie dog model. Δ represents 'change in.'**

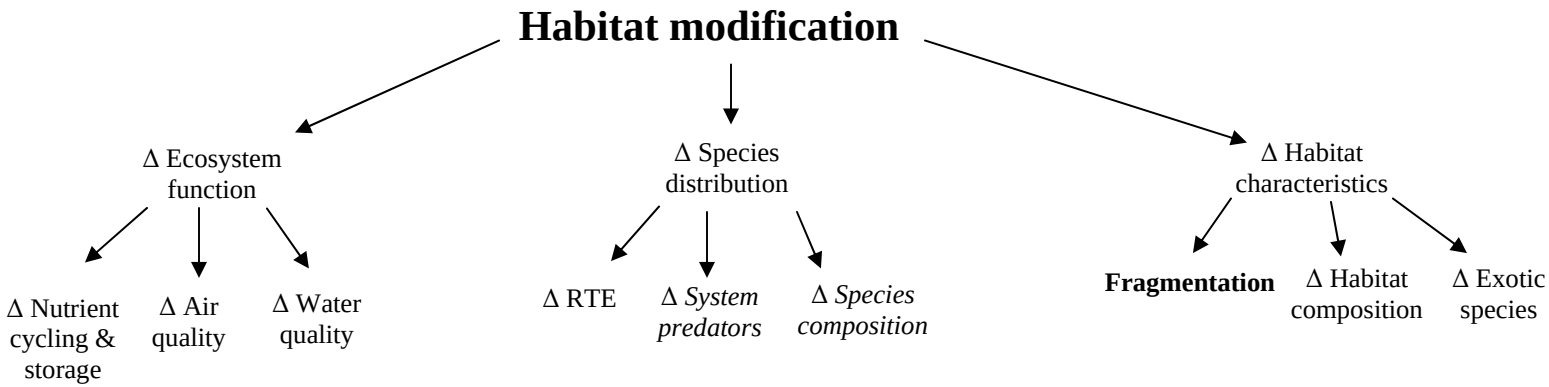
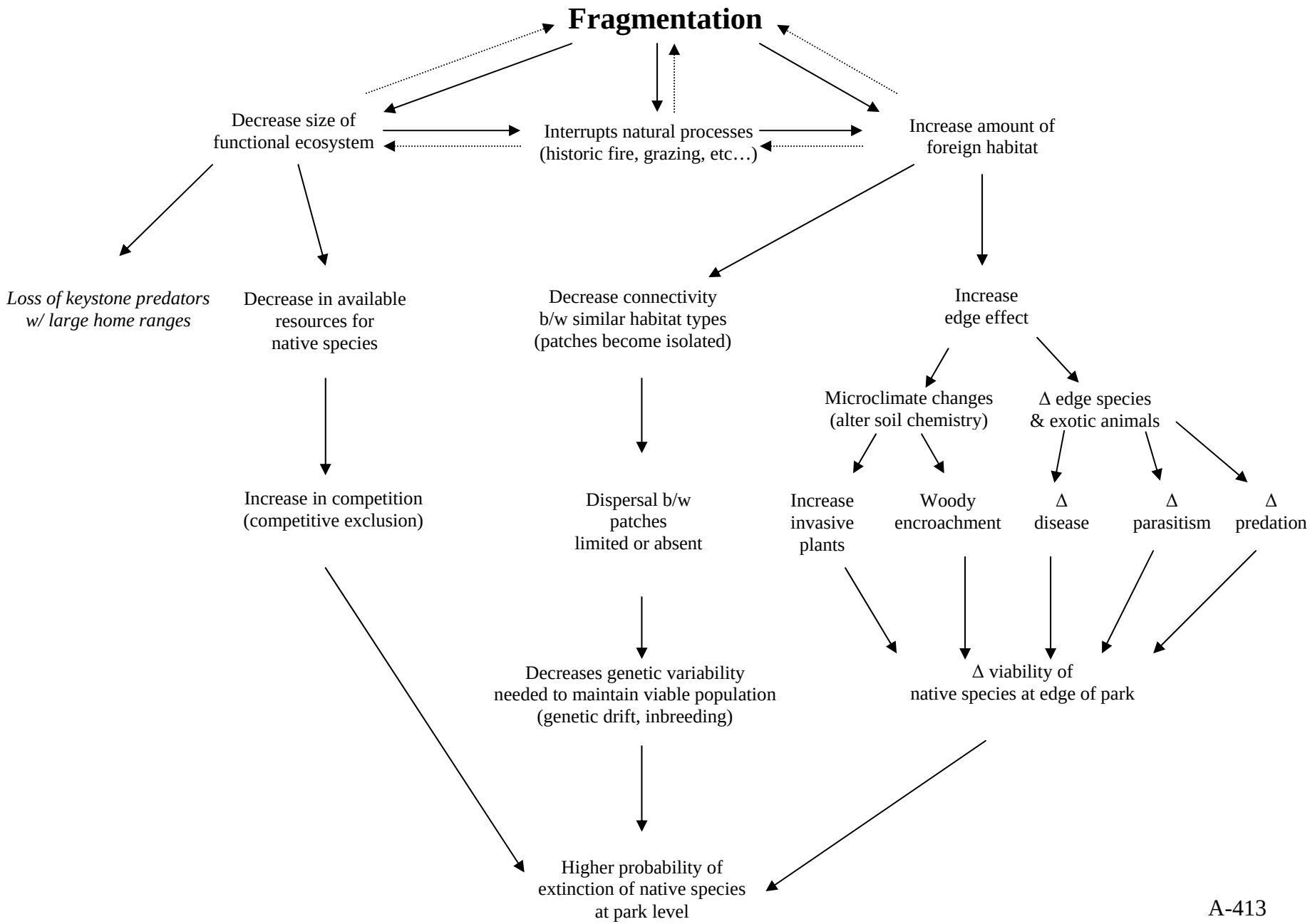


**Figure 9 – Submodel representing the possible effects of human-mediated landscape-level fragmentation. Topics in italics are thoroughly addressed in the prairie dog model. Δ represents 'change in.'**



# APPENDIX U. PIÑON-JUNIPER FOREST ECOSYSTEMS IN THE SOUTHERN PLAINS NETWORK: A DESCRIPTION AND CONCEPTUAL MODEL

Karie Cherwin and Dusty Perkins

## INTRODUCTION TO PIÑON-JUNIPER FORESTS

Piñon-juniper forests cover a significant portion of Western and Southwestern United States (Davenport, et al. 1998). Stands of piñon-juniper forests are most often found in arid to semi-arid watersheds. Piñon-juniper forests are characteristically comprised of relatively small, xeric coniferous trees, which tend to be drought-resistant and cold-tolerant, and that form an open canopy. The understory will likely consist of mixed-grasses and shrubs. The composition and relative dominance of the contrasting functional groups that form the canopy and the ground cover will highly influence piñon-juniper ecosystems (Breshears and Barnes 1999, Whitford 2002;). This influence can be demonstrated through rates of transpiration (Kerkhoff et al. 2004), soil infiltration and erosion, and nutrient cycling (Schlesinger et al. 1996). The positive feedback loop between soil, vegetation, and climate in Piñon-Juniper forests ten to make them especially sensitive to anthropogenic changes in land use and global climatic changes.

Major droughts can strongly affect the distribution and community structure of Piñon-Juniper forests Although they are capable of surviving on a variety of soil types (Wilcox and Davenport 1995) their soils will typically be aridsols, mollisols, or entisols and will commonly be derived from basalt, limestone, and sandstone parent materials.

Piñon-juniper forests can provide unique and often irreplaceable ecological services, including plant and animal habitats, food for herbivores, nutrient cycling, and water capture and retention (Whitford 2002). However, piñon-juniper forest ecosystems have exhibited widespread and rapid changes over the past century, which has often produced adverse ecological effects and caused interruptions to their ecological services. In particular, increased woody-plant density and range expansion have facilitated erosion, debilitated soil processes, eliminated habitat, and diminished forage productivity (Peiper 1990; Kerkhoff 2004). An additional concern of increasing woody-plant density that Southern Plains Network (SOPN) Park managers are currently facing is the recent infestation of the Ips beetle (*Ips confuses*), which is taking advantage of the changes in piñon-juniper forests

## CONCEPTUAL MODEL FOR PIÑON-JUNIPER ECOSYSTEM

Quantitative and qualitative analyses suggest that woody-plant abundance has substantially increased in grasslands in the Southwest region of North America over the last two centuries and replaced grasslands in the process (Hobbs and Mooney 1986; Archer 1989). While a growing number of studies have focused on the mechanisms controlling this trend, factors that make an ecosystem more or less susceptible to woody-plant encroachment are not entirely clear. Figure 1 explains the general ecosystem dynamics controlling a piñon-juniper forest; Figure 2 is a conceptual model adapted from Archer (1989) that depicts the transition in community structure between woody-plant and grassland ecosystems; Figure 3 illustrates the ball-and-cup theory of a ecosystem stability and the energy needed to an ecosystem past a threshold by which it will become an altered state. The narrative that follows will describe this model in the context of piñon-juniper forest ecosystems at Pecos National Historical Park (PECO) and Capulin Volcano National Monument (CAVO).

Within grassland communities, grazing pressure will change the composition and productivity of herbaceous species while decreasing fire fuel load. Therefore, the probability of piñon-juniper encroachment increases (shrub-driven succession). Alternatively, if grazing pressure is reduced in a grassland that borders a piñon-juniper forest, succession toward a stronger grass-dominated community may arise (Graminoid-driven succession). However, if an adequate number of piñon-juniper trees become established in a grass-dominated community, successional processes will shift the community towards a “steady-state”, or alternative-state (Chapin et al. 1996), condition. Once a community has become dominated by piñon-juniper trees, the area will not revert to a grassland without a considerable amount of energy input, especially if the displaced grassland plants were established under different climatic conditions. Returning a community to a less piñon-juniper-dominated and a more grass-

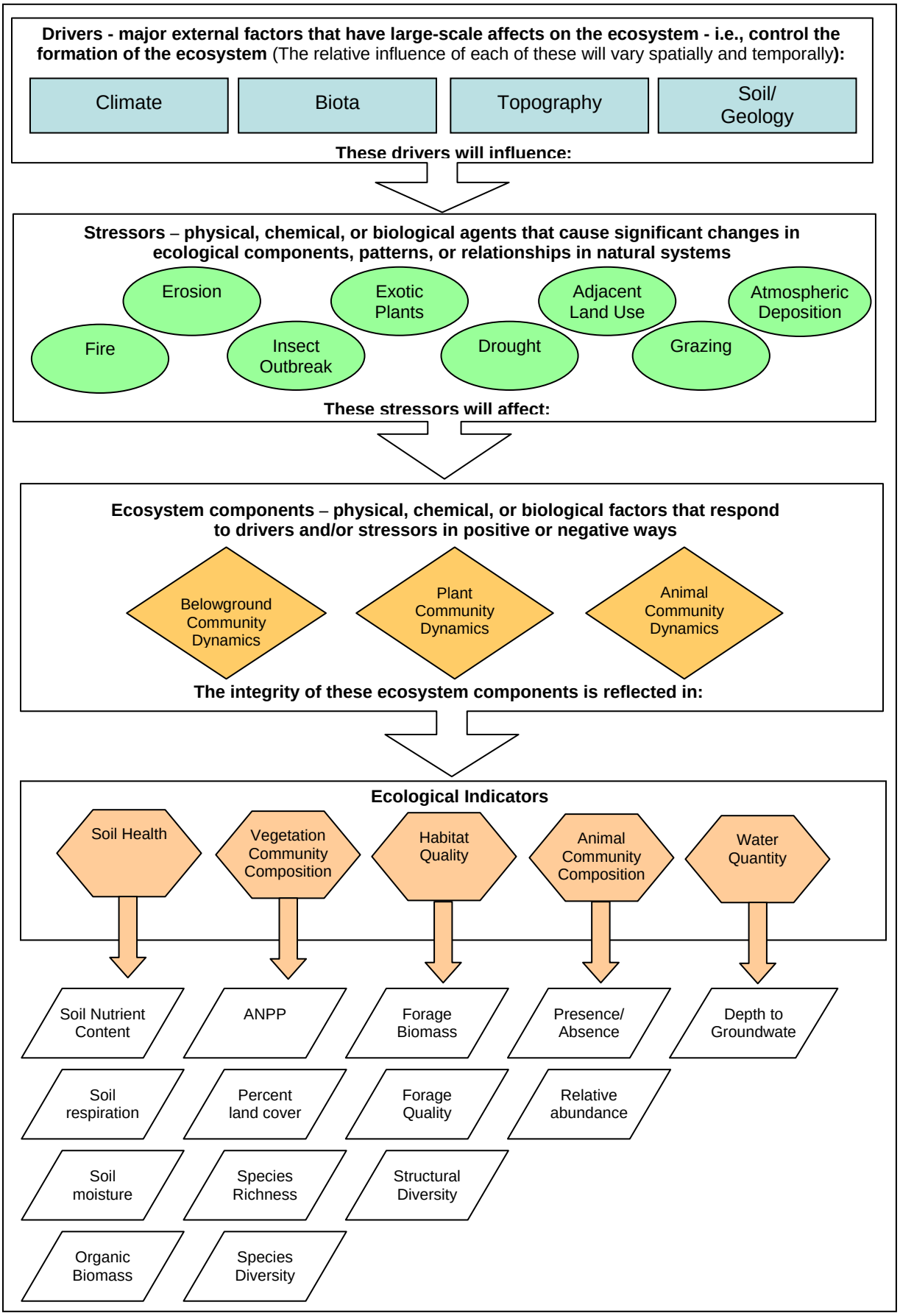



**Figure 1. Piñon-Juniper Forest Ecosystem Conceptual Model**

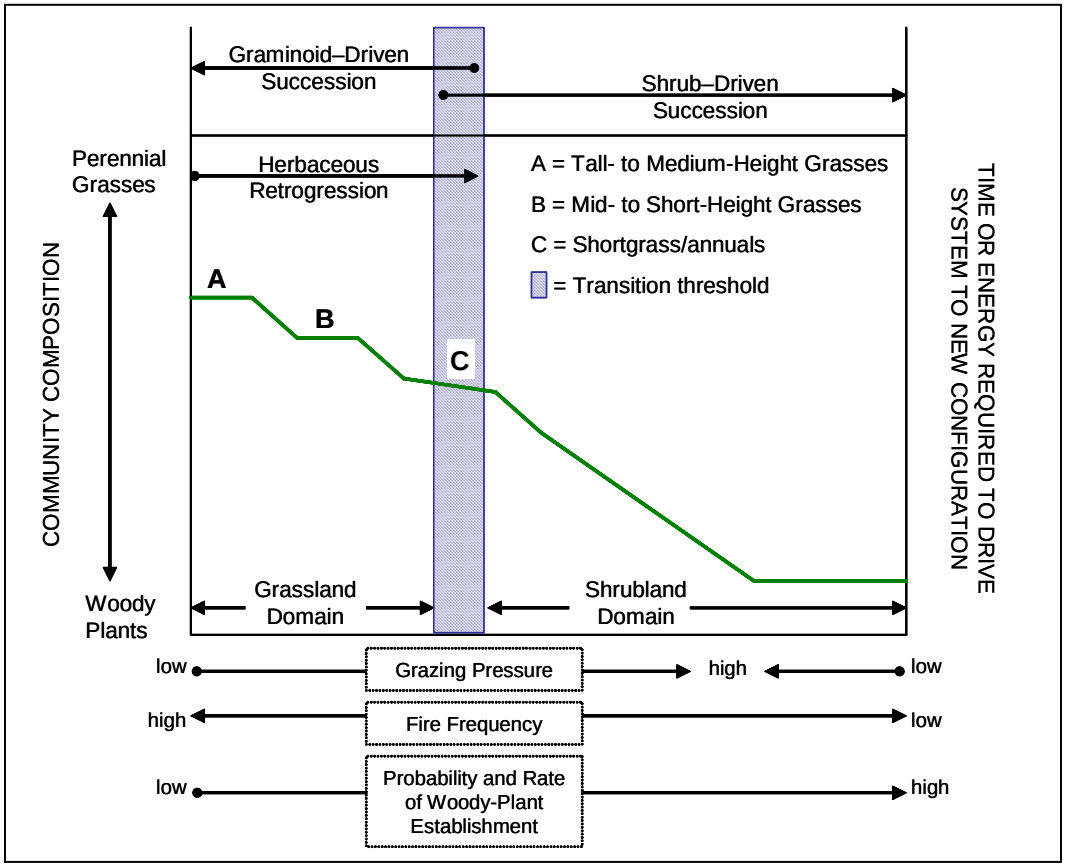



**Figure 2. Conceptual Model depicting community structure transition between herbaceous vs. woody plant domination in (Archer 1989).**

dominated condition will take vigilant anthropogenic maintenance to prevent the rapid return of a piñon-juniper forest ecosystem (Archer 1989). Costly restoration efforts are required (Whisenant 1999). The energy needed to maintain the stability of the restored grassland is also considerable.

The ball-and-cup diagram provides a helpful illustration of the concept of ecosystem stability (Figure 3). In this diagram the cup represents the natural range of variability in the ecosystem and the ball represents the ecosystem state. The probability of a driver or stressor (Figure 1) forcing the ecosystem across a threshold into a new state depends on its characteristics and magnitude. Ecosystem resilience to the drivers and stressors can of course change as the environmental changes occur. For example, fluctuating climatic conditions may alter the stability of an ecosystem and increase the probability that a separate stressor, such as an insect infestation, could drive the threshold across a threshold.

Grasses can tolerate some grazing (stressor in Figure 1 or 3 (B)). However, if grazing pressure passes a certain threshold, the plant community composition is likely to shift in favor of herbaceous plants. If grazing is eliminated, soil, seed bank, and seedling establishment could potentially drive the community towards the preceding species composition.

Climatic change, atmospheric deposition, overgrazing, and fire suppression, and the complex interactions between these, are potential causes for piñon-juniper encroachment into grassland communities. Spatial and temporal scales will influence the impact of these mechanisms (Archer 1989). Broadly, the vegetation in semi-arid systems such as PECO and CAVO are generally controlled by climate (Chew 1982; Archer 1989). However, climate cannot account for some of the small-scale patterns.

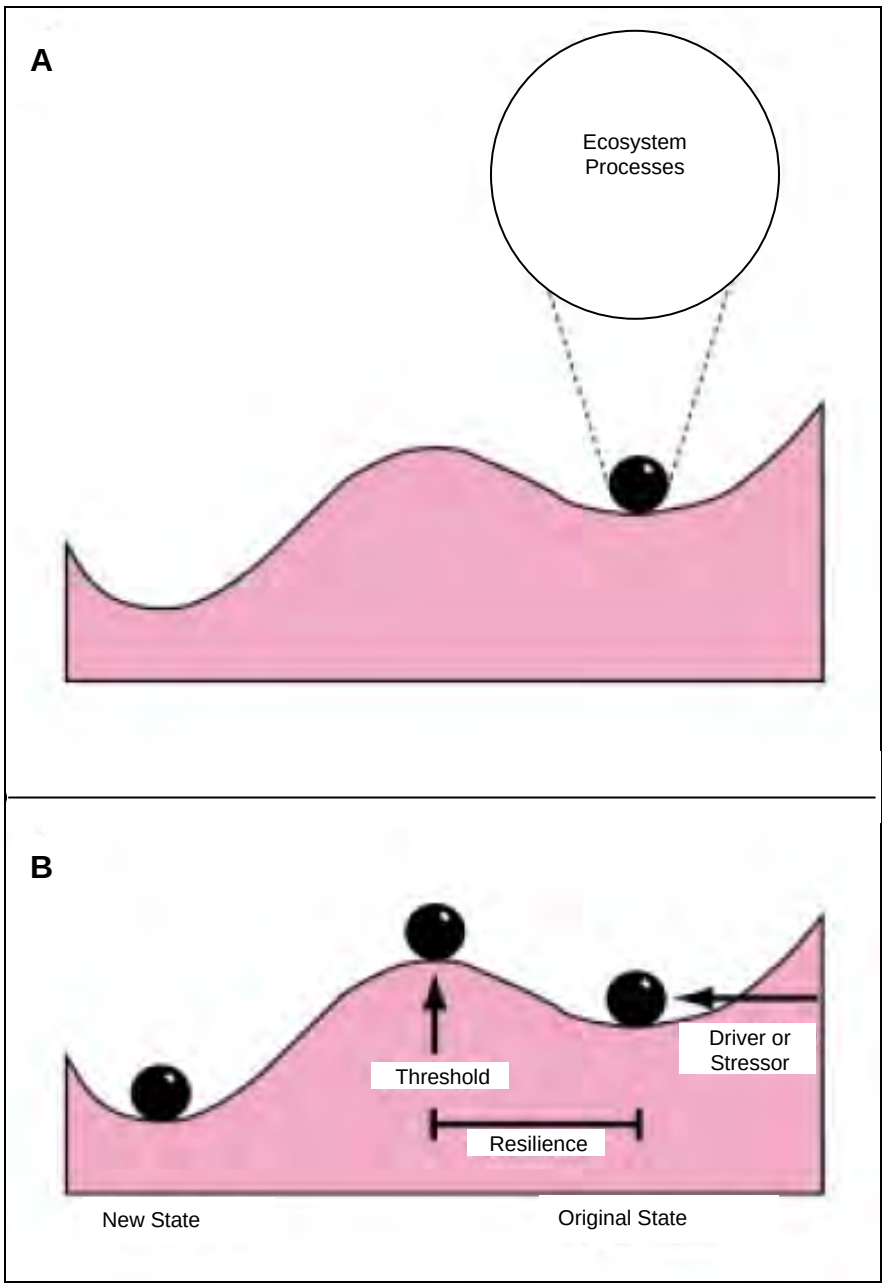



**Figure 3. Ball-and-cup diagram integrated with general ecosystem model.** In (A), the ecosystem is persisting in its *original state*. In (B), an ecosystem *driver or stressor* is placing pressure on the ecosystem, shifting it to a *new (altered) state*. The magnitude of the *driver or stressor* can face some level of *resilience* by the ecosystem before crossing the *threshold*. After crossing the *threshold*, the energy needed to return the ball, or *ecosystem* to its original state would be considerable. (Derived from Scheffer et al. 2001).

More than just soil moisture will control the expansion of piñon-juniper forests. For example, as the relative values of landform features and mircotopographic features in resource capture increase, piñon-juniper establishment becomes more likely, and the reversion to a Graminoid-dominated system will again require more energy.

## PIÑON-JUNIPER FORESTS IN SOPN

Piñon-juniper forests are present in two SOPN Parks, Pecos National Historical Park (PECO) where they are the dominant ecosystem-type, and Capulin Volcano National Monument (CAVO) where they reach the eastern-most edge of their distribution. Within the range of piñon-juniper forests 32 piñon (Pinaceae) and 23 juniper (Cupressaceae) species can be found. However, only one piñon species, *Pinus edulis* (Colorado piñon pine), and two juniper species, *Juniperus monosperma* (one-seeded juniper) and *Juniperus scopulorum* (Rocky Mountain juniper), occur at PECO and CAVO.

*Pecos National Historical Park (PECO)*

Piñon-juniper forests are the most common vegetation community present at PECO and the surrounding area. Approximately 41% of the Park is covered by piñon-juniper forests, interspersed with ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*). Another 26% of the Park is covered primarily by piñon-juniper communities and 10% with a piñon-juniper/grassland cover. Small areas of old-growth piñon, which is an increasingly rare habitat type in New Mexico, are present (NPS 1984).

PECO lies in the Pecos River valley, in the Rocky Mountain conifer vegetation zone, which is a transition zone between piñon-juniper and ponderosa pine. On the land surrounding PECO, piñon-juniper forests cover the valley floor between the Glorieta Mesa and the foothills of the Sangre de Cristo Mountains. Moreover, most of the land surrounding PECO that has not been developed or grazed is covered by piñon-juniper forests. Interspersed in the piñon-juniper forests, usually on the north-facing slopes of more mesic sites, are clusters of ponderosa pine. On the east side of the Pecos River are larger stands of ponderosa pine and Douglas fir interspersed among the piñon-juniper forests. Additionally, the backcountry zone of PECO is dominated by ponderosa pine and Douglas-fir and has been relatively undisturbed by humans. Cottonwoods (*Populus deltoides*) and willows (*Salix spp.*) dominate the riparian plant community along the Pecos River and Glorieta Creek. Cottonwood trees are dying in areas away from the main channel that were no longer flooded and speculated that these cottonwoods eventually may be replaced by piñon-juniper (Muldavin 1991).

Naturally occurring fires have been suppressed for at least 50 years in the Pecos and Glorieta units. The entire area has been subjected to a long period of human use, including hunting, gathering, cattle and sheep grazing, and grain and fruit production. Lack of fire, human use of the land, and climatic changes are likely the cause for the spread of piñon-junipers into grasslands at lower elevation of PECO and into ponderosa pine forests at higher elevations.

*Capulin Volcano National Monument (CAVO)*

The piñon-juniper forest community covers approximately 523 acres of CAVO, which is over 60% of the total Monument. The land cover of piñon-juniper forests includes the entire cinder cone and much of the lava boca. Sufficient time has passed since volcanic activity ceased for weathering to decompose much of the lava at CAVO (Harfert no. date). Soil now covers the volcano and the surrounding lands. Capulin Volcano is primarily covered with piñon-juniper forests. These communities began increasing in density and distribution in the late 1800's due to climatic change, grazing pressure, and fire suppression.

## LITERATURE CITED


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

Breshears, D.D. and F.J. Barnes. 1999. Interrelationships between plant functional types and soil moisture heterogeneity for semiarid landscapes within the grassland/forest continuum: a unified conceptual model. Landscape Ecology 14: 465-478.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. TheAmerican Naturalist 148: 1016-1037.

Chew, R.M. 1982. Changes in herbaceous and suffrutescent perennials in grazed and ungrazed desertified grasslands in southeastern Arizona, 1958-1978. American Midland Naturalist 108: 159-169.

Davenport, D.W., D.D. Breshears, B.P. Wilcox, and C.D. Allen. 1998. Viewpoint: Sustainability of piñon-juniper ecosystems – a unifying perspective of soil erosion thresholds 51: 231-240.
Harfert, R.C. No Date. A study of the vegetation on volcanic cinder cones and their relationship to the caliche layers of Capulin mountain.
Hobbs, R.J. and H.A. Mooney. 1986. Community changes following shrub invasion of grassland. Oecologia 70: 508-513.
Kerkhoff, A.J., S.N. Martens, G.A. Shore, and B.T. Milne. 2004. Contingent effects of water balance variation on tree cover density in semiarid woodlands. Global Ecology and Biogeography 13: 237-246.
Muldavin, E. 1991. Riparian and wetlands survey, Pecos National Historical Park. New Mexico Natural Heritage Program, University of New Mexico, Albuquerque.
National Park Service, U.S. Department of Interior. 1984. Resource assessment of Forked Lightning/Los Trigo Ranches, San Miguel County, New Mexico. Southwest Regional Office, Santa Fe, New Mexico.
Peiper, R.D. 1990. Overstory-understory relations in piñon-juniper woodlands in New Mexico. Journal of Range Management 43: 413-415.
Schlesinger, W.H., J.A. Raikes, A.E. Hartley and A.F. Cross. 1996. On the spatial pattern of soil nutrients in desert ecosystems. Ecology 77: 364-374.
Walker, B.H., D. Ludwig, C.S. Holling, and R.M. Peterman. 1981. Stability of semi-arid savanna grazing systems. Journal of Ecology 69: 473-498.
Whisenant, S. G. 1999. Repairing damaged wildlands: a process-oriented, landscape-scale approach. Cambridge University Press, Cambridge. 312 pp.
Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego. 343 pp.
Wilcox, B.P. and D.W. Davenport. 1995. Juniper encroachment: potential impacts to soil erosion and morphology. Interior Columbia Basin Ecosystem Management Project. 1-16.

## APPENDIX V. PALUSTRINE WETLANDS CONCEPTUAL MODEL

This model and text was developed by Dr. Darren Carlisle with the United States Geological Service for the Heartlands Inventory and Monitoring Network. Dusty Perkins adapted the model to fit the needs of the Southern Plains Network. A wetland model developed for the Great Lakes Network (also developed by Dr. Carlisle) was also used in the development of this model.

### INTRODUCTION

The term "wetland" is a generic descriptor of a wide variety of places, including saltwater marsh, freshwater marsh, tidal marsh, wet meadow, wood swamp, bog, muskeg, mire, pothole, vernal pool, river bottom, mangrove forest, and floodplain swamp. The commonality among these environments is the presence of water sufficient to inundate the ground. The following U.S. Fish and Wildlife Service definition by Cowardin et al. (1979) is widely accepted

> *"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water…wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."*

Wetlands naturally form in places where surface water periodically collects for some time or where groundwater discharge is sufficient to saturate soils. Such places include depressions surrounded by upland and with or without a drainage system; relatively flat, low-lying areas along major water bodies; shallow portions of large water bodies; sloped areas below sites of groundwater discharge; arctic and subarctic lowlands; and slopes below melting snow banks and glaciers.

Although wetlands often comprise a small portion of the world's land surface (4-6%, Mitsch and Gosselink 2000), they contribute greatly to local and regional biological diversity (National Research Council [NRC] 1995). Wetland-dependent fish, waterfowl, furbearers, and timber provide important and valuable harvests and recreational opportunities. Wetland ecosystems moderate floods, improve water quality, and have heritage and aesthetic values that are difficult to quantify. On a global scale, wetlands contribute to stable levels of available nitrogen, atmospheric sulfur, carbon dioxide, and methane. Wetland habitats are required for the survival of a disproportionately high percentage of threatened and endangered species. Despite comprising <10% of the landscape in North America, wetlands are important habitat for 68% of birds, 66% of mussels, and 75% of amphibians on the U.S. list of threatened and endangered species (Mitsch and Gosselink 2000).

Despite the obvious benefits of wetland environments, they have been extensively modified or destroyed by human development. In the contiguous United States, approximately 53% of all wetlands have been lost in the last century (NRC 1995, Mitsch and Gosselink 2000). The U.S. government actually encouraged the widespread destruction of wetlands via established policies until the 1970s (NRC 1995). Currently, wetlands are the only ecosystem type that is comprehensively regulated across all public and private lands within the United States (NRC 1995). Nevertheless, wetland losses have continued over the past two decades (Dahl 2000). Urban development, rural development, and agriculture accounted for 30, 21, and 23%, respectively, of these recent losses (Dahl 2000).

Numerous definitions and classifications have been developed for wetlands, but the system adopted by the U.S. Fish and Wildlife Service and the National Park Service (Cowardin et al. 1979) is the one most commonly used by scientists worldwide (Mitsch and Gosselink 2000). This classification system is hierarchical and all-encompassing and SOPN will adopt also use this

classification system. There are at least three general types of wetlands within the SOPN according to Cowardin et al. (1979).

*Emergent Wetland, Persistent (Freshwater Marshes)*

This class and subclass belongs to palustrine wetlands group as classified by Cowardin et al. (1979). Palustrine systems are wetlands dominated by persistent vegetation (Figure 1). Wetlands without persistent vegetation are also included in this system if they are< 20 acres (8 ha), < 6.5 feet (2 m) deep during low water times, and no portion of the boundary contains wave-formed or bedrock shoreline (Cowardin et al. 1979).

Freshwater marshes include a very diverse group of wetlands that are characterized by: 1) emergent, soft-stemmed aquatic plants such as cattails, arrowheads, reeds, and other species of grasses and sedges; 2) a shallow water regime; and 3) generally shallow deposits of peat. This wetland type is the most ubiquitous in North America and includes places like the prairie potholes and Florida Everglades. Freshwater marshes are the ecosystem used for the development of this model. Within the SOPN, they are present at Bent's Old Fort National Historic Site (BEOL), Sand Creek Massacre National Historic Site (SAND), Chickasaw National Recreation Area (CHIC), Pecos National Historical Park (PECO), and Lake Meredith National Recreation Area (LAMR).

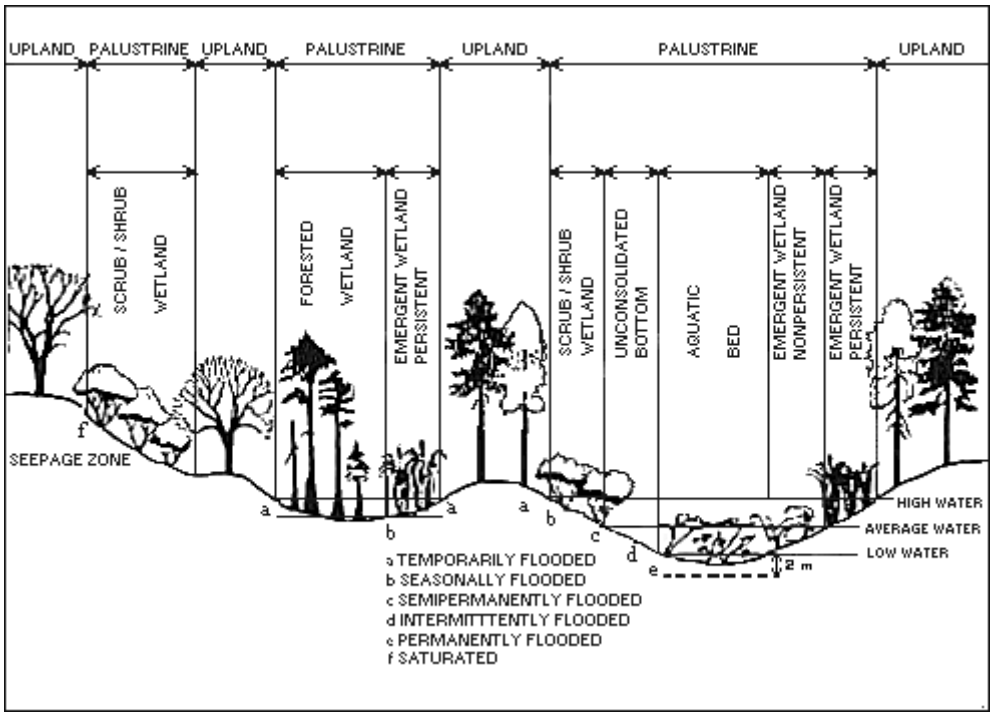



**Figure 1. Distinguishing features and examples of habitats in the Palustrine System (from Cowardin et al. 1979).**

*Riverine Ecosystems*

Riverine ecosystems generally include all wetlands and deepwater habitats contained within a channel. They are bounded by uplands, by wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, or where the channel enters a lake or reservoir. Water is usually, but not always, flowing in this system. Upland islands or Palustrine wetlands may occur in the channel, but they are not included in the Riverine System (Cowardin et al. 1979). Riverine ecosystems are present at Lyndon B. Johnson National Historical Park (LYJO), Washita

Battlefield National Historic Site, Fort Larned National Historic Site, LAMR, CHIC, BEOL, SAND, and PECO. These ecosystems are modeled for SOPN by Sue Braumiller of NPS.

*Lacustrine Ecosystems*

The Lacustrine System includes permanently flooded lakes and reservoirs, intermittent lakes, and tidal lakes with ocean-derived salinities below 0.5 %. Typically, there are extensive areas of deep water and there is considerable wave action. The lacustrine system includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 20 acres (b ha) (Cowardin et al. 1979). Similar wetland and deepwater habitats totaling less than 20 acres (8 ha) are also included in the lacustrine system if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 6.5 feet (2 m) at low water. Lacustrine systems formed by damming a river channel are bounded by a contour approximating the normal spillway elevation or normal pool elevation, except where palustrine wetlands extend lakeward of that boundary (Cowardin et al. 1979). Lacustine ecosystems are present at LAMR, LYJO, and CHIC. These ecosystems are modeled for SOPN by Sue Braumiller of NPS.

## DRIVERS

All ecosystems are influenced by natural and anthropogenic forces. By virtue of being wetlands, hydrology is the major driver for freshwater marsh ecosystems. The periodic drying and inundation is crucial to the ecosystem function of freshwater marshes (Figure 2). Variation in climate, succession, herbivory, and fire are also all important natural processes controlling all wetlands.

Climatic fluctuations over the past century have resulted in changes in local watershed hydrology which directly affect the condition of freshwater marsh ecosystems. Long-term droughts not only reduce water levels but they diminish groundwater supplies. Human accelerated climate change may create more erratic climatic fluctuations and could potentially produce extended droughts.

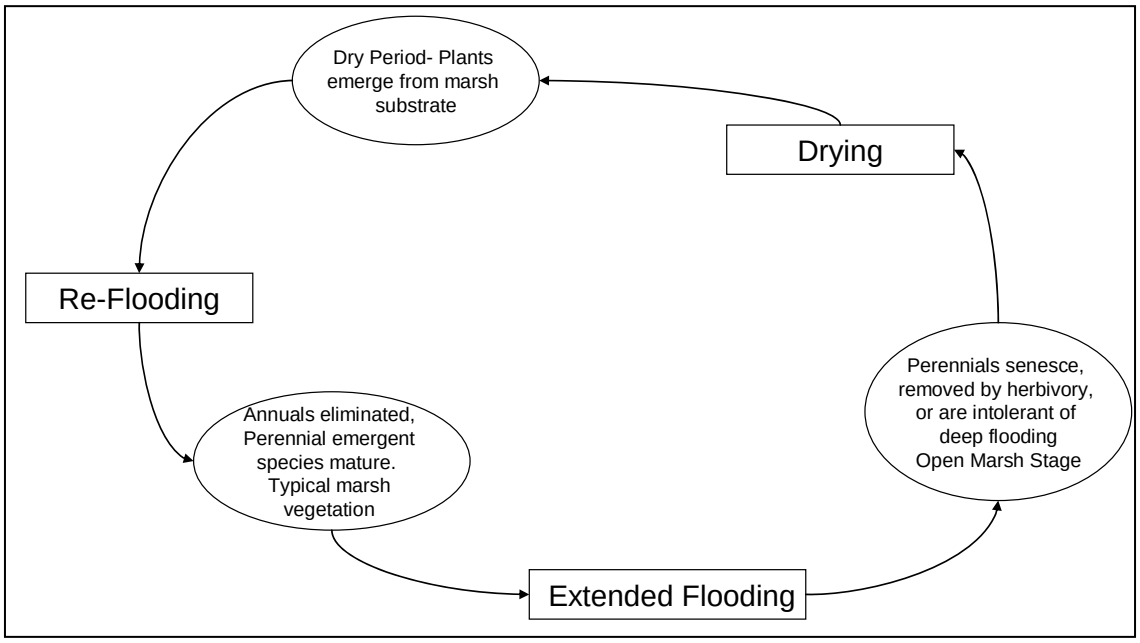



**Figure 2. Typical hydrologic cycle of a freshwater marsh.**

## STRESSOR TYPES

The definition of stress offered by Barrett et al. (1976) is used in this model. Specifically, “Stress is defined here as a perturbation (stressor) applied to a system (a) which is foreign to that system or (b) which is natural to that system but applied at an excessive [or deficient] level.” (Barrett et al. 1976). Hence, agricultural pesticides are a stressor foreign to wetlands. Similarly, nutrients and fire suppression are stressors applied at unnaturally high and low levels respectively.
For the purposes of this model, there are three major stressors that influence wetland ecosystems. They are represented by rectangles in Figure 3.

### *Natural Processes*

Hydrology is the most important factor in wetland ecosystem maintenance and processes. The hydrologic regime is defined as the magnitude, frequency, duration, timing, and rate of change of water level fluctuation (Poff et al. 1997). The hydrologic regime affects soil bio-geochemical processes, nutrient cycling, and nutrient availability. These processes, in turn, influence the biological communities that can be supported in a wetland. Wetland biological communities exert strong influences on the hydrologic regime. For example, accumulation of senesced plants can hinder water circulation. Similarly, beavers (*Castor canadensis*) are considered “ecosystem engineers” because they directly alter water levels and circulation. Duration, frequency, and timing of water level fluctuations are the primary determinants of hydroperiod, which is characteristic of different wetland types. Climatic variation can cause large seasonal and annual fluctuations of the hydroperiod, leading to profound changes in wetland ecosystem structure and function.

The dynamics of succession, or ecosystem development, have been documented in a variety of wetlands. Although alternative theories of succession exist, the collective evidence suggests that wetland biological communities undergo natural changes due to external influences on the hydrologic regime (e.g., climate change) and internal processes that alter environmental conditions (e.g., accumulation of organic matter) (Mitsch and Gosselink 2000).

### *Urbanization*

Urbanization is the leading cause of wetland loss in the United States (Dahl 2000), and directly or indirectly threatens emergent wetlands at LAMR, CHIC and BEOL. Compared to land converted to agriculture, wetland losses to urban and suburban development are small. Nevertheless, wetlands that are not directly affected (e.g., removed or altered) by development are subject to a variety of indirect influences. Drainage and physical disturbance are stressors directly to wetlands if development occurs on the wetland itself. Adjacent development and navigation corridors may alter wetland hydrology, usually by means of hydrologic stabilization. Polluted runoff from urban areas contains toxicants, nutrients, and sediments that potentially enter nearby wetlands. Water diversion, flood control, and reservoir projects often associated with local human population growth, cause permanent flooding in wetlands. Finally, fire suppression generally accompanies urban development due to fears of property loss.

### A*griculture*

Conversion to agricultural land is the major cause of wetland loss worldwide (Mitsch and Gosselink 2000). In fact, some of the world’s most fertile soils were once wetlands in the present states of Iowa, Illinois, and southern Minnesota. Although most land conversion occurred prior to the 1970s, current losses can be attributed to farm programs and economic conditions. Agricultural activities outside park boundaries pose threats to wetlands with SOPN parks. Runoff contaminated with sediment, nutrients, and pesticides reach park wetlands through waterways and drainages that have inadequate buffer zones. Aerial deposition of pesticides and nutrients

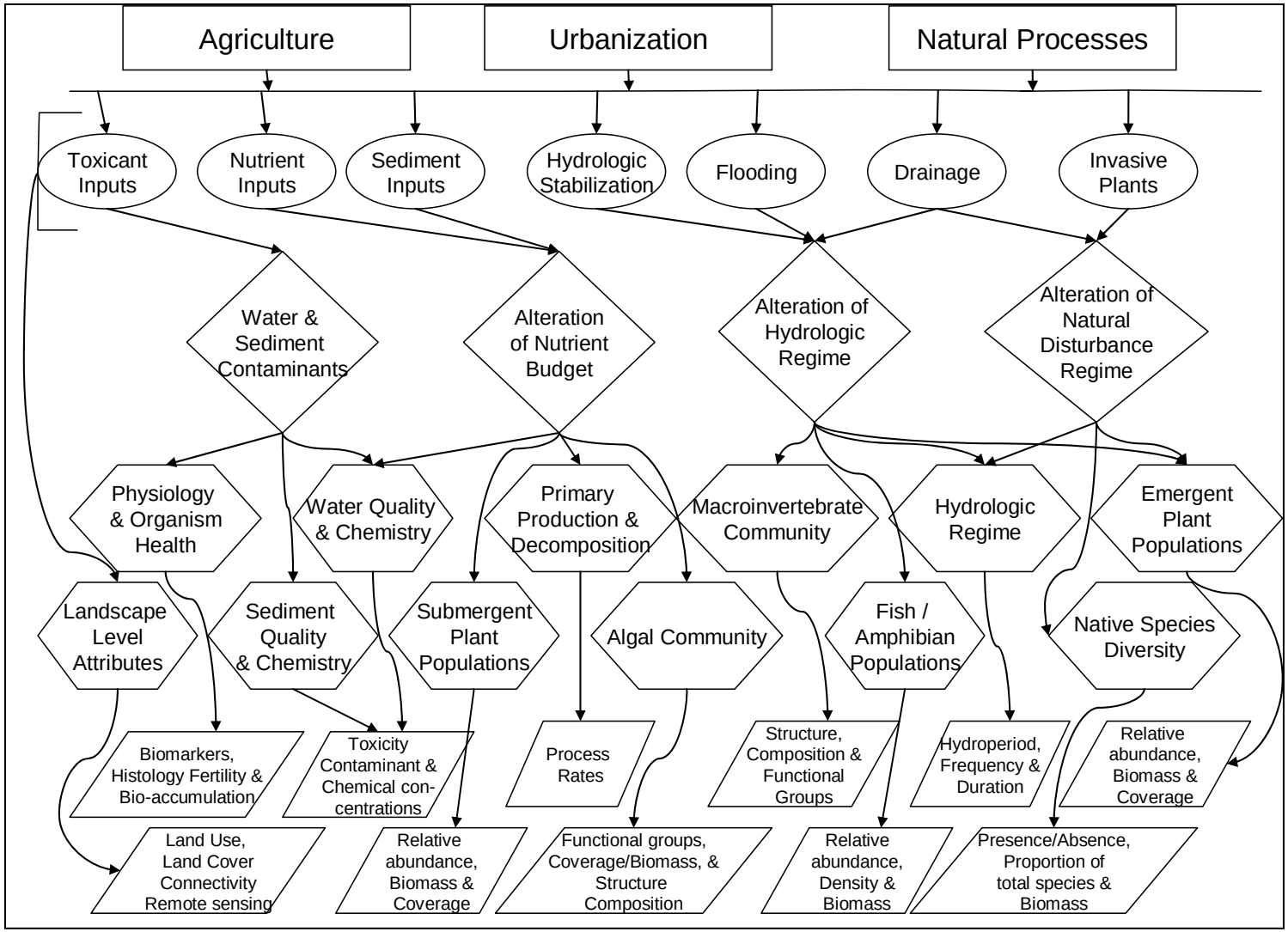



**Figure 3. Freshwater Marsh Conceptual Model.**

has been documented in wetlands downwind of agricultural areas. Wetland destruction and fragmentation on adjacent lands threatens wetland species dependent on migration or dispersal corridors. The primary stressors associated with agricultural activity are drainage, sediments, nutrients, and toxicants. With the discovery of atmospheric contaminant deposition and global climate change, it appears likely that every ecosystem in the biosphere is or will be influenced by humans (Vitousek et al. 1997).

## INDIVIDUAL STRESSORS

All of these individual stressors are a direct or indirect result of one of the major stressor types. The individual stressors are represented in Figure 3 by ovals. All of these stressors affect one or more of the major processes (represented by diamonds) of freshwater marsh ecosystems.

### *Toxicants*

"Toxicants" in this model refers to any anthropogenic chemical that reaches wetlands and potentially elicits toxic effects on organisms, communities, or the ecosystem (Rand 1995). Wetlands receive toxicant inputs from upstream water sources, direct releases, and deposition. Polluted streams, runoff, and groundwater transport toxicants from adjacent or distant sources. Natural or artificial wetlands are often used specifically for filtering contaminants that are released directly into the system. Finally, wetlands receive toxicant inputs from aerial deposition, which has become recognized by widespread mercury contamination of water bodies (Wiener et al. 2002).

The well-known ability of wetlands to assimilate contaminants and "purify" water (Mitsch and Gosselink 2000) is largely due to the perception that contaminants entering wetlands are eventually "locked-up" in sediments, and therefore benign to organisms. However, there is mounting evidence that contaminants buried in wetland soils and sediments are still available to biota and therefore threaten aquatic and terrestrial ecosystems (Landrum and Robbins 1990, McIntosh 1991). For example, up to 2% of the total amount of organochlorines present in lake's sediments were removed from the lake as sediment-dwelling insects emerged into the terrestrial environment. The contaminated insects became a source of contamination to aquatic and terrestrial food webs (Fairchild et al. 1992).

Toxicants influence biota at varying levels of ecological organization. Typically, toxicant exposure is first manifested by the presence of detoxifying enzymes or toxicant metabolites in organism tissues. These so-called "bio-markers" are an active area of research and have the potential to signal early warnings of toxicant exposure. As toxicant exposure time or levels increase, organisms suffer malformations, tumors, stunted growth, lost reproduction, and eventually death. Populations are therefore affected when sufficient individuals suffer toxic effects and alter population abundance, biomass, and productivity. Disproportionate losses of populations lead to changes in community composition, and conceivably alterations in ecological processes.

### *Nutrients*

The most common reason for impairment of U.S. surface waters is eutrophication caused by excessive inputs of nitrogen and phosphorus from non-point sources. More than half of the rivers and lakes that currently fail to meet water quality standards are impaired by nutrients (United States Environmental Protection Agency [USEPA] 1998). The dominant source of nutrients in U.S. surface waters is non-point runoff from agricultural and urban areas (Carpenter et al. 1998). Excessive nitrogen and phosphorus can cause drastic changes in plant communities. The most prominent effect of nutrient enrichment is a proliferation of algae, which can lead to a wide array of additional problems. Algal blooms cause fish kills as decomposition and respiration consume large amounts of oxygen. High algal biomass reduces water transparency, which hinders growth of submergent plants. Aesthetic, recreational, and drinking water values are also reduced by eutrophication.

*Sediment*

Sediment considered in this model is comprised of mostly inorganic particles <2 mm in diameter, thus emcompassing sand, silt, and clays (Wood and Armitage 1997). Although sediments are a natural part of most aquatic ecosystems, human activities have dramatically increased sediment inputs to lakes, streams and wetlands. Most sediment enters wetlands through urban and agricultural runoff. When suspended in water, fine sediments increase turbidity, decrease light penetration, and alter primary productivity. Sediment particles < 63 micrometers (µm) in size are frequently adsorbed to by a variety of contaminants, especially nutrients and heavy metals (Wood and Armitage 1997). Consequently, sediments are an integral part of nutrient- and toxicant-related effects in wetlands. In some cases, excessive sediment accumulation can alter the hydrologic regime.

*Drainage*

Draining, dredging, filling, and ditching are human modifications specifically designed to dry out wetlands. By removing the source of water influx, wetlands are desiccated and the land used for urban development, highway construction, or agriculture. Levees are often constructed with the primary goal of preventing water from entering the former wetland area. This practice has led to farming and development in the floodplains of many rivers, which has also caused widespread property damage and loss of life when rivers flood. Wetland removal and subsequent fragmentation of remaining habitats is associated with declines in the diversity wetland organisms (Lehtinen et. al. 1999).

*Flooding*

Wetlands are sometimes flooded as part of water development and management programs. The most common scenario is the loss of riparian wetlands by reservoir construction. A related human impact is the stabilization of wetland hydrology, typically a result of dams designed to reduce flooding. Because the hydrologic regime is unquestionably the most important controller of wetland ecosystems, human alterations of water flow have damaged wetlands on a grand scale. The effects of drainage, flooding, or any other hydrologic alteration are variable. On one extreme, wetlands are drained and entirely obliterated. On the other hand, many wetlands are cut off from their water source by roads or levees, but remain physically in tact. The loss or alteration of water influx reduces inputs of sediments, nutrients, and propagules. Consequently, long-term changes in plant and animal community composition are the most common effects of hydrologic alteration.

*Invasive Exotic Plants*

The invasion of non-indigenous species seriously threatens wetland ecosystems nationwide (U.S. Congress 1993). Most invasive species in wetlands have escaped landscaping cultivation or were intentionally planted to stabilize sites already disturbed by human activities. Lacking natural enemies, many exotic species rapidly infest wetlands and displace native flora and fauna. Historically, climate, fire, and grazing controlled the diversity and abundance of vegetation in prairie wetlands. Changes in grazing patterns and animals and altered hydrology often favor the survival of introduced species (e.g., tamarisk [*Tamarix spp.*]) and allows thriving non-natives to displace native species. Russian-olive (*Elaeagnus angustifolia*) and tamarisk are two non-native species that have greatly altered western riparian communities (Brock 1984; Shafroth et al. 1998). Not only have they altered the communities they have invaded, they are difficult to remove. For example, tamarisk can repeatedly resprout after fire, cutting, or browsing, and it survives in very wet, very dry, or very salty soils (Gladwin and Roelle 1998; Smith et al. 1998).

In prairie wetlands, disruption of natural processes such as fire has led to domination by robust, emergent plants, particularly in the prairie pothole region. Cattail (*Typha spp.*) and purple loosestrife (*Lythrum salicaria*), once rare on the Great Plains, have spread across thousands of prairie wetlands and threatening waterways across the United States (U.S. Congress 1993;

Malecki and Blossey 1994). Exotic plants such as tamarisk may be increasing fire frequencies and subsequently increasing in dominance after fire (Busch 1995).

## ECOSYSTEM ATTRIBUTES

The twelve attributes shown in Figure 3 are represented by hexagons and are characteristics of the physical (e.g. hydrologic regime), biological (e.g. macroinvertebrates) and chemical (e.g. water chemistry) environment. Potential vital signs are shown in parellograms below each attribute in Figure 3.

### *Physiology and Organism Health*

Some attributes of physiological processes and organism health are indicative of stress on ecosystems and therefore useful in long-term monitoring. Contaminant-induced biochemical processes provide evidence that organisms are being exposed to contaminants in their environment. For example, exposure to heavy metals stimulates cellular production of metallothionein, a protein used to regulate essential metals in most organisms. Cellular damage is minimized because the toxic metal is sequestered by metallothionein and effectively removed from circulation (Klaverkamp et al. 1991). Similarly, analyses for contaminants that accumulate in the tissues of organisms provide important information exposure. Finally, growth and reproduction, which are essential for all organisms, are often indicative of anthropogenic stress (e.g., Beyers et al. 1999).

### *Sediment Quality and Chemistry*

Sediment is defined here as the organic and inorganic soils and substrates of wetlands. Sediments are a major part of biogeochemical cycling in wetland ecosystems (Mitsch and Gosselink 2000) and provide habitat for many organisms. Most anthropogenic chemicals eventually accumulate in sediments due to a variety of hydrological and chemical processes (Ingersoll 1995). Sediment contamination is a widespread problem in aquatic ecosystems of the U.S. and poses significant threats to ecological and human health (NRC 1989). Contaminated sediments may be directly toxic to organisms or can be a source of contamination in the food chain. The most common contaminants found in sediments are heavy metals, pesticides, persistent organic chemicals, and hydrocarbons.

### *Primary Production and Decomposition*

Ecosystem processes, and the biogeochemical cycles they control, are fundamental attributes of all ecosystems. Primary production, which is the rate of plant biomass accumulation, is sensitive to anthropogenic alteration of the nutrient budget, hydrologic regime, and natural disturbance processes. Primary production in freshwater marshes often equals or exceeds cultivated crops (Mitsch and Gosselink 2000). Primary production in freshwater swamps is highly influenced by the duration and timing of flooding, and therefore sensitive to anthropogenic alterations of wetland hydrology.

Decomposition, which is the rate at which carbon from organic matter is metabolized and released as carbon dioxide, is a significant part of wetland ecosystems. Decomposition is slow in anaerobic or permanently wetted environments (Mitsch and Gosselink 2000). Wetlands are therefore a major carbon sink in the biosphere because they tend to accumulate dead organic matter (Mitsch and Gosselink 2000). Hence, much of the food webs supported in these ecosystems are ultimately dependent on detritus and microbes.

### *Submergent Plant Populations*

Submergent plants have their photosynthetic tissues completely submerged, but flowering structures often extend above the water surface (Richardson and Vymazal 2001). Submerged

plant communities are important habitat for numerous wetland animals. For example, many fish species rely on submergent beds for spawning and larval development (Tiner 1999). The productivity and distribution of submergents is strongly influenced by light penetration to the benthic environment. Consequently, anthropogenic increases in suspended inorganic particles or phytoplankton biomass are detrimental to submergent plant populations.

*Water Quality and Chemistry*

Water quality is fundamental to the functioning of all aquatic and semi-aquatic ecosystems. Although water quality standards for lakes and streams are well-established, chemical and biological criteria for wetlands are still under development. The U.S. Environmental Protection Agency mandated that states would have water quality standards for wetlands by 1993 (USEPA 1990). However, most states are still developing standards and criteria (Apfelbeck 2001).

*Macroinvertebrate Community*

Insects, crustaceans, and other invertebrates are highly diverse and abundant, and play central roles in aquatic food webs. Within most taxonomic groups there are typically many species with a variety of environmental requirements and sensitivity to stressors. As a result, macroinvertebrate communities have been used for over three decades in ecological evaluations of aquatic systems (Rosenberg and Resh 1993) and are currently being used by the Heartlands Network and Prairie Cluster Prototype (Peterson et al. 1999).

*Algal Community*

Algae occur in most wetlands that contain standing water for even short periods. Algae are important sources of wetland primary production, transform and retain nutrients, stabilize substrates, provide habitat for other taxa, and are an important food source for many animals (Stevenson 2001). Algae are useful for wetland biological assessments because they are diverse, abundant, and have a wide range of known tolerance to environmental (e.g., water quality) factors (Mayer and Galatowitsch 1999). Taxonomy is sufficiently developed to ensure consistency and relative ease in identifying most common algal genera.

*Emergent Plant Populations*

Emergent macrophytes are the dominant form of plant life in most wetlands (Richardson and Vymazal 2001). In general, they produce aerial stems and leaves and an extensive root system. These plants are morphologically and physiologically adapted to growing in waterlogged environments, and are therefore used to delineate wetlands (NRC 1995). Emergent macrophytes are a major component in wetland food webs and nutrient cycles. Because many emergent plants have narrow tolerances of hydrologic conditions, salinity, water chemistry, and nutrient levels, population and community-level monitoring can be used to detect changes in environmental conditions (Tiner 1999).

*Hydrologic Regime*

As discussed above, the hydrologic regime is the dominant environmental control of wetland ecosystems. Consequently, the hydrologic regime itself is an important ecosystem component and requires monitoring in addition to other physical, chemical, and biological attributes. This model adopts the definition of hydrologic regime given by Poff et al. (1997), which includes magnitude, frequency, duration, timing, and rate of change of flows in river systems. Each of these attributes of river hydrology apply to wetland ecosystems as well, and are briefly described below.

The magnitude refers to the water that inundates a wetland, and can be measured by water depth or volume. The frequency refers to how often a wetland is inundated. Seasonal inundation is most

common, but annual time scales are relevant for many wetlands. The duration is the period of time associated with a specific inundation level and may be weeks or years depending on the type of wetland and climate. The timing refers to the regularity with which inundation occurs. For example, although many wetlands are predictably inundated during specific seasons, others may be inundated intermittently and unpredictably based on weather conditions. The rate of change refers to how quickly water levels change and strongly influences the water residence time in wetlands. This, in turn, has important implications for numerous ecological processes. Lent et al. (1997) developed indicators for monitoring wetland hydrologic regimes.

*Fish and Amphibian Populations*

Although small, ephemeral wetlands rarely support fish, deeper wetlands that are hydrologically connected to larger water bodies may support great varieties and abundance of fish species. The relatively warm, productive habitat with abundant plants provides ideal nursery habitat for many fish species. Population monitoring of such fish species would provide an important linkage between vegetation communities and vertebrate populations (Mitsch and Gosselink 2000).

Amphibian species are currently in a global decline (Blaustein and Wake 1990), and have therefore received much attention in scientific and public dialogue. Because their life cycle integrates aquatic and terrestrial systems amphibians are excellent indicators of overall watershed condition. Amphibians are also an important trophic link between aquatic invertebrates and birds, reptiles, and mammals.

*Native Species Diversity*

The Endangered Species Act is a legislative affirmation that the preservation of native species is a long-standing priority in the United States. The NRC (2000) also identified native species diversity as an important indicator of ecosystems. In general, native species diversity is negatively associated with the degree of human disturbance in ecosystems, and therefore represents a useful indicator of the human imprint on the land (NRC 2000). This indicator would undoubtedly be useful in wetland ecosystem monitoring.

*Landscape Level Attributes*

The size, position, and number of wetlands, as well as land use and land characteristics in the vicinity of wetlands are examples of this category. These attributes, often measurable through an analysis of a series of remote sensing or aerial images, can affect all of the other attributes described above. Sediment supply (e.g., through erosion), concentration of nutrients and toxins (e.g., through nonpoint and point source pollution), changes in hydrology (e.g., through dams, shoreline stabilization, dredging, diking, and flooding), introduction of invasive species, and metapopulation dynamics (e.g., through vicinity of and corridors between wetlands) may all be affected by landscape level attributes.

Increasing the percent cover of impervious surfaces within a watershed will increase runoff and the sediments, nutrients, and toxins carried by runoff. Shoreline stabilization may decrease the areal extent of a wetland. Invasive species may be introduced to a wetland more readily if the wetland is surrounded by urban or agricultural land use. Fewer wetlands and loss of connective corridors between wetlands may contribute to population extinctions or genetic bottlenecks through restricted gene flow.

## LITERATURE CITED

Apfelbeck, R.S. 2001. Development of biocriteria for wetlands in Montana. Pages 141-166 in Bioassessment and management of North American freshwater wetlands. R.B. Rader, D.P. Batzer and S.A. Wissinger (eds.). John Wiley & Sons, Inc. New York, USA.

Barrett, S.W., G.M. Van Dyne, and E.P. Odum. 1976. Stress ecology. BioScience 26(3):192-94.

Beyers, D.W., J. A. Rice, and W.H. Clements.1999. Evaluating biological significance of chemical exposure to fish using a bioenergetics-based stressor-response model. Canadian Journal of Fisheries and Aquatic Sciences 56:823-829.

Blaustein, A.R., and D.B. Wake. 1990. Declining amphibian populations: A global phenomenon? Trends in Ecology and Evolution 5:203-204.

Brock, J.H. 1984. Tamarix spp. (salt cedar), an Invasive Exotic Woody Plant in Arid and Semi-Arid Riparian Habitats of Western USA. In: Ecology and Management of Invasive Riverside Plants.L. de Wall, L. Child, P. Wade, and J. Brock (eds.). John Wiley and Sons, New York, NY, USA. pp. 27-44.

Busch, D. E. 1995. effects of fire on southwestern riparian plant community structure. Southwestern Naturalist 40(3):259-267.

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8(3): 559-568.

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jmestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm (Version 04DEC98).

Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp.

Fairchild, J.F., E.E. Little, and J.N. Huckins. 1992. Aquatic hazard assessment of the organophosphate insecticide Fonofos. Archives of Environmental Contamination and Toxicology 22(4):375-379.

Gladwin, D.N. and J.E. Roelle, 1998. Survival of Plains Cottonwood (*Populus deltoides subsp. monilifera*) and Salt Cedar (*Tamarix ramosissima*) Seedlings in Response to Flooding. Wetlands 18:669-674.

Ingersoll, C.G. 1995. Sediment tests. Pages 231-256 in Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. G.M. Rand (ed.). Taylor and Francis. Washington, D.C., USA

Klaverkamp, J.F. Dutton, M.D. Majewski, H.S. Hunt, R.V., and L.J. Wesson. 1991. Evaluating the effectiveness of metal pollution controls in a smelter by using metallothionein and other biochemical responses in fish. Pp 33-64 in Metal ecotoxicology: concepts and applications. Newman, M.C., and A.W. McIntosh, (eds.). Lewis Publishers, Chelsea, Michigan, USA.

Landrum P. F. and Robbins J.A. 1990. Bioavailability of sediment_associated contaminants to benthic invertebrates. Pp. 237-263 in: Sediments: Chemistry and Toxicity of In-Place Pollutants. R. Baudo, J. P. Giesy, and H. Muntau, (eds.). Lewis Publishers, Inc. Ann Arbor, Michigan, USA.

Lehtinen, R.M., S.M. Galatowitsch, and J.R. Tester. 1999. Consequences of habitat loss and fragmentation for wetland amphibian assemblages. Wetlands 19:1-12.

Lent, R.M., P. K. Weiskel, F. P. Lyford. and D. S. Armstrong. 1997. Hydrologic indices for nontidal wetlands. Wetlands 17: 19-30.

Malecki, R., and B. Blossey. 1994. Insect biological weed control: an important and underutilized management tool for maintaining native plant communities threatened by exotic plant introductions. Transactions of the North American Wildlife and Natural Resources Conference 59:400-404.

Mayer, P.M., and S.M. Galatowitsch. 1999. Diatom communities as ecological indicators of recovery in restored prairie wetlands. Wetlands 19:

McIntosh, A. W. 1991. Trace metals in freshwater sediments: A review of the literature and an assessment of research needs. Pp. 243-260 in Metal ecotoxicology: concepts and applications. M. C. Newman and A.W. McIntosh, (eds.). Lewis Publishers, Chelsea, MI, USA.

Mitsch, W.J., and J.G. Gosselink. 2000. Wetlands. Third Edition. John Wiley and Sons, Inc., New York, USA.

National Research Council. 1989. Contaminated Marine Sediments: Assessments and Remediation. National Academy Press, Washington, D.C., USA.

National Research Council. 1995. Wetlands: Characteristics and boundaries. National Academy Press, Washington, D.C., USA.

National Research Council. 2000. Ecological Indicators for the Nation. National Academy Press, Washington, D.C., USA.
Peterson, J. T., W. M. Rizzo, E. D. Schneider, and G. D. Willson. 1999. Macroinvertebrate biomonitoring protocol for four prairie streams. U.S. Geological Survey 48pp.
Poff, N.L, J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Ritcher, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. BioScience 47: 769-784.
Rand, G.M., ed. 1995. Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. Second Edition. Taylor and Francis, Washington, D.C.
Richardson, C.J. and J. Vymazal. 2001. Sampling macrophytes in wetlands. Pp. 297-338 (Chapter 14) in: Rader, R., D.P. Butzer, and S.A. Wissinger (eds.), Bioassessment and Management of North Americn Freshwater Wetlands . John Wiley and Sons, New York, USA.
Rosenberg, D. and V. Resh. 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman Hall Publishers.
Shafroth, P.B., G.T. Auble, J.C. Stromberg and D.T. Patten, 1998. Establishment of Woody Riparian Vegetation in Relation to Annual Patterns of Streamflow, Bill Williams River, Arizona. Wetlands 18:577-590.
Smith, S.D., D.A. Devitt, A. Sala, J.R. Cleverly and D.E. Busch, 1998. Water Relations of Riparian Plants from Warm Desert Regions: Vegetation Water Sources, Effects of Streamflow Diversion and Invasion of *Tamarix ramosissima*. Wetlands 18:687-696.
Stevenson, R. J. 2001. Using algae to assess wetlands with multivariate statistics, multimetric indices, and an ecological risk assessment framework. In: R. R. Rader, D. P. Batzger, S. A. Wissinger, (eds.). Biomonitoring and Management of North American Freshwater Wetlands. Pp. 113-140. John Wiley & Sons, Inc. New York, USA.
Tiner, R. 1999. Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping. Lewis Publishers, Inc., Chelsea, Michigan, USA.
US Congress. 1993. Harmful Non-Indigenous Species of the United States (OTA-F-565). Office of Technology Assessment, U.S. Government Printing Office, Washington DC., USA
United States Environmental Protection Agenct. 1990. Agency Operating Guidance, FY 1991: Office of Water. Office of the Administrator, Washington, DC., USA.
United States Environmental Protection Agency. 1998. The Quality of our nation's waters: a summary of the national water quality inventory: 1998 report to congress. Office of Water. Pub. No. 841-S—00-001. Washington, DC, USA.
Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of earth's ecosystems. Science 277:494-499.
Wiener, J. G., D. P. Krabbenhoft, G. M. Heinz, and A. M. Scheuhammer. 2002. Ecotoxicology of mercury. Pages 409-463 in Handbook of ecotoxicology, Second edition. D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, (eds.). CRC Press, Boca Raton, Florida, USA.
Wood, P. J. and P. D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21:203-217.

## APPENDIX W. SOPN RIVERINE AND LACUSTRINE CONCEPTUAL MODEL

Sue Braumiller

TABLE OF CONTENTS

Table of Contents ..... A-432
List of Figures ..... A-434
List of Tables ..... A-435
Acknowledgments ..... A-436

W.1. INTRODUCTION AND BACKGROUND ..... A-437
*W.1.1. Purpose and Content of This Appendix ..... A-437*
*W.1.2. Water Resources of the Southern Great Plains ..... A-437*
W.1.2.1. Streams and Rivers (Riverine Sytems) ..... A-439
W.1.2.2. Reservoirs (Lacustrine Systems) ..... A-440
W.1.2.3. Prairie Wetlands (Palustrine Systems) ..... A-440
*W.1.3 Overview of Stream, Reservoir, and Riparian Ecosystem Models ..... A-441*
W.2. STREAM ECOSYSTEM MODEL ..... A-444
*W.2.1. Summary of Drivers, Stressors, Attributes, and Indicators of Stream Ecosystem Function and Condition ..... A-444*
W.2.1.1. Hierarchy of System Drivers ..... A-446
*W.2.2. Stream Ecosystem Function under Natural/Desired Conditions ..... A-449*
W.2.2.1. Streamflow Regime ..... A-449
W.2.2.2. Stream Sediments / Geomorphology ..... A-451
W.2.2.3. Water Quality/Chemistry ..... A-455
W.2.2.4. Stream Biota ..... A-456
W.2.2.5. Stream Ecosystem Dynamics ..... A-458
*W.2.3. Natural and Anthropogenic Stresses and Stream Ecosystem Response ..... A-460*
W.2.3.1. Disturbance Regime Theory ..... A-461
W.2.3.2. Streamflow Alteration ..... A-461
W.2.3.3. Alteration of Stream Geomorphology ..... A-463
W.2.3.4. Ungulate Grazing and Trampling ..... A-464
W.2.3.5. Recreation ..... A-465
W.2.3.6. Altered Fire Regime ..... A-466
W.2.3.7. Non-Point and Point Contaminant Releases ..... A-467
*W.2.4 Benefits of Stream Classification for Long-Term Monitoring ..... A-467*
W.3. RESERVOIR ECOSYSTEM MODEL ..... A-484
*W.3.1. Summary of Drivers, Stressors, Attributes, and Indicators of Reservoir Ecosystem Function and Condition ..... A-484*
*W.3.2. Reservoir Ecosystem Function under Desired Conditions ..... A-484*
W.3.2.1. Major Habitats of Reservoir Ecosystems ..... A-487
W.3.2.2. Natural Processes ..... A-488
*W.3.3. Natural and Anthropogenic Stresses and Reservoir Ecosystem Response ..... A-488*
W.3.3.1. Anthropogenic Influences ..... A-488
W.3.3.2. Specific Stressors ..... A-489
W.4. RIPARIAN ECOSYSTEM MODEL ..... A-507
*W.4.1. Summary of Drivers, Stressors, Attributes, and Indicators of Riparian Ecosystem Function and Condition ..... A-507*
*W.4.2. Riparian Ecosystem Function under Natural/Desired Conditions ..... A-507*
W.4.2.1. Riparian Water Resources ..... A-507
W.4.2.2. Riparian Zone Soils/Morphology ..... A-510
W.4.2.3. Riparian Vegetation ..... A-512

W.4.2.4. Riparian Zone Invertebrates and Vertebrates ..... A-513
W.4.2.5. Riparian Ecosystem Dynamics..... A-514
*W.4.3. Natural and Anthropogenic Stresses and Riparian Ecosystem Response ..... A-514*
W.4.3.1. Stream Flow Alteration ..... A-515
W.4.3.2. Alteration of Riparian Zone Soils/Morphology..... A-517
W.4.3.3. Ungulate Grazing and Trampling ..... A-517
W.5. AQUATIC INVERTEBRATES AS INDICATORS OF ECOSYSTEM CONDITION..... A-536
W.6. REFERENCES..... A-537

LIST OF FIGURES


Figure 1. Physical boundaries of stream, reservoir, and riparian ecosystem models ..... A-442
Figure 2. Palustrine wetlands as a subset of riparian ecosystems. From Mitsch and Gosselink (2000) ..... A-444
Figure 3. Overview of drivers, stressors, attributes, and indicators of stream ecosystem function and condition ..... A-445
Figure 4. An idealized diagram of a fluvial system featuring: (1) a zone of sediment production (watershed); (2) zone of transport (rivers and streams); and (3) zone of deposition (alluvial fans and deltas). From Scott et al. (2005), after Schumm (1981) ..... A-448
Figure 5. Natural/desired stream ecosystem function. Modified from Scott et al. (2005) ..... A-450
Figure 6. Idealized flow paths from a watershed to a stream. Adapted from Scott et al. (2005), after Dunne (1978) and Ziemer & Lisle (1998) ..... A-451
Figure 7. Stream hydrographs. (a) Idealized relationship between stormflow and baseflow components of a stream hydrograph for a discrete rainfall event. (b) Idealized hydrograph of an ephemeral stream featuring highly variable and temporally unpredictable peak flows. (c) Idealized hydrograph of an unregulated, large perennial stream featuring variable but temporally predictable seasonal peak flow (from Scott et al. 2005, modified after Dunne 1978) ..... A-452
Figure 8. A qualitative classification of stream channels based on pattern (straight, meandering, or braided) and type of sediment load, along with flow and sediment variables and stability (level of erosional activity). From Scott et al. (2005), after Schumm (1981) ..... A-453
Figure 9. Broad level stream classification based on channel slope, channel shape (cross-section geometry), and channel pattern (sinuosity, meander width ratio, and single, braided, or anastomosed channel configuration). From Rosgen (1996)..... A-454
Figure 10. River continuum concept. From Mitsch and Gosselink (2000) ..... A-460
Figure 11. Overview of drivers, stressors, attributes, and indicators of reservoir ecosystem function and condition ..... A-485
Figure 12. Desired reservoir ecosystem function ..... A-486
Figure 13. Overview of drivers, stressors, attributes, and indicators of riparian ecosystem function and condition ..... A-508
Figure 14. Natural/desired riparian ecosystem function. Modified from Scott et al. (2005) ..... A-509

LIST OF TABLES

Table 1. Fluvial system variables over geologic time scales. From Scott et al. (2005), after Schumm (1981) ..... A-446
Table 2. Stresses and impacts on streamflow regime ..... A-468
Table 3. Stresses and impacts on stream sediments/geomorphology ..... A-470
Table 4. Stresses and impacts on stream water quality/chemistry ..... A-473
Table 5. Stresses and impacts on stream biota ..... A-476
Table 6. Summary of stresses and indicators of stream ecosystem function and condition ..... A-480
Table 7. Stresses and impacts on reservoir inflows, outflows, and water level ..... A-492
Table 8. Stresses and impacts on reservoir sediments/morphology ..... A-493
Table 9. Stresses and impacts on reservoir water quality/chemistry ..... A-495
Table 10. Stresses and impacts on reservoir stratification/mixing ..... A-498
Table 11. Stresses and impacts on reservoir biota ..... A-499
Table 12. Summary of stresses and indicators of reservoir ecosystem function and condition ..... A-503
Table 13. Stresses and impacts on the availability of water in the riparian zone ..... A-518
Table 14. Stresses and impacts on riparian zone soils/morphology ..... A-520
Table 15. Stresses and impacts on riparian zone water quality/chemistry ..... A-523
Table 16. Stresses and impacts on riparian zone biota ..... A-527
Table 17. Summary of stresses and indicators of riparian ecosystem function and condition ..... A-531

**Acknowledgements**

Documentation has been adopted extensively from materials prepared for the Northern and Southern Colorado Plateau I&M Networks (Scott et al. 2005) [Sections 1, 2, 4, and 5] and the Great Lakes I&M Network (Inland Lakes, Sager 2004) [Section 3].

## W.1. INTRODUCTION AND BACKGROUND

### *W.1.1. Purpose and Content of This Appendix*

This appendix presents conceptual models describing the structure and functioning of aquatic and riparian ecosystems[1] of the Southern Plains I & M Network (SOPN). These models have been developed to support the selection of vital signs for use in long-term monitoring of SOPN aquatic and riparian resources in 11 National Park Service units located in Texas, New Mexico, Colorado, Kansas, and Oklahoma (see Appendix E for natural resource summaries of each park).

Conceptual models for stream, reservoir, and riparian ecosystems of SOPN parks are presented in Sections 2, 3, and 4, respectively. Each section begins with a general description of ecosystem drivers, stressors (both anthropogenic and natural), major ecosystem components/attributes, and a summary of indicators of ecosystem function and condition. A second subsection describes natural/desired ecosystem function, including a detailed description of ecosystem attributes and processes and functional relationships between abiotic and biotic components. A third subsection describes specific ecosystem stresses, responses, and indicators of ecosystem condition as an aid in selecting vital signs representing the greatest number of key ecosystem processes and attributes. Section 2 also includes a discussion of the benefits of stream classification for long-term monitoring of stream and riparian ecosystems. This appendix closes with a discussion of the value of aquatic macroinvertebrates as indicators of aquatic ecosystem function and condition.

Included in this report are all aquatic and riparian ecosystems of SOPN parks - lotic (flowing water systems), including perennial and intermittent streams/rivers, and lentic (standing water systems), comprised primarily of reservoirs. In general, the abiotic characteristics of lotic systems are more heterogeneous, increasing the biological diversity of stream ecosystems (Thorp and Covich 1991). An additional model for palustrine freshwater marshes is presented as a separate model elsewhere in Appendix V.

### *W.1.2. Water Resources of the Southern Great Plains*

The SOPN has recognized from the beginning that the water resources of the network, whether in the form of precipitation or in water bodies, are a primary component of all the network ecosystems. Water has long been a scarce resource in the western and central portions of the Great Plains. Surface water is important for ecological reasons, but the presence of surface water was also important for European settlers. Eight of the 11 SOPN parks were created, at least in part, due to their cultural significance to Native Americans or early settlers. All of these cultural parks are located near flowing rivers because of their importance to Native Americans and early settlers. So while, surface water is still a rarity in the Great Plains, SOPN parks have a higher proportion of surface waters then would occur on a random selection of prairie areas. Lake Meredith NRA and Chickasaw NRA were created largely for the large reservoirs present. All SOPN parks except for Capulin Volcano NM, Alibates Flint Quarries NM, and Fort Union NM have permanent water resources, with the latter two being located very close to permanent water.

Many of the basic features of historical Great Plains streams, such as flow and substrate, are unknown (Matthews 1988), as these were among the first things altered by early settlers. Great

[1]An *ecosystem* is a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries (Likens 1992, cited by Christensen et al. 1996:670). *Ecosystem structure* refers to the types, amounts, and spatial arrangement of biotic and abiotic components of an ecosystem. *Ecosystem functioning* refers to the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem (includes processes such as primary production, trophic transfer from plants to animals, nutrient cycling, water dynamics and heat transfer).

Plains Rivers generally flow from west to east and are characterized by extreme turbidity, high evaporation rates, moderate flow velocity and dynamic channels. Great Plains streams fall into three categories: the shallow stream with shifting sand beds; clear brooks, ponds, and marshes supported by seeps and springs; and residual pools of intermittent streams (Cross and Moss 1987). In general, streams in the southern plains are characterized by irregular flow, small particle size in substrates, and a distinct wet-dry cycle. Much of the water originates from the western mountains, while many types of sediment originate from thunderstorm runoff on the Great Plains. Early travelers were inhibited by quicksands in small channels, fine particles held in suspension. These fine particles also cause extreme turbidity during low flows. Like the plains themselves, river temperatures can fluctuate widely with summer, open-river water temperatures exceeding 86°F (30°C), and high salinity levels due to salt- and gypsum-laden groundwater.

The High Plains aquifer, also known as the Ogallala aquifer, is located in the central Great Plains and consists predominantly of unconsolidated gravel, sand, silt, and clay (the Ogallala Formation). The aquifer is essential for agriculture, water supply (urban and residential), and environmental resources in the area, underlying about 20% of irrigated farmland in the High Plains and providing about 30% of water for irrigation (Huntzinger 1996). Precipitation is the principal source of recharge to the aquifer, but additional recharge occurs as seepage from streams and lakes. Discharge from the aquifer occurs as evapotranspiration where the water table is near the surface.

There have been significant changes in the amount and permanency of surface and ground water since pre-Columbian times as a result of ranching (e.g., stock ponds), irrigation, flood control, and other anthropogenic changes. Few major rivers in the Great Plains still exhibit the conditions evident before agricultural development and water management had occurred. Dams, irrigation, municipal withdrawals, and other land use changes have significantly impacted flows and water levels in streams, rivers, reservoirs, and wetlands of the Great Plains (Cross and Moss 1987, Longo and Yoskowitz 2002). Sediment deposition is part of reservoir design but remains a maintenance concern. In virtually all the river systems, dewatering has altered the timing and extent of flows, downstream temperatures, levels of dissolved nutrients, sediment transport and deposition, and the structure of plant and animal communities. Dams exist at three SOPN parks and all of the SOPN aquatic resources are affected by altered flows primarily from agriculture and development.

Water quality and quantity are high priority issues at SOPN parks. Water quality throughout the Great Plains has also been affected by herbicides and other pollutants, and SOPN parks are no exception. Agricultural use of nitrogen fertilizers is the largest source of nitrates in near-surface aquifers in the midcontinent (Koplin et al. 1994). For example, over 100,000 metric tons of pesticides (herbicides, insecticides, and fungicides) were applied in the midcontinent in 1991, often to control nonindigenous plants and animals. Effects of these pollutants on the quality of human life and on the integrity of the ecological community are largely unknown. The U.S. Environmental Protection Agency has initiated an effort to develop stressor information to help recognize areas where urban development, agricultural nonpoint pollution (pesticides, toxic chemicals, nutrient pollution), and agricultural development may exacerbate ecological decline. Elevated *E.coli* levels are also a concern at Chickasaw NRA.

Groundwater depletion is of regional concern for both Great Plains ecology and human needs. Kromm and White (1992) observed that groundwater depletion has destroyed much of the water-supported habitat for fish and mammals in parts of the Great Plains. They reported that more than 700 miles (1,127 km) of once permanently flowing rivers in Kansas no longer flow year round. From the mid-1940's to 1980, groundwater levels dropped 10 to 50 feet in most areas of the High Plains aquifer, and 50 to more than 100 feet in heavily irrigated portions of the Southern High Plains of Texas, out of a total saturated thickness of 650 feet or less (U.S. Geological Survey Groundwater Atlas of the United States; Dugan et al. 1994). Groundwater quantity and quality

are important resource and management issues at Chickasaw NRA and Bent's Old Fort NHS, in particular, where large-scale groundwater developments have been proposed and (in the case of Bent's Old Fort) irrigation pumping is significant.

W.1.2.1. Streams and Rivers (Riverine Systems)

The study of prairie streams and rivers is still in the ecological exploration stage compared to forested streams. The standard River Continuum Concept (Vannote et al. 1980) may not apply to prairie streams. The most detailed work on prairie streams has been completed at King's Creek located at the Konza LTER site in tall-grass prairie (Gray and Dodds 1998, Gray et al. 1998), with less work occurring in the mixed- and short-grass prairies.

Most watersheds in the SOPN drain the eastern slope of the Rocky Mountains and flow from west to east, traversing plains of Quaternary sediments underlain by the Ogallala aquifer (Eschner et al. 1983). Prairie streams and rivers are usually characterized by stable flows during spring and early summer, and intermittent flow to completely dry in the summer. Floods can scour the channel at any time. Flow in the main stem of rivers during early summer is derived from snowmelt runoff, which can decline and leave some channels intermittent during the summer (Jordan 1891, Mead 1896, Eschner et al 1983, Cross et al. 1985). In the plains tributaries, the flows come primarily from spring rains and summer thunderstorms which produce flash floods due to impermeable soils that produce high runoff (Fausch and Bramblett 1991).

Historically rivers would have resulted in narrow gallery forests. However these riparian forests have expanded since pre-European times (Wedel 1986, Knopf and Scott 1990). Fringe riparian forests would have cycled on 50-150 year intervals (Scott et al. 1996) due to large runoff periodically eliminating woody species and contributing large woody debris to channels. Some streams in the west may have been almost devoid of trees. As the stream flow varies, so does physicochemical variables such as water temperature, dissolved oxygen, turbidity, and salinity (Matthews and Zimmermann 1990). Channel beds of large rivers were historically shifting sand, wide and shallow with braided shifting sand beds that formed numerous bars and islands, and turbid water due to the high sediment load (Cross and Moss 1987, Bramblett and Fausch 1991a). The biotic community that has evolved with prairie streams has developed the ability to adjust to a patchy environment that is created by the variable streamflow and associated large changes in temperature and turbidity.

Variable stream flows and regular droughts create a particularly harsh environment for fish. Little is known about the original distributions and ecology of many fish in the Great Plains because habitats were drastically altered before observations had been made (Eschner et al. 1983). Great Plains fish species can be characterized by being relatively small (<8 inches (200 mm)), highly vagile, having life spans <6 years, and being well-adapted to withstand floods and extremes during droughts (Fausch and Bestgen 1997). Most plains fish species are generalists that occupy habitats and consume food resources in proportion to what is available (Bramblett and Fausch 1991b).

With the discovery of gold in the mountains west of Denver in 1858, development progressed rapidly. Water development began with small ditches that were followed by larger canals for irrigating terraces in the 1840's to 1860's. Since some of the rivers went dry, reservoirs were built in the late 1800's and early 1900's. With the demand for water still increasing, groundwater began being pumped from the Ogallala aquifer in the 1930's (Fausch and Bestgen 1997). These water development projects had drastic effects on river channels, including narrowing, and becoming more sinuous due to encroaching vegetation (Nadler and Schumm 1981). Reduced runoff allowed seedlings of woody vegetation to stabilize shifting sand bars. The vegetated sand bars trapped sediment and eventually attached to the floodplain, changing the straight wide braided channels to single narrow sinuous ones. The increase in cottonwood (*Populus deltoides*) riparian forests now contributes more woody debris to the stream channel then historic levels.

The creation of the John Martin Reservoir on the Arkansas River in 1942 combined with groundwater pumping in Colorado and western Kansas completely eliminated flow in 100 miles (160 km) of the Arkansas, except for discharge from municipal wastewater treatment plants (Fausch and Bestgen 1997).

W.1.2.2. Reservoirs (Lacustrine Systems)

Reservoir systems are the principal resources at two parks in the SOPN, LAMR and CHIC, and therefore drive many of those Park's management decisions and visitor usage. Additionally, the Pedernales River is impounded by three dams in, and adjacent to at LYJO. These artificial lakes were originally designed to satisfy the increasing need for water resources. They supplied water to surrounding municipalities, industries, agricultural communities, and regulated stream flow. Today, reservoirs continue to satisfy the well-defined economic objectives for which they were developed. However, at the same time reservoir systems are posing challenges to natural resource managers, including those at CHIC, LAMR, and LYJO. When reservoirs replace riverine ecosystems, new physical and biological conditions are created that managers must protect and preserve. Reservoirs have unique operational and maintenance characteristics compared to those of natural lakes (Flug 1998).

The effects that reservoirs have upon the surrounding natural ecosystems are broad. For example, man-made reservoirs, unlike natural lakes, tend to experience large fluctuations in water levels, and are highly susceptible to bank instability and erosion (Flug 1998). Furthermore, reservoirs trap river sediments, often create deltas at the mouth of river inflows, alter water quality and temperature, create habitat for non-native fish species, present an obstacle to native fish migration, and may create wetlands or new riparian resources (Flug 1998). For recreational users, reservoirs provide lake resources that include swimming, boat access, beaches, and sport fishing; however, the reservoir may have displaced historical viewsheds.

The effects of large dams on natural rivers are well documented (Vanoni 1975). Typically, rivers downstream from large dams experience fewer and smaller floods. Water released below dams may cause erosion that degrades stream beds, eroding bars and cutting into vegetated stream banks. Upstream of dams, sedimentation increases. In general, dams induce changes in sediment transport which lead to changes in river substrates (bed composition), channel dimensions, channel bars, and channel stability (Flug 1998), as well as turbidity and other water quality characteristics (e.g., temperature). Downstream of dams, decreases in turbidity alter light penetration – thus, primary production and fish and macroinvertebrate habitat.

Regulated flow releases from dams can provide benefits for boating and swimming, extreme fluctuations can be detrimental to recreational water use. These fluctuations also favor non-native vegetation species that may proliferate and out-compete native species that have evolved and adapted to natural flow cycles and stream dynamics (Flug 1998).

W.1.2.3. Prairie Wetlands (Palustrine Systems)

Emergent wetlands naturally form in places where groundwater discharges or surface water collects for some time in a manner sufficient to saturate soils. Such places in the Great Plains include depressions surrounded by upland and sloped areas below sites of groundwater discharge. Small prairie wetlands play an important role in Great Plains hydrology by storing surface water, moderating floods, improving water quality, and by recharging ground water and soil moisture. These wetlands are also highly productive habitat for waterfowl and other wildlife in a generally arid region. The disruption of natural processes such as fire and grazing since pre-European times has led to domination of these wetlands by robust, emergent plants. Climate, fire, and grazing previously controlled the diversity and abundance of vegetation in prairie wetlands. As these processes have changed, belowground seed reserves favor those species with seeds that germinate under a wide range of conditions, such as cattail, purple loosestrife, and other

nonindigenous species. Cattail, once rare on the Great Plains, has spread across thousands of prairie wetlands.

Persistent emergent wetlands (freshwater marshes) (Cowardin et al. 1979) are the major type of palustrine wetland within SOPN and they are present at BEOL, SAND, CHIC, PECO, and LAMR. These wetlands dominated by persistent vegetation present for most of the growing season in most years. The vegetation generally remains standing from one year to the next. Wetlands without persistent vegetation are also included in this system if they are< 20 acres (8 ha), < 6.7 feet (2 m) deep during low water times, and no portion of the boundary contains wave-formed or bedrock shoreline. Freshwater marshes are characterized by: 1) emergent, soft-stemmed aquatic plants such as cattails, arrowheads, reeds, and other species of grasses and sedges; 2) a shallow water regime; and 3) generally shallow deposits of peat. These wetlands are usually dominated by perennial plants.

In the Great Plains wetlands comprise a small portion of the landscape, but they are often the areas of highest species diversity. Despite comprising <10% of the landscape in North America (on an areal basis), wetlands are important habitat for 68% of birds, 66% of mussels, and 75% of amphibians on the U.S. list of threatened and endangered species (Mitsch and Gosselink 2000). Wetland losses have been extensive in the SOPN Region. Dahl (2000) estimated that between 51 and 75% of wetlands had been lost in Texas and Oklahoma and between 25 and 50% in Kansas, Colorado, and New Mexico. Agriculture and urbanization are the dominant human influences on Great Plains wetlands.

Agricultural activities outside park boundaries pose threats to wetlands with SOPN parks. Runoff contaminated with sediment, nutrients, and pesticides reach park wetlands through waterways and drainages that have inadequate buffer zones. Aerial deposition of pesticides and nutrients has been documented in wetlands downwind of agricultural areas. Wetland destruction and fragmentation on adjacent lands threatens wetland species dependent on migration or dispersal corridors. The primary stressors associated with agricultural activity are drainage, sediments, nutrients, and toxicants.

*W. 1.3. Overview of Stream, Reservoir, and Riparian Ecosystem Models*

For the purposes of this work, stream deep water habitats and riverine wetlands are described by the stream ecosystem model. Palustrine wetlands and upland riparian zones associated with streams are described in the riparian model, consistent with U. S. Fish and Wildlife guidelines for the classification of wetlands and deep water habitats of the United States (Cowardin et al. 1979). Reservoir deep water habitats and lacustrine wetlands at Lake Meredith and Chickasaw National Recreation Areas, as well as spring pool habitat at Chickasaw, are described by the reservoir ecosystem model. Again, palustrine wetlands and upland riparian zones associated with SOPN reservoirs (and spring pools) are described in the riparian model. The physical boundaries and distinguishing characteristics of stream, reservoir, and riparian models are shown in Figure 1. Palustrine wetlands, are described in Appendix V, represent a subset of riparian ecosystems (Mitsch and Gosselink 2000) as shown in Figure 2.

An important goal of conceptual model development is to depict how natural drivers (e.g., climate) and anthropogenic stressors affect ecosystem structure and functioning. SOPN aquatic and riparian models are presented as a combination of diagrams and tables showing associations between significant ecosystem features (attributes and processes) and the impacts of existing and potential ecosystem stresses in sufficient detail to support the development of the SOPN monitoring program. No single conceptual model can satisfy all needs. Spatially explicit applications, such as ecological resource assessments, monitoring design, and landscape-level ecological modeling will ultimately require site-specific models. The goal of the present modeling effort is to provide generalized ecological models to facilitate communication among scientists,

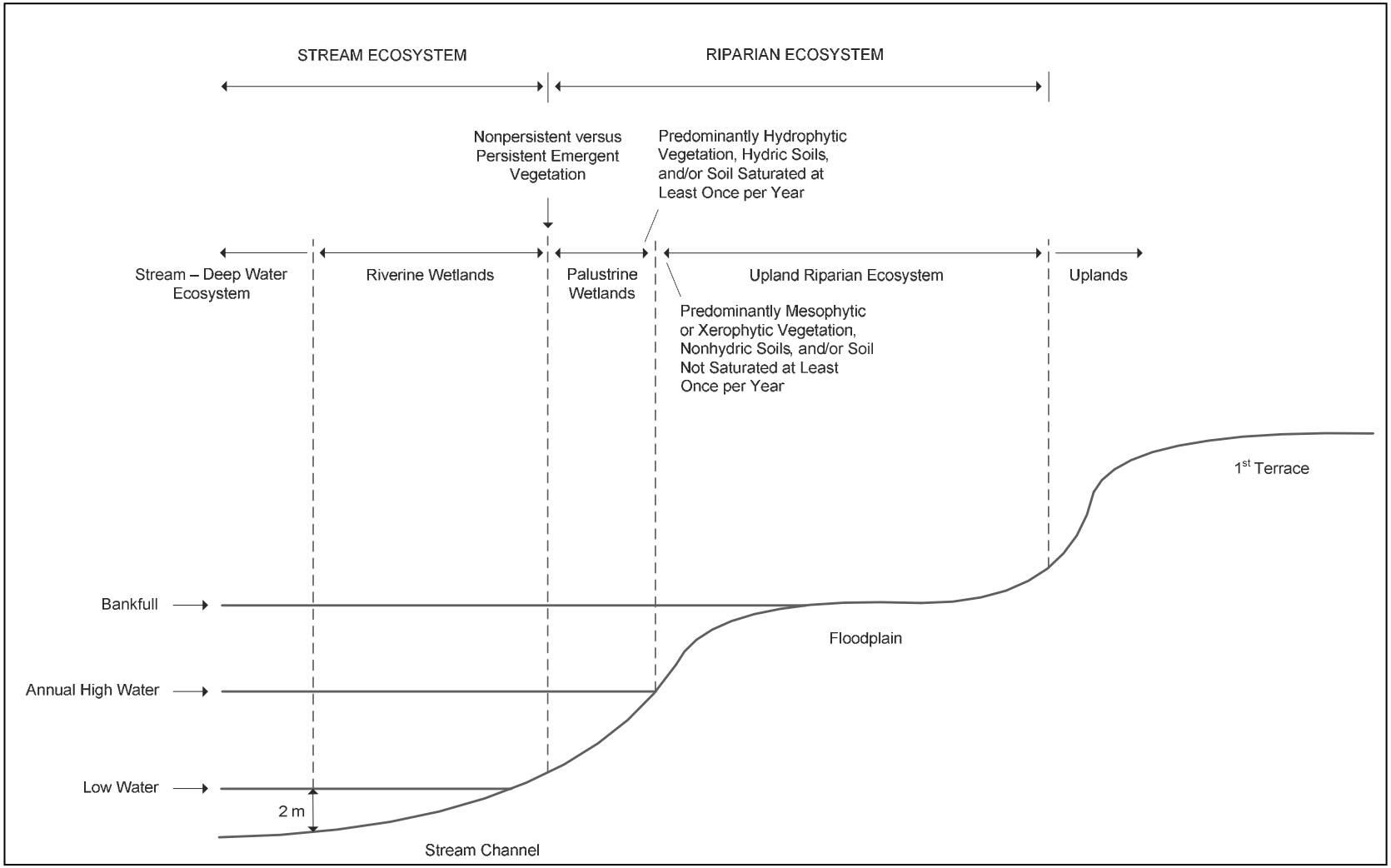



**Figure 1. Physical boundaries of stream, reservoir, and riparian ecosystem models (Cowardin et al. 1979).**

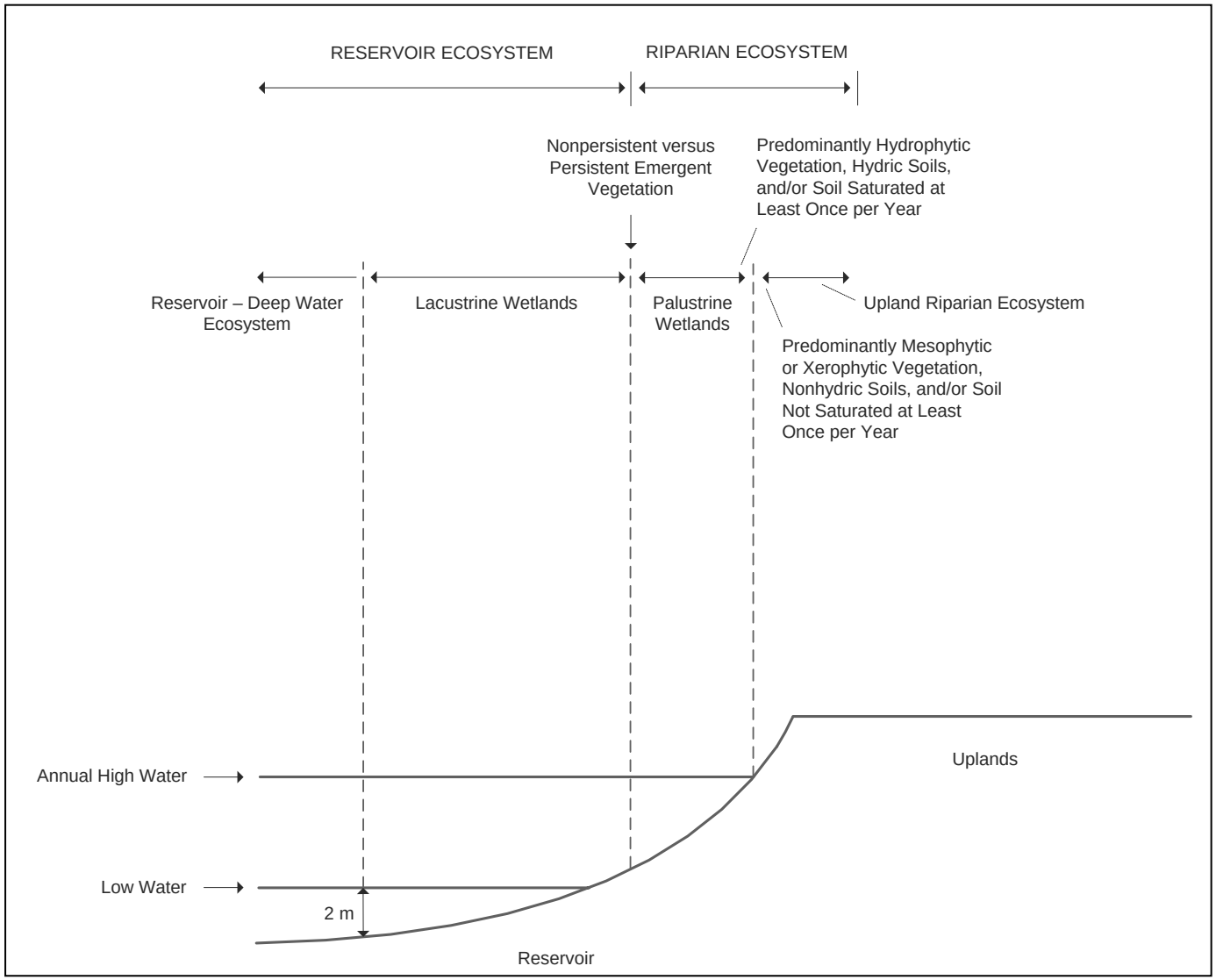



**Figure 1 – *Continued***

managers, and the public regarding ecosystems and how they are affected by human activities and natural processes. Consequently, the models presented are generalized to circumscribe the diversity of aquatic and riparian ecosystems found in SOPN park units.

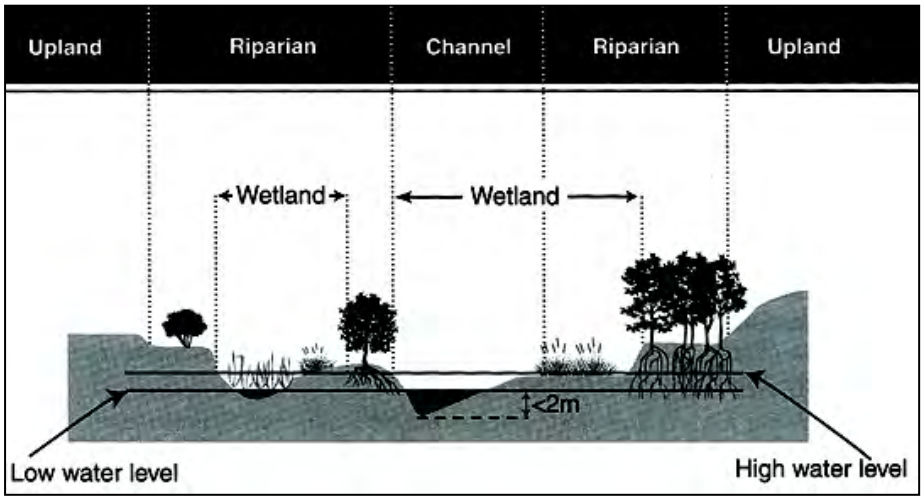



**Figure 2. Palustrine wetlands as a subset of riparian ecosystems. From Mitsch and Gosselink (2000).**

## W. 2. STREAM ECOSYSTEM MODEL

The SOPN has adopted a modified version of the Jenny-Chapin model as a general ecosystem framework for guiding the development of conceptual models and consideration of vital signs (see Chapter 2, Figure 9 for Jenny-Chapin Model). Jenny (1941, 1980) proposed that soil and ecosystem processes are determined by five *state factors* – climate, organisms, relief (topography), parent material, and time since disturbance. Jenny's state-factor approach has been widely applied as a framework for examining temporal and spatial variations in ecosystem structure and functioning (e.g., Walker and Chapin 1987, Vitousek 1994, Seastedt 2001). Chapin et al. (1996) recently extended this framework to develop a set of ecological principles concerning ecosystem sustainability. They defined "...a sustainable ecosystem as one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016). These ecosystem characteristics are determined by a set of four "interactive controls" – climate, soil-resource supply, major functional groups[2] of organisms, and disturbance regime – and these interactive controls both govern and respond to ecosystem attributes. Interactive controls are constrained by the five state factors, which determine the "constraints of place" (Dale et al. 2000).

### *W.2.1. Summary of Drivers, Stressors, Attributes, and Indicators of Stream Ecosystem Function and Condition*

Regional climate, atmospheric conditions, geology, landform, time, and upland watershed characteristics are drivers (major forces of change) for stream ecosystems of SOPN parks (Figure 3).

[2] *Functional groups* are groups of species that have similar effects on ecosystem processes (Chapin et al. 1996). This concept is generally synonymous with *functional types*.

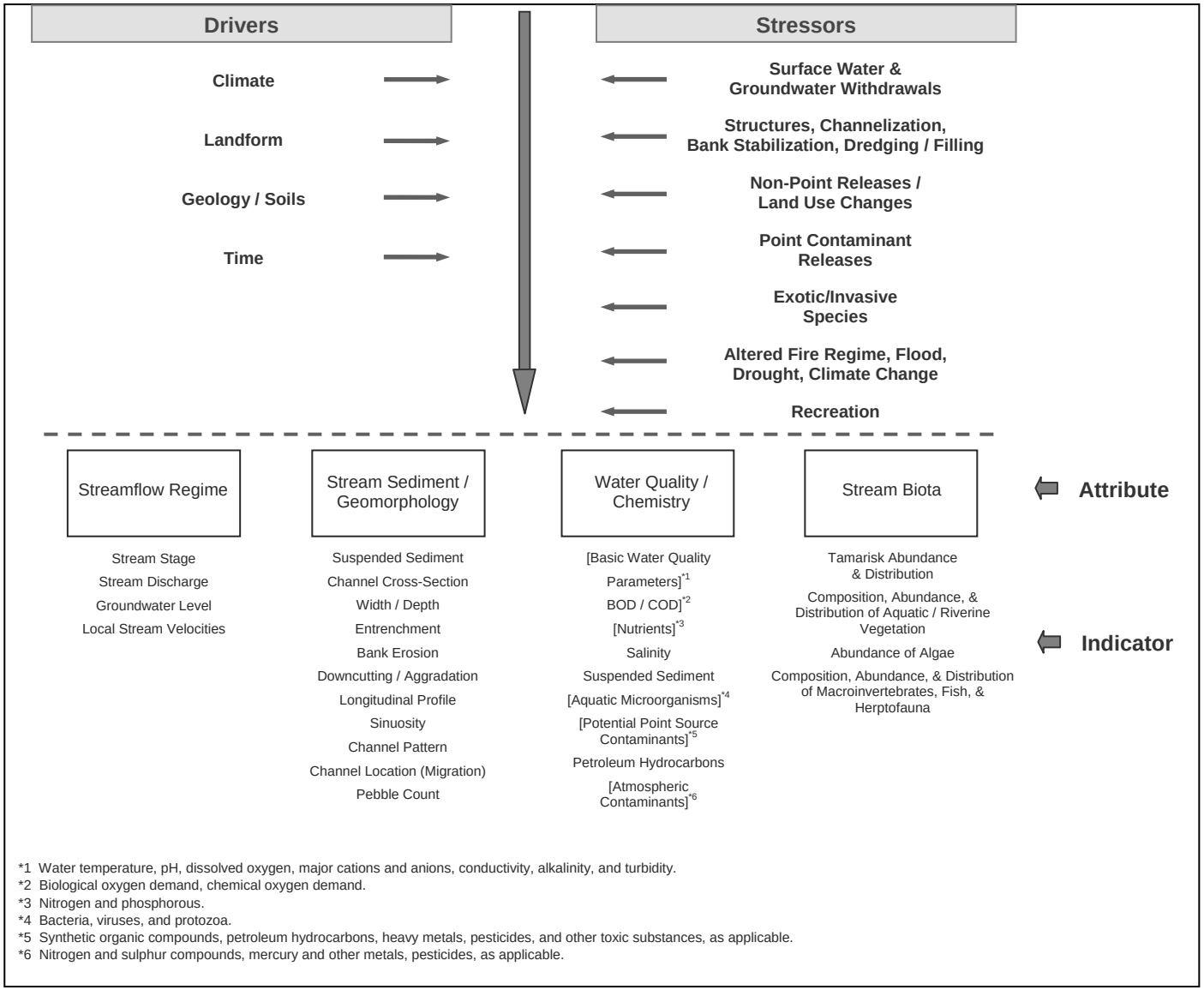



**Figure 3. Overview of drivers, stressors, attributes, and indicators of stream ecosystem function and condition.**

W.2.1.1. Hierarchy of System Drivers

*Time, Landform, Geology, and Climate* - Over geologic time scales, Schumm and Lichty (1965) describe four independent variables that influence the erosional evolution of a landscape and its hydrology; (1) time, (2) initial topographic relief, (3) geology, and (4) climate (Table 1). The initial relief of a landscape represents potential energy. Over time, this energy is transformed to kinetic energy as climate, acting on the underlying geological materials, progressively modifies landscape morphology through the process of erosion. Eight additional dependent variables, elements of fluvial systems, influence the nature of aquatic ecosystems through their effects on streamflow and sediment transport. These variables, discussed in more detail in subsection *'Upland Watershed Characteristics'*, include: (5) vegetation, (6) watershed relief, (7) watershed hydrology, (8) drainage network morphology, (9) hillslope morphology, (10) runoff and sediment flux, (11) valley morphology and channel/floodplain form, and (12) depositional processes and patterns (Schumm 1981).

Precipitation regime is the most important climatic factor shaping the characteristics of aquatic ecosystems in SOPN parks. Precipitation inputs are key drivers of fluvial geomorphic processes and support water-limited ecological processes, including primary production, nutrient cycling, and plant reproduction (Noy-Meir 1973, Comstock and Ehleringer 1992, Whitford 2002). Precipitation seasonality (i.e., timing in relation to the annual cycle of potential evapotranspiration) is of particular importance because it strongly controls the partitioning of precipitation into various compartments of the hydrologic budget – evaporation, transpiration, runoff, soil-water storage, and streamflow. Because of its effects on hydrologic partitioning, precipitation seasonality is a major determinant of aquatic ecosystem dominance by different plant life forms and functional groups (Bagstad et al. in press).

**Table 1. Fluvial system variables over geologic time scales. From Scott et al. (2005), after Schumm (1981)**

| Fluvial System Variables | Dependence of Variables |
|---|---|
| 1. Time | Independent |
| 2. Initial Relief | Independent |
| 3. Geology (rock type and geologic structure) | Independent |
| 4. Climate | Independent |
| 5. Vegetation (type and cover) | Dependent on climate and geology (soils) |
| 6. Relief (percentage of watershed remaining above | Dependent on preceding variables |
| 7. Runoff and sediment yield (from upland watershed) | Dependent on preceding variables |
| 8. Drainage network morphology (stream density, channel shape, gradient and slope) | Dependent on preceding variables |
| 9. Hillslope morphology (hillslope angle and length) | Dependent on preceding variables |
| 10. Discharge of water and sediment (from the watershed to the valleys) | Dependent on preceding variables |
| 12. Depositional system (alluvial fan, delta) | Dependent on preceding variables |

Precipitation regime also plays a major role in shaping the aquatic macroinvertebrate community. For example, a study in the United Kingdom demonstrated that the North Atlantic Oscillation (NAO) has significant effects on the growth and phenology of aquatic macroinvertebrates (Briers et al. 2004). Predicted time for mayfly nymph development varied by nearly two months due to alterations in winter stream thermal regime which resulted from fluctuations in the NAO. Variations in growth and the phenology of benthic invertebrates due to the NAO, in turn, influences temporal fluctuations in the composition and dynamics of stream communities (in the United Kingdom). Variations of this type can result in mismatches between the timing of life history stages, leading to changes in the biotic or physical environment that may have important long-term consequences for stream ecosystem function (Briers et al. 2004). Monitoring strategies can also be affected as changes in phenology lead to shifts in benthic community composition by altering normal seasonal changes in relation to a fixed survey date (Briers et al. 2004).

Regional precipitation patterns are affected by global-scale fluctuations in sea-surface temperatures, atmospheric pressure, and atmospheric circulation patterns that vary at two different time scales (Hereford et al. 2002). Short-term, inter-annual variations in precipitation are related in part to the occurrence of El Niño and La Niña conditions – the two contrasting phases of the El Niño – Southern Oscillation (ENSO) phenomenon that is driven by variations in sea-surface temperatures in the eastern tropical Pacific Ocean (Hereford and Webb 1992, Cayan et al. 1999, Hereford et al. 2002). Hereford et al. (2002) found that the detailed relationships were complex, but that strong El Niño episodes generally increased the variability of warm-season precipitation or the frequency of above-normal cool-season precipitation. In contrast, strong La Niña episodes tended to cause normal, low-variability warm-season precipitation and below-normal cool-season precipitation. Whether characterized by dry or wet conditions, extreme years featuring floods or droughts can have long-lasting consequences for ecosystem structure and functioning by causing episodes of plant mortality or establishment (Burkham 1972, Ehleringer et al. 2000, Friedman and Lee 2002).

Decadal-scale variations in precipitation patterns are related to a recently recognized phenomenon known as the Pacific Decadal Oscillation, or PDO (Mantua and Hare 2002, Hereford et al. 2002). Precipitation variability associated with the PDO is partly related to cyclical variations in sea-surface temperatures in the northern Pacific Ocean, although mechanisms driving PDO variability remain poorly understood (Mantua and Hare 2002).

In addition to temporal variability, spatial variability is a defining attribute of precipitation regimes in dry regions (Noy-Meir 1973, Whitford 2002). Topography and storm type are two factors that control spatial variability in precipitation. On a local scale, precipitation tends to increase with increasing elevation due to orographic effects of topography (precipitation caused by adiabatic cooling of rising air masses), but rain shadows can also develop on the lee side of significant topographic features. As for storm type, summer precipitation derived from convective thunderstorms is characterized by greater spatial variability than winter precipitation from frontal storms (Noy-Meir 1973, Whitford 2002). The size of precipitation events is also an important attribute of dry-region precipitation regimes (Noy-Meir 1973, Sala and Lauenroth 1982, Ehleringer et al. 2000, Whitford 2002). Event size and timing (seasonal, diurnal, and in relation to antecedent environmental conditions) in combination are important for determining the ecological effects of precipitation.

Precipitation intensity (amount per unit time period) also affects hydrologic partitioning of precipitation. Precipitation intensity, soil characteristics (e.g., texture and antecedent moisture conditions), and ground-surface features (e.g., ground-surface roughness, amount and distribution of ground cover, versus bare soil or bedrock) together determine whether precipitation events result in infiltration or runoff (Whitford 2002, Breshears et al. 2003). Generally, as precipitation intensity increases, a greater proportion of the total rainfall is partitioned to

streamflow (Gregory 1916). If precipitation intensity exceeds the soil infiltration rate, runoff will be generated – increasing the potential for soil erosion, debris flows, and flash floods.

*Upland Watershed Characteristics* - Schumm (1981) described an idealized fluvial system consisting of three zones: (1) watersheds or zones of net sediment production, (2) streams and rivers representing zones of transport of water and sediment from the watershed, through valleys, to, (3) zones of net deposition, such as deltas and alluvial fans (Figure 4). These zones are not as spatially segregated as represented by Figure 4 because in reality there is a rather complex interpenetration of zones. For example, alluvial sediments may be temporarily stored as channel or flood plain deposits within the channel network of a watershed or in the valley of a large river (zones 1 and 2) (Schumm 1981, Benda et al. 2004). Likewise, deltas (zone 3) may be actively eroded as declining lake levels lower local stream baselevels (J. Schmidt, personal communication).

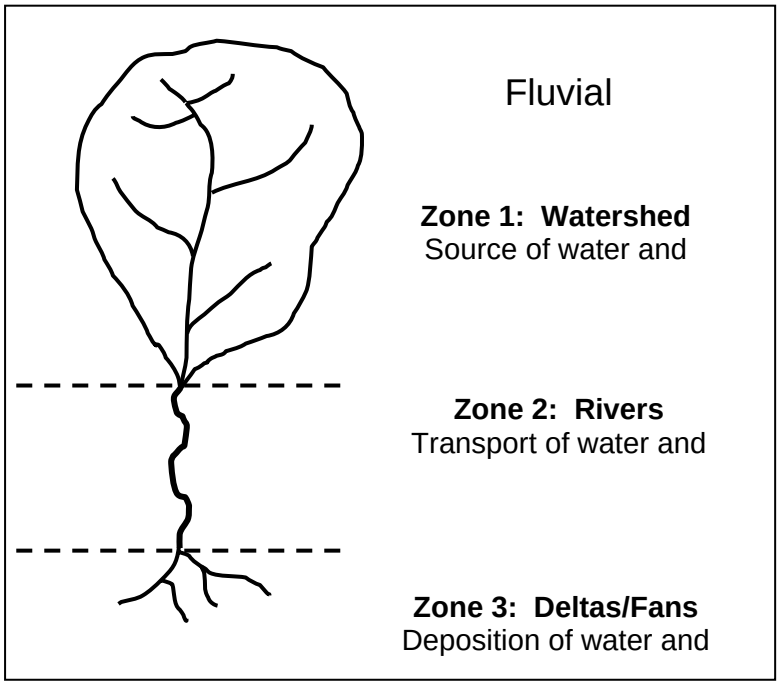



**Figure 4. An idealized diagram of a fluvial system featuring: (1) a zone of sediment production (watershed); (2) zone of transport (rivers and streams); and (3) zone of deposition (alluvial fans and deltas). From Scott et al.**

The upland watershed contains a diversity of landform features including drainage divides, hillslopes, stream channels and flood plains. Water and sediment are ultimately derived from the upland watershed (zone 1) through the interaction of the nine watershed variables listed in Table 1. The four independent variables of time, initial relief of the watershed, geology, and climate influence the type and cover of vegetation, watershed topography, which in turn influence the runoff and sediment flux from the watershed, the development of stream network and hillslope morphologies, and thus the discharge of sediment and water to receiving streams and rivers (zone 2). The amount and timing of flow and the amount and size of sediment, delivered from thewatershed to the valleys, establishes channel and flood plain form and processes, which provides the physical template for aquatic and riparian ecosystems (Frisell et al. 1986).

Given the number of interactive controlling variables, watershed characteristics can be endlessly diverse. However, regional characteristics allow some generalized inferences about the influence of watershed characteristics on streamflow patterns and sediment flux. In the Southern Plains, thunderstorm events deliver high precipitation rates that cannot infiltrate the soils of typical watersheds, and short duration overland flow events are characteristic of the monsoon season. Land use activities like livestock grazing that increase the area of exposed bedrock, or which decrease soil stability and infiltration rates, result in increased delivery rates of water to stream channels, which in turn lead to more rapid runoff and larger flood events. High surface runoff

rates tend to increase soil erosion, and the removal of vegetation also leads to soil erosion by raindrop impact. Delivery of larger amounts of water and sediment from the watershed (zone 1) to stream channels (zone 2) has the potential to alter channel form and process and thus alter riparian and aquatic ecosystems.

*W.2.2. Stream Ecosystem Function under Natural/Desired Conditions*

Chapin et al. (1996) defined "...a sustainable ecosystem as one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016). The latter are determined by four "interactive controls" – climate, soil-resource supply, major functional groups of organisms, and disturbance regime (Dale et al. 2000). Streamflow regime, stream geomorphology, and instream habitat, the major 'soil-resources' influencing stream ecosystem function, are described in this section, followed by a discussion of the role of stream biotic functional groups and stream ecosystem dynamics under natural/desired (sustainable) conditions. The attributes and functioning of SOPN stream ecosystems under natural/desired conditions are summarized in Figure 5.

W.2.2.1. Streamflow Regime

Streamflow originates from precipitation falling within a watershed. However, resulting streamflow patterns (streamflow hydrographs) can vary greatly across a watershed due to differences in local climatic conditions, geology, topography, soils and vegetation cover. Precipitation reaches a stream through various pathways, including direct precipitation, unsaturated or Horton overland flow, ground-water flow, shallow subsurface flow, and saturated overland flow (Figure 6) (Dunne 1978). Each of these flow paths respond differently to precipitation events (rain or snow) and thus contribute differentially to two important components of streamflow - baseflow and stormflow. Because rates of groundwater flow are slow and flowpaths are relatively long, water moving to streams along these paths contribute to the baseflow of streams between precipitation events. Surface runoff from precipitation reaches streams more quickly, contributing to stormflow during and shortly after precipitation events (Figure 7a). Because of the potential for high intensity rainfall events, thin, patchy soils, exposures of relatively impermeable bedrock, and sparse vegetation, the hydrographs of Southern Plains streams are dominated by relatively high-magnitude, short-duration, temporally unpredictable stormflow hydrographs with little or no baseflow (Figure 7b). In contrast, larger extraregional rivers in other areas of the country feature snowmelt hydrographs with temporally predictable, longer-duration snowmelt peaks and baseflow (Figure 7c). Streamflow regime determines the mechanical forces available in a valley to erode, transport and deposit sediment and maintain channel form and channel processes.

Temporal (seasonal) variations in streamflow are important in maintaining the ecological integrity of aquatic and riparian ecosystems. The natural flow regime paradigm holds that natural flow variability is primarily responsible for structuring and maintaining the physical and biotic integrity of aquatic and riparian ecosystems (Richter et al. 1996, Stanford et al. 1996, Poff et al. 1997).

Ecologically relevant elements of streamflow include the magnitude, frequency, duration, timing, and change rate of flow. These elements have been used to describe regional streamflow patterns, which vary as a function of climate and watershed characteristics (Poff and Ward 1989). They may also be used to characterize specific hydrologic events, such as extreme high or low flows, or human-modified flow patterns, both of which can exert lasting influence on the ecological integrity of aquatic and riparian systems (Richter et al. 1996).

Although extreme flow variations can eliminate species (Zimmerman 1969, Bain et al. 1988), episodic floods and droughts are necessary for persistence of some species of fish (Meffe 1984) and plants (Nilsson et al. 1991, Friedman et al. 1996). In fact, the high biological diversity of

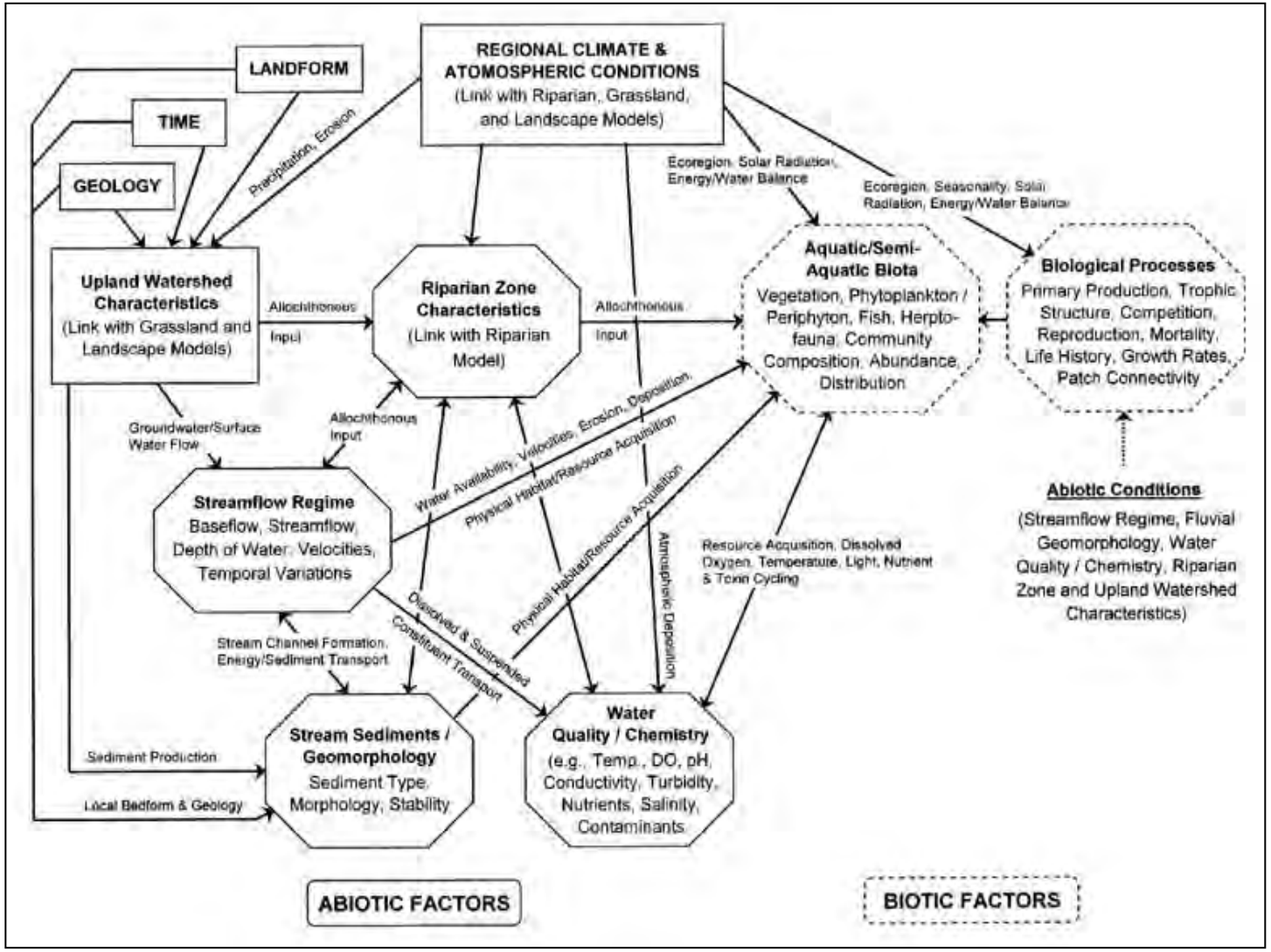



**Figure 5. Natural/desired stream ecosystem function. Modified from Scott et al. (2005).**

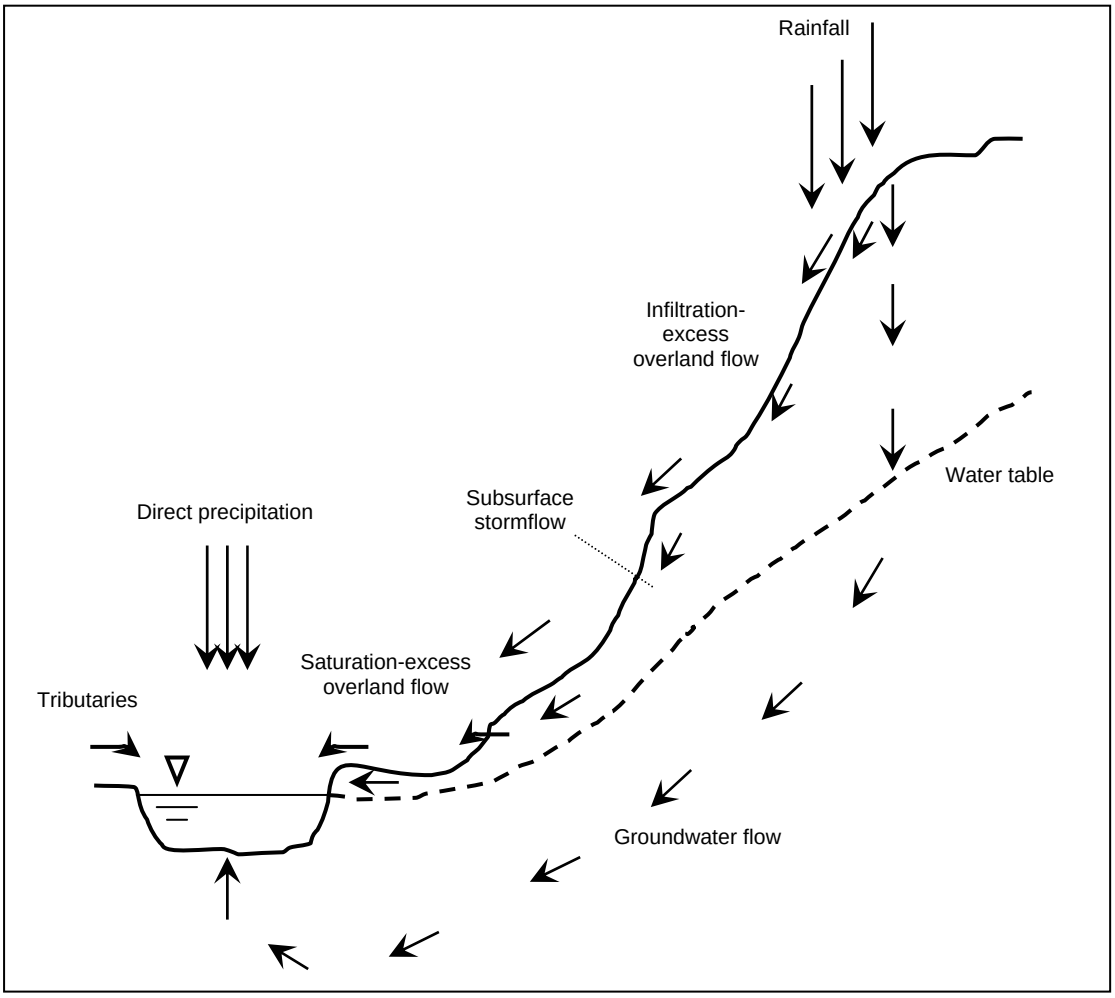



**Figure 6. Idealized flow paths from a watershed to a stream. Adapted from Scott et al. (2005), after Dunne (1978) and Ziemer & Lisle (1998).**

riverine ecosystems may be attributable to relatively frequent hydrologic disturbance events, which would act to limit the process of competitive exclusion of species (Huston 1979).

Given the importance of flow variability in structuring and maintaining aquatic and riparian ecosystems, identification of a parsimonious set of hydrologic indicators that are sensitive to anthropogenic disturbances, would be an important element of any efforts to monitor, manage, and restore aquatic and riparian ecosystems (Olden and Poff 2003).

W.2.2.2. Stream Sediments/Geomorphology

Stream channels adjust to variations in streamflow and the size and amount of sediment supplied to the stream from the watershed. Flow governs channel dimensions such as width, depth and meander pattern, as well as the amounts of bed load (sands and gravels) and suspended load (silts and clays) carried by the stream. Channel form is mostly determined by the amount and size of bedload, even where bedload is a small portion of the total sediment flux. Schumm (1981) has identified five general channel types based on plan-view pattern and channel stability, the latter a function of sediment size, sediment load, flow velocity, and stream power (Figure 8).

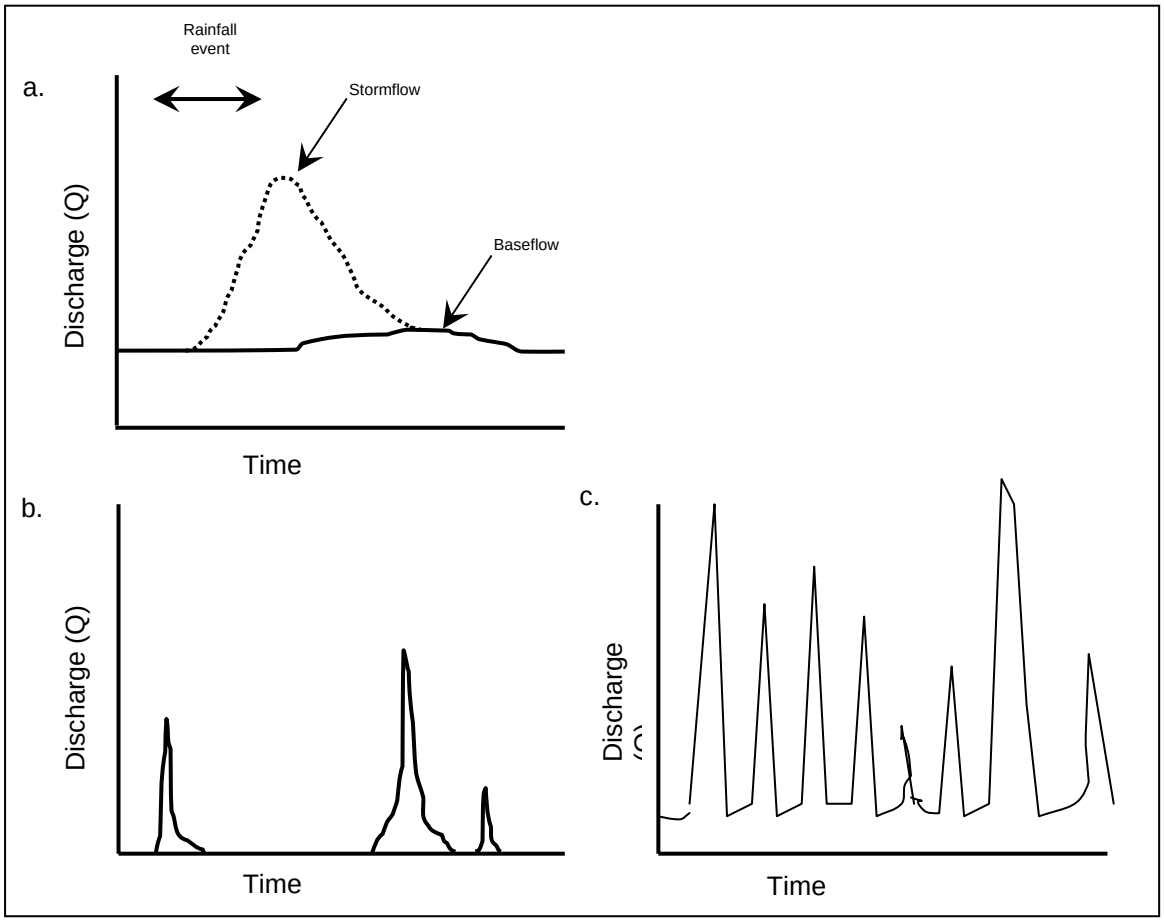



**Figure 7. Stream hydrographs. (a) Idealized relationship between stormflow and baseflow components of a stream hydrograph for a discrete rainfall event. (b) Idealized hydrograph of an ephemeral stream featuring highly variable and temporally unpredictable peak flows. (c) Idealized hydrograph of an unregulated, large perennial stream featuring variable but temporally predictable seasonal peak flow (from Scott et al. 2005, modified after Dunne 1978).**

An alternative stream classification system has been proposed by Rosgen (1996) based on channel pattern (single, braided, or anastomosed channel configuration, sinuosity, and meander width ratio), channel slope, width/depth ratio, entrenchment ratio, channel materials, and additional parameters quantifying the condition and stability of streams (Figure 9). Stream classification is used to anticipate the response of a stream to changes in streamflow, sediment load, and other stresses (e.g., bank stabilization, channel straightening, and instream structures) given stream type. Since the impact of stream geomorphology and changes in stream geomorphology on aquatic and riparian habitat are great, periodic, albeit infrequent, geomorphic surveys of representative stream reaches (both perennial and ephemeral) in SOPN parks would be an important element of any effort to monitor, manage, and restore aquatic and riparian ecosystems.

*Effects of Stream Geomorphology on Instream Habitat* - Associations among biological stream communities and habitat characteristics at various spatial scales have been well described in recent studies (Lyons 1996; Lohr and Fausch 1997; Maret et al. 1997; Brown 2000; Waite and Carpenter 2000). Important physical habitat factors include flow regime, substrate, and

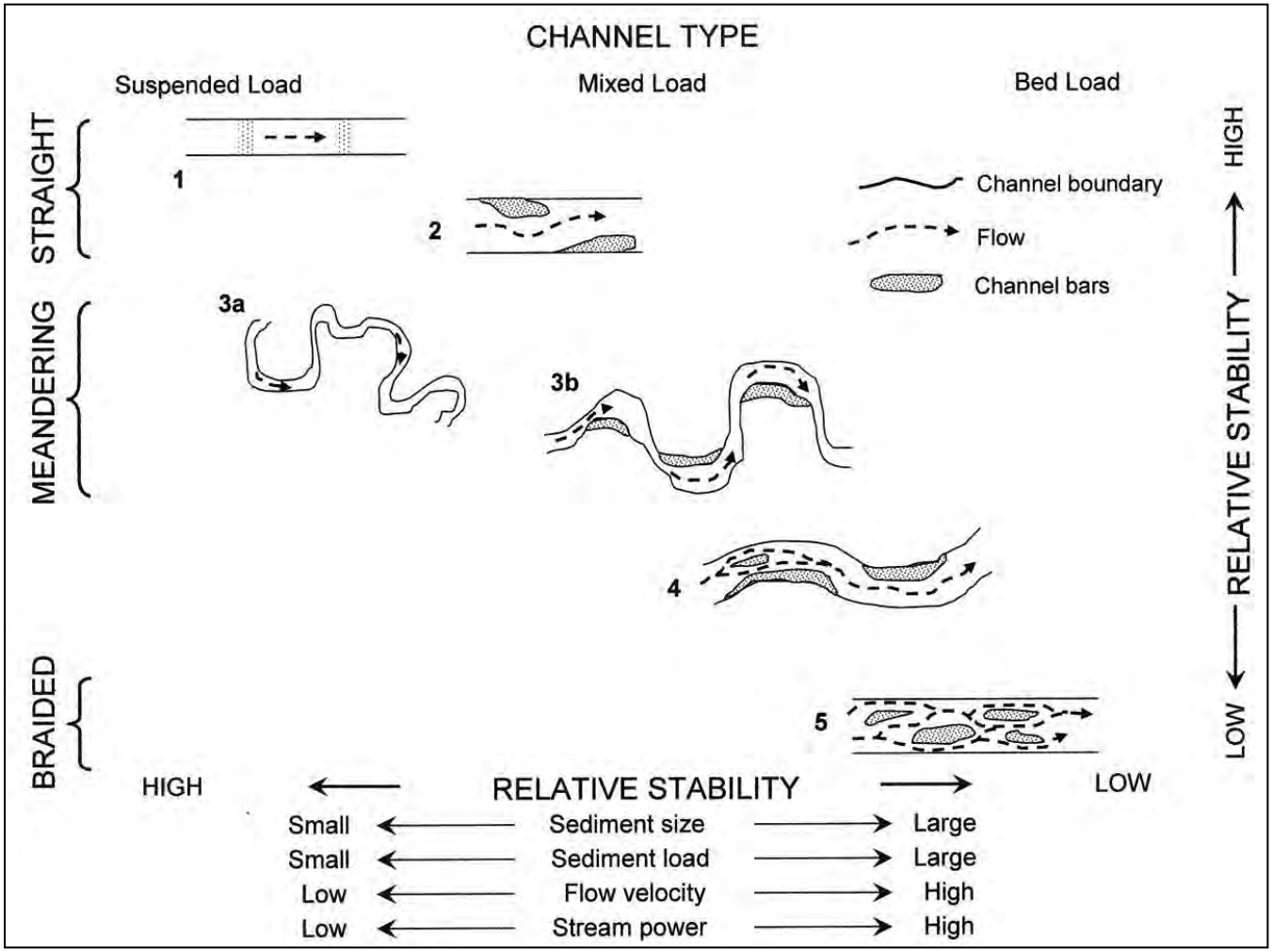



**Figure 8. A qualitative classification of stream channels based on pattern (straight, meandering, or braided) and type of sediment load, along with flow and sediment variables and stability (level of erosional activity). From Scott et al. (2005), after Schumm (1981)**

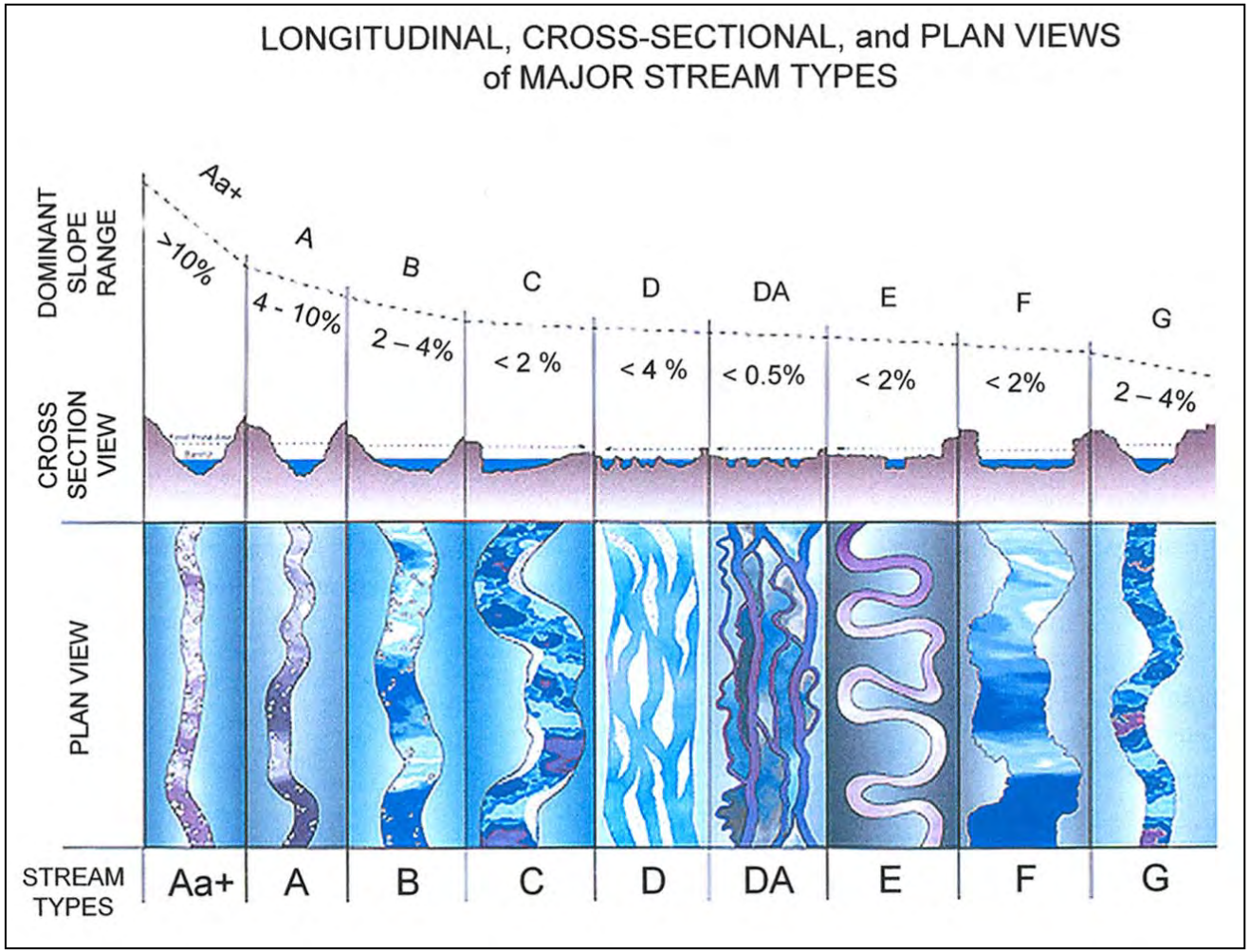



**Figure 9. Broad level stream classification based on channel slope, channel shape (cross-section geometry), and channel pattern (sinuosity, meander width ratio, and single, braided, or anastomosed channel configuration). From Rosgen (1996).**

temperature (Allan 1995). In unaltered systems, dissolved oxygen is rarely limiting, but can become a critical environmental variable in altered (polluted or diverted) systems (Allan 1995).

Flow regime is an important determinant of aquatic community structure. Flow regime can affect macroinvertebrates both directly (physiological and morphological adaptations) and indirectly (through its effects on algae and fish). The majority of studies assessing the impacts of streamflow have focused on fish. For example, Brown and Ford (2002) demonstrated the importance of natural flow regime on the spawning success of native fishes in the Tuolumne River in California. Altered flow regimes often favor introduced fish species that are generalists and can tolerate a wide array of environmental conditions (Meador et al. 2003). Because of their different feeding habits, introduced fish can alter macroinvertebrate community structure (McDowall 2003). Other studies have demonstrated that when flows are reduced, fish taxa richness is also reduced (Cuffney et al. 1997).

Additionally, streamflow is a determinant of stream width and depth and the formation of features such as pools, riffles, wide meander loops, and sand bars – important microhabitat for aquatic biota (Gordon et al. 1992). Water velocity is a factor in determining the distribution of microhabitats (Munn et al. 2002) and thus plays a role in influencing benthic community structure. Habitat homogenization, which reduces the number of microhabitats, can have detrimental impacts on native stream biota. For example, several native fish in California streams require riffles for successful spawning (Brown 2000). Today, these native fish are only found at upper tributary sites because anthropogenic modification has eliminated downstream riffle habitat and non-native fish now occupy the disturbed areas (Brown 2000). Microhabitat diversity is necessary for the survival of some species, and may vary seasonally. For example, Baltz et al. (1991) found that rainbow trout (*Oncorhynchus mykiss*) require slower, deeper reaches of stream when temperatures are cool. Although macroinvertebrate community structure was not examined in these studies, it is likely that macroinvertebrate communities also changed in response to abiotic (flow regime) and biotic (fish community) alterations.

Direct effects of flow regime and habitat type on benthic macroinvertebrates and algae have also been studied. Algal community structure has been shown to change in response to flow regime (Munn et al. 2002), which can then alter macroinvertebrate communities. In one study, algal decreases resulting from low flow in a Colorado stream resulted in a shift from a collector-gatherer macroinvertebrate community structure to a shredder community structure (Canton et al. 1984). When assessing the effects of environmental stressors and drivers on benthic community structure, it is critical to understand the underlying effects of flow regime on these communities.

Flow regime and parent material determines substrate composition (Allan 1995), which plays a critical role in aquatic macroinvertebrate survival (Thorp and Covich 1991) due to their benthic lifestyle. Substrate provides sites for resting, food acquisition, reproduction, and development, as well as refuge from predators and physical conditions. A sharp distinction occurs between the types of fauna found on hard streambeds (bedrock or boulder) and those found on smaller substrate (Gordon et al. 1992). Different groups of macroinvertebrates require different substrate types and microhabitats. These groups also play different functional roles in their environment. For example, “bioturbators,” such as oligochaetes and crustaceans, live in fine sediments, mix organic matter, and stabilize soil structure, whereas “shredders,” such as stoneflies, shred organic matter and prepare it for decomposers (Freckman et al. 1997). In general, diverse substrate characteristics promote diverse taxonomic assemblages. The diversity and abundance of aquatic macroinvertebrates increases with substrate stability and the presence of organic detritus (Allan 1995).

W.2.2.3. Water Quality/Chemistry

Water temperature varies seasonally and daily from one location to another due to differences in climate, elevation, the extent of streamside vegetation, and relative contributions of groundwater

to streamflow (baseflow). The temperature of large rivers is less likely to be affected by shading, as their size conveys thermal inertia and large portions of the river are exposed to the sun (Allan 1995). In small streams typical of SOPN parks, however, shading can play an important role in regulating water temperatures. Many anthropogenic activities (stressors), such as grazing, roads, and stream channelization, can remove riparian vegetation along banks and consequently eliminate shading.

Temperature affects the growth and respiration of individual organisms and the productivity of ecosystems through its influence on metabolic processes. Organisms generally perform best within the subset of possible temperatures that corresponds to an unaltered habitat in their location (Allan 1995). Baltz et al. (1987) demonstrated the importance of temperature as a control on habitat preference of four fish species in a California stream. Temperature may influence organisms directly or indirectly due to changes in oxygen saturation levels (Thorp and Covich 1991). It has not, however, been determined if the association between macroinvertebrate diversity and temperature is causal or merely coincidental because many biotic and abiotic parameters covary (Thorp and Covich 1991).

The life history characteristics of macroinvertebrates can be altered by changes in water temperature. This results in changes in survival, fecundity, and time of emergence, and can ultimately alter macroinvertebrate species assemblage structure (Vinson 2001). In one case, immediately downstream from a cold-release dam, taxa tolerant of cold water such as chironomids and amphipods were dominate and less tolerant species of the orders Plecoptera, Ephemeroptera, and Trichoptera were uncommon (Stevens et al. 1997). Similarly, if water temperature is increased, native cold-water taxa can be replaced by non-native warm water taxa (Maret 1995). And changes in water temperature also alter algal assemblages (community composition and abundance), leading to changes in macroinvertebrate communities (Stevens et al. 1997).

Due to their influence on habitat quality, certain natural chemical features of aquatic systems significantly affect species composition, abundance, and diversity of macroinvertebrates. Of these chemical features, dissolved oxygen and conductivity (salinity or hardness) are the most important (Thorp and Covich 1991). Increases in salinity and alkalinity and decreases in dissolved oxygen are correlated with decreases in macroinvertebrate density and diversity (Earl and Blinn 2003). Anthropogenic pollution has had a severe impact on the integrity of aquatic ecosystems by altering these chemical parameters, as well as by introducing organic and inorganic toxicants (Thorp and Covich 1991).

W.2.2.4. Stream Biota

*Biotic Functional Groups* - Chapin et al. (1996) identified biotic functional groups (hereafter described as *functional types*) as one of the four interactive controls of ecosystem sustainability because of the capacity of dominant functional types to shape the structure and functioning of whole ecosystems. Associated with efforts to the model ecological consequences of global climate change, a vast literature has developed concerning different approaches to deriving or classifying functional types – particularly with respect to vegetation (e.g., Smith et al. 1997). Identification and use of a particular functional-type scheme depends on the ecosystem function(s) of interest. It has been proposed that the most important functions in dryland terrestrial ecosystems are those that control the retention of water and nutrient resources because productivity and diversity cannot be sustained in systems that fail to retain resources (Ludwig and Tongway 1997, Whisenant 1999, Whitford 2002). Because of their landscape position and highly connected linear forms, aquatic and riparian ecosystems receive large fluxes of water and sediment from upland and upstream sources. Similarly, their potential to store flood water and nutrient-rich sediments are considered key functional attributes (Mitsch and Gosselink 1993). Functions affecting the cycling and retention of water and nutrient resources will be emphasized here, but other functions will not be excluded. For purposes of this report, it is less

important to adopt a specific functional-type classification scheme than it is to include a broad functional perspective when considering the biotic components of aquatic and riparian ecosystems.

Without adopting a particular classification scheme, it remains useful to identify two general categories of functional types that are equally important for ecosystem dynamics. These are (1) *functional effect types* –organisms with similar effects on ecosystem functions such as primary production, nutrient cycling, and sediment trapping, and (2) *functional response types* – organisms with similar responses to environmental factors such as climate, resource availability, natural disturbances, and water management activities (Walker 1997, Walker et al. 1999, Díaz and Cabido 2001). The distinction between these two types is important for considering how biotic composition affects the resistance and resilience of ecosystems to climatic fluctuations and changes, natural disturbances, and anthropogenic stressors (Walker et al. 1999). Although some workers have emphasized the importance of overall functional diversity for sustaining ecosystem processes (Tilman et al. 1997), the effect-response distinction suggests that long-term ecosystem functioning may be favored when different functional response types are nested within the same functional effect type (Walker et al. 1999, Díaz and Cabido 2001). Thus, functional redundancy and functional diversity may both be important for long-term persistence of ecosystem structure and functioning.

*Aquatic / Semi-Aquatic Biota* - Aquatic ecosystems include biotic functional groups that fall into four main categories: algae, benthic macroinvertebrates, fish and amphibians. The relative abundance of different types of primary producers (algae) depends on many factors including nutrient availability, water depth and velocity, the stability of the substrate, and disturbance regime. Unshaded streams can support dense algal growth (autochthonous productivity) (Covich et al. 1999), but shaded streams rely more on terrestrial (allochthonous) inputs and algal growth is therefore minimized. Although the function of algal assemblages is similar in both shaded and non-shaded systems, the magnitude of algal contribution is different under these two conditions. Primary producers are the interface between the abiotic and biotic environment because they respond to physical variables and influence biotic communities. Macroinvertebrate “grazers” or “scrapers” consume algae and therefore the type and abundance of algae can strongly influence macroinvertebrate communities. Some studies indicate that an increase in algal abundance is correlated with an increase in macroinvertebrate density and growth, and decreases in algal abundance are associated with reduced macroinvertebrate densities (Feminella and Hawkins 1995).

Benthic macroinvertebrates are a vital link in aquatic and riparian systems. They are a food source for fish, amphibians and birds, and they also play a consumer role as they graze on many algae species (McCafferty 1998, Steinman 1996). Macroinvertebrates are useful indicators of aquatic ecosystem quality and have therefore been used for biomonitoring since the early 1900’s (Cairns and Pratt 1993). Recent efforts focus on the development of indicator species, diversity indices, and multivariate techniques, which link macroinvertebrate communities with habitat conditions. Because conditions such as riparian vegetative structure, geology, and climate determine the state of a stream and therefore the community of organisms that occupy that stream (Townsend et al. 1997), it is also important to understand regional climatic and atmospheric conditions, as well as any drivers or stressors in the system, whether anthropogenic or natural.

Macroinvertebrates respond to physical parameters such as temperature, substrate, and current velocity (Covich et al. 1999) and they are also influenced by their chemical environment, including pH, oxygen availability, and any anthropogenic chemical additions (Johnson et al. 1993). Biotic factors (predation, parasitism, competition) and food availability (the presence or absence of algae or detritus) in a community can also impact macroinvertebrate communities (McCafferty 1998, Power 1990). Macroinvertebrate indicator species can be helpful in determining ecosystem

characteristics and can be used to compare different aquatic systems. A good indicator species is sensitive to its physical and chemical environment (Johnson et al. 1993). When the environmental requirements for an indicator species are known, the presence of that species indicates that those requirements have been met.

When using macroinvertebrates to assess stream quality, it is also important to examine communities and populations in addition to specific indicator species. One commonly used index that examines entire community and species assemblages is the Index of Biological Integrity (IBI). The IBI employs metrics of certain characteristics, such as trophic composition, native and non-native species composition, and species diversity and abundance, to determine "scores" that indicate the biological integrity of a given site compared to the integrity of a comparable "least-disturbed" site (Karr 1991). A diverse environment promotes a diverse macroinvertebrate community and a loss of species diversity or abundance, may indicate environmental degradation (Covich et al. 1999). It is important to assess the integrity of a stream system on a site-specific basis, as macroinvertebrate community structure will naturally vary from site to site and across regions. Environmental conditions including physical, chemical, and biological parameters can be used to determine the "least-disturbed" condition of a given system (Covich et al. 1999).

Many different statistical techniques exist to assess stream quality using data describing macroinvertebrate communities. For example, univariate techniques are used to relate macroinvertebrate response to a single variable (i.e. sewage inputs) (Johnson et al. 1993) and multivariate techniques assess the effects of multiple variables on a stream system. Multivariate techniques are especially useful for addressing and discerning between the variety of anthropogenic influences. With the advancement of statistical bioassessment techniques, macroinvertebrates have become an integral part of evaluating stream and watershed quality.

W.2.2.5. Stream Ecosystem Dynamics

*Biotic vs. Abiotic Controls* - Power et al. (1988) examined the enormous complexity of the influence of abiotic and biotic factors on the structure and functioning of aquatic communities. They concluded that many of these processes are not well understood for stream systems and will require much additional research in order to develop a full understanding of the dynamics involved. Abiotic conditions of the local environment often determine whether stream organisms can colonize or persist in new or changing habitats. Many different abiotic variables or interactive processes may be involved, and in many cases the distributions of stream organisms with respect to physical (abiotic) variables are mediated by interactions with other organisms.

Few ecosystems possess either the frequency or intensity of environmental changes that are observed in stream systems (Power et al. 1988). Seasonal fluctuations in discharge are crucial in the life histories of many fluvial species (Welcomme 1985). As water levels rise and fall, river and stream habitats expand and contract, resource availabilities shift, certain habitats become more or less isolated from others, and flow regimes change, altering other physical gradients (Power et al. 1988). Yet extreme events (such as scouring or dewatering episodes) can eliminate much biota and set the stage for periods of biotic recovery or succession between disturbances (Fisher 1983, Power et al. 1988). Changing water levels play a key abiotic role in structuring stream communities. As water levels rise, the availability of food increases for grazers, insectivores, and detritivores that forage over inundated flood plains. Inundated flood plains also provide nurseries and refugia for many species. The duration of these refuges depends on the hydrograph, channel morphology, and on the ability of various species and size classes to cross barriers under certain hydrologic conditions (Power et al. 1988).

Functional relationships among stream species may change with both density and ontogeny (developmental stage) (Power et al. 1988). Most aquatic species are omnivorous, at least during a portion of their life cycle, and derive their energy and elemental constituents from several trophic levels. Webs of direct and indirect interactions link disparate taxa within channels and

radiate through the riparian zone to the divides between catchments (Hynes 1975) or even into adjacent watersheds (Power et al. 1988). It can be argued that streams are abiotically controlled since physical disturbance, a continual stressor, maintains populations at such low densities that biotic interactions are not important. However, biotic interactions may be important in allowing populations to endure abiotic disturbances (Power et al. 1988). In fact, the relative importance of abiotic and biotic factors controlling stream community structure and function may shift with dynamic changes in density of organisms and environmental conditions (Power et al. 1988).

*River Continuum Concept* - The river continuum concept (Figure 10) describes a transition in ecosystem structure and functioning from narrow headwater streams to broad rivers (Vannote et al. 1980). Based on the principles of fluvial geomorphology, the river continuum concept emphasizes gradual adjustments of biota and ecosystem processes in rivers in accordance with gradual downstream changes in hydrologic and geomorphic properties (Benda et al. 2004).

Headwater streams are often shaded by terrestrial vegetation. These plants reduce light availability to aquatic primary producers (algae) and provide most of the organic input to the stream. Leaves and wood (allochthonous input) fall into the stream and are colonized by aquatic fungi and, to a lesser extent, bacteria. The resulting leaf packs and woody debris are consumed by invertebrate shredders that break leaves and other detritus into pieces and digest the microbial particles. As material is carried downstream, some suspended particles are consumed by filter feeders and some material trapped in benthic sediments is consumed by collectors.

As headwater steams merge to form broader streams, the greater light availability supports more instream production (autochthonous productivity), and the input of terrestrial detritus contributes proportionately less to stream energetics. This coincides with a change in the invertebrate community from one dominated by shredders to one dominated by collectors and grazers. The middle reaches of rivers are typically less steep than headwaters and begin to accumulate sediments from upstream erosion. These sediments support rooted vascular plants and a benthic detrital community of collectors. The largest downstream reaches are typically deep and slow moving, dominated by collectors and detritivores that live in the sediment.

*Nutrient Spiraling* - In most ecosystems nutrients can be described as cycling largely in place, with minimal transport. In running waters however, transport must be incorporated into the conceptual framework (Allan 1995). Since the cycle involves downstream transport, it is best described as a spiral. In contrast to terrestrial systems where the longer-lived and larger primary producers on land can store and internally recycle nutrients for years, there is a much more rapid turnover of nutrients and carbon in aquatic systems (Chapin et al. 2002). A number of abiotic and biotic processes influence nutrient spiraling. Some uptake, especially of phosphorus, is by physical-chemical sorption of sediments. High flows reduce the opportunity for biological uptake and increase downstream transport. Low flows, stream channel retention, and interchange between subsurface and surface flows increase opportunities for uptake. In addition to direct uptake by autotrophs and microbes, the biological community affects nutrient dynamics through consumption and egestion, and by a number of microbial transformations. Repeated recycling during downstream transport is a key feature of the nutrient spiraling model.

*Network Dynamics Hypothesis* - Hierarchically branching river networks interact with dynamic watershed disturbances, such as fires, storms, and floods, to impose a spatial and temporal organization on the non-uniform distribution of riverine habitats, with consequences for biological diversity and productivity (Benda et al. 2004). Abrupt changes in water and sediment flux occur at channel confluences in river networks and trigger changes in channel and floodplain morphology. Based on the concept of a river network as a population of channels and their confluences, Benda et al. (2004) have developed testable predictions about how basin size, basin shape, drainage density, and network geometry interact to regulate the spatial distribution of physical diversity in channel and riparian attributes through a river basin.

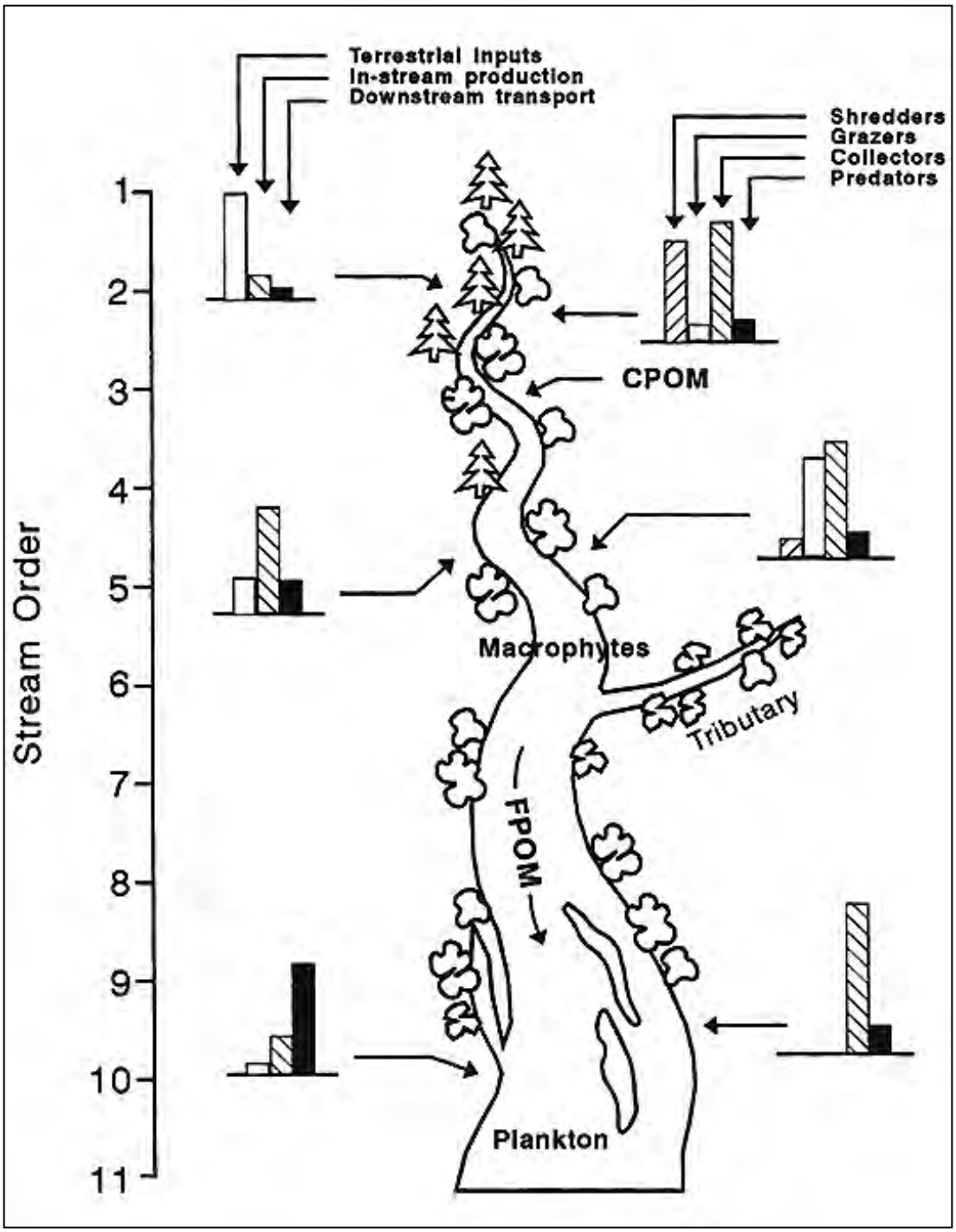



**Figure 10. River continuum concept. From Mitsch and Gosselink (2000).**

*W.2.3. Natural and Anthropogenic Stresses and Stream Ecosystem Response*

The success of the monitoring program in detecting the ecological effects of anthropogenic stresses depends on the ability to interpret trends in resource condition against the backdrop of

intrinsic variation. Hypotheses concerning the effects of anthropogenic stressors on ecosystem structure and functioning must be grounded in an understanding of the relationship between natural drivers and ecosystem structure, functioning and dynamics. Ecosystems and their components can be characterized on the basis of more structural and functional attributes than can be affordably monitored. Thus an important goal of this model is to guide the identification of a parsimonious set of "information-rich" attributes that provide information concerning multiple aspects of stream ecosystem response and condition (Noon 2003).

This section describes predominant natural and anthropogenic stressors affecting the structure and functioning of stream ecosystems of the Southern Plains, and presents conceptual models of degradational processes related to those stressors. The discussion begins with a description of disturbance regime theory.

W.2.3.1. Disturbance Regime Theory

Disturbance in aquatic ecosystems can be described in terms of frequency, intensity, predictability, time since disturbance, predation intensity, resource variability, and environmental heterogeneity. Responses to both natural and anthropogenic disturbances vary regionally, due to constraints imposed by geomorphic and hydrologic regimes. Three prominent hypotheses explain the role of disturbance on stream community structure: the equilibrium hypothesis, the intermediate disturbance hypothesis, and the dynamic equilibrium hypothesis (Resh et al. 1988).

Historically, the equilibrium hypothesis, which assumes a constant environment, was viewed as the appropriate model for describing community structure. This model assumes that community structure is controlled by biotic processes. Therefore, in the absence of disturbance, community structure is the direct result of competitive, mutualistic, and trophic interactions among species (Resh et al. 1988). In recent years, views on disturbance have moved away from the equilibrium hypothesis and towards the intermediate disturbance hypothesis.

The intermediate disturbance hypothesis (Hutchinson 1961, Connell 1978, Ward and Stanford 1983) suggests that intermediate levels of biotic or abiotic disturbances (e.g., frequency of substrate shifting or periodic flooding events) can promote maximum species diversity under certain circumstances. The intermediate disturbance hypothesis assumes a competitive hierarchy of species. Thus, in the absence of disturbance, superior competitors will eliminate inferior ones, reducing the species richness of a system (Resh et al. 1988). In contrast, if disturbances are too frequent or too large, the resident competitors will be eliminated and colonizing species will dominate the system (Resh et al. 1988). Maximum biotic diversity is maintained in aquatic systems by a level of disturbance that maintains environmental heterogeneity, but also allows biotic communities to become established (Ward and Stanford 1983).

In the dynamic equilibrium model, Huston (1979) suggests that if the recurrence interval of disturbance is shorter than the time necessary for competitive exclusion, then species that are poorer competitors will persist, increasing species richness in the system. In some cases, however, disturbance can be severe or frequent enough to eliminate species with long life cycles. This model allows for the differentiation between rarely disturbed systems with equilibrium conditions, and those with "opportunistic" community types associated with frequent disturbance (Resh et al. 1988), among which are a number of SOPN streams. In an example of one such system, Reice (1985) found that frequent disturbances kept the macroinvertebrate community in perpetual disequilibrium, always responding to the latest event. Frequent disturbance prevented competitive exclusion in this case, resulting in high species richness.

W.2.3.2. Streamflow Alteration

Streamflow variability is the principle force that creates and maintains the integrity of stream ecosystems (Brinson et al. 1981, Poff et al. 1997, Bunn and Arthington 2002). Thus, any

anthropogenic activity that disrupts the natural flow regime represents a significant threat to the structural and functional integrity of these ecosystems, both directly and indirectly. Large, in-channel dams have significantly altered riverine ecosystems throughout the western United States by disrupting the flow of water and sediment and fragmenting once-continuous aquatic and riparian corridors. Because water storage behind dams is large relative to runoff, the alteration of aquatic and riparianecosystems is correspondingly greater in this region (Graf 1999). Diversions and dams affect regional streams that enter all SOPN parks. The geomorphology of streams changes in response to alterations in streamflow.

Channel adjustments, involving changes in cross-sectional form, the size and distribution of bed and bank materials, slope and planform, accompany streamflow alteration and reflect complex adjustments to temporal variations in streamflow and the amount and size of sediment particles supplied to the stream from the watershed. Complex interactions among flow, channel response, and plant and animal life history contribute to considerable spatial and temporal variability in the response of aquatic and riparian ecosystems. Biotic changes typically show a lagged response to driving physical variables, frustrating efforts to develop simple predictive models of ecosystem response (Petts 1987). This suggests the potential importance of using measures of physical processes or attributes, like channel form, as leading indicators of degradational change in stream ecosystems.

*Flow Depletion* - Flow depletions resulting from the diversion of streamflow, can have a range of effects on aquatic and riparian ecosystems. Concerns about the effects of water abstractions on spring, stream, and river biota are not limited to surface water abstractions. Groundwater abstractions for municipal and agricultural uses can also alter aquatic communities (Erman and Erman 1995, Armitage and Petts 1992). Flow reduction due to groundwater withdrawal can generally have the same physical results as flow reduction through surface water diversions. Biotic community alterations have been observed in response to groundwater withdrawal (Wood and Petts 1994, Bickerton et al. 1993), but studies are scarce. Despite the lack of studies that directly examine community structure in response to groundwater withdrawal, it is known that groundwater inputs provide important nutrients that are not readily available in surface-water dominated streams (Dahm et al. 2003). These nutrients can be important to stream biota such as algae, which in turn shape macroinvertebrate community structure (Dahm et al. 2003).

*Altered Flow Variability* - Physical changes resulting from flow alteration downstream of dams typically degrades the biotic integrity of stream ecosystems by altering habitats and competitive interactions in favor of non-native aquatic and riparian species. Native fish and macroinvertebrate species have evolved life-history characteristics specifically adapted to natural flow regimes (Bunn and Arthington 2002). In the west, flow variability is a critical component of natural flow regimes. Streamflow alterations can result in an increase or decrease of baseflow, a change in flow patterns (especially peak flows), and the conversion of intermittent to completely dry reaches (Vinson 2001, Weisberg et al. 1990, Blinn et al. 1998). Flow alteration can negatively affect native species with specific flow adaptations and requirements, while increasing opportunities for the establishment of non-native species that tolerate relatively regulated flows (Blinn et al. 1998, Bunn and Arthington 2002, Haden et al. 2003). This leads to changes in species composition, diversity, abundance, and the density of fish, macroinvertebrates, and algae communities (Weisberg et al. 1990, Castella et al. 1995, Benenati et al. 1998). Dry stream channels also prevent movement between stream sections which impacts species dependent on stream connectivity for population maintenance (Bunn and Arthington 2002). In addition to the direct effects of changes in flow regime, changes in macroinvertebrate communities may be the result of changes in fish or algal communities.

Algal communities can be significantly altered by disturbances such as dams, as well as grazing and agriculture (Shannon et al. 1994, Haefner and Lindahl 1991). Changes in algal community structure are followed by changes in the macroinvertebrate community. The biochemical,

physiological, morphological, and life-history characteristics of a macroinvertebrate are indicative of the state of the environment in which it occurs (Johnson et al. 1993). Physical deformities and life-history characteristics (survival, growth, and reproduction) can be examined to assess habitat quality (Johnson et al. 1993). Abnormal biochemical, physiological, morphological, and life-history characteristics are associated with an influx of toxins to a system (Johnson et al. 1993).

The status of native fish communities is a high priority vital sign for many NPS I & M Networks. Macroinvertebrates are an important food source for fish, thus influence fish community structure. Predation by fish, in turn, influences macroinvertebrate communities. Because these trophic levels are dependent on each other, disturbance to one affects the other. For example, mining, dams, non-native species establishment, flow reduction, trampling, and organic pollutants negatively affect both macroinvertebrate and fish communities (Minckley and Deacon 1968, Diamond and Serveiss 2001, Sappington 1998, Matta et al. 1998, Shannon et al. 1996, Woodward et al. 1994, Canton et al. 1984).

Damming of streams and rivers can also alter macroinvertebrate community structure by altering instream temperatures. Temperatures may either decrease or increase depending on where (what elevation) water is drawn from a reservoir (Vinson 2001, Benenati et al. 2000). Altered temperature can affect macroinvertebrate community structure because life-history characteristics such as fecundity, growth rate, survival, and time of emergence are regulated by water temperature (Vinson 2001). These temperature alterations can be detrimental for some species and favorable for others, creating a changed community structure that has lower taxa richness and may not recover quickly, even if original temperatures are restored (Vinson 2001).

In addition to changes in flow regime and temperature, suspended sediments are often reduced downstream from dams, which can cause changes in fish and macroinvertebrate community structure (Blinn et al. 1998, Stevens et al. 1997). Communities that exist before flow regulation are typically characterized by species that are tolerant of high sediment loads. These same conditions inhibit autochthonous (algal) productivity and favor allochthonous inputs from terrestrial organic material (Haden et al. 2003).

*Floods and Drought* - The effects of extreme flow events on benthic communities depend on both precipitation and the hydrogeologic characteristics of a given watershed. Scouring floods may enhance co-existence of species by maintaining an intermediate level of disturbance. Where climatic, geologic, or anthropogenic factors decrease the permeability of catchment soils and eliminate intermediate storage compartments for water, discharge can fluctuate extremely and abruptly, resulting in scouring episodes that destroy biota (Power et al. 1988). Drought also acts as an extreme disturbance event. Many stream species have adapted resistance to flooding and drought events, including physiological and behavioral adaptations. While these disturbance events can alter community structure in streams, such events are also critical to the life histories of many stream organisms.

The effects of regional climatic drought on aquatic ecosystems are expressed most directly through reduced surface flows and depletion of alluvial groundwater aquifers. Thus, the stress effects of naturally occurring drought mimic those produced by anthropogenic stressors such as damming and diversion of streamflow, groundwater pumping, and channel incision resulting from altered flows of water and sediments, bank stabilization, stream channelization, or in-stream gravel mining (Bravard et al. 1997, Kondolf 1994, 1997, Rood et al. 1995, Stromberg et al. 1996, 1997, Scott et al. 2000).

W.2.3.3. Alteration of Stream Geomorphology

*Stream Channelization* - Stream channelization is typically carried out to improve drainage or flood-carrying capacity, resulting in a smooth uniform channel with enhanced water conveyence and more predictable hydraulic behavior. The straightening of channels and reduction in

roughness leads to greater flow velocities and higher erosive forces, resulting in increased turbidity and sedimentation (Gordon et al. 1992). Excessive siltation of gravel and cobble beds can lead to suffocation of fish eggs and aquatic insect larvae, and can affect the density and composition of periphyton (algal) communities (Gordon et al. 1992). Suspended sediments reduce light penetration and consequently primary productivity. Stream channelization is frequently accompanied by removal of riparian vegetation, changing the relative contribution of allochthonous and autochthonous nutrient sources to the system. A decrease in canopy cover can also result in increased water temperatures and daily temperature fluctuations. Large algal blooms and daily temperature fluctuations are accompanied by large daily fluctuation in oxygen concentrations.

*Changes in Channel Morphology Due to Land Use Changes and Instream Structures* - Abrupt changes in channel pattern, from straight through braided forms, can occur in response to a range of factors, as critical geomorphic thresholds are exceeded by changes in external variables such as stream power, channel gradient, and sediment (Schumm and Kahn 1972). Such channel pattern-shifts can be triggered by episodic events, which may have long-lasting effects on stream and valley morphology, erosional and depositional processes, and aquatic and riparian ecosystems. Rare, large floods have eroded flood plains and terraces and transformed meandering channels near the threshold of pattern-change to a braided pattern. Subsequent channel narrowing and re-establishment of a meandering channel form can then occur through the process of flood plain construction and the establishment of riparian vegetation on portions of the former channel bed (Schumm and Lichty 1963, Friedman et al. 1996). Channel narrowing can also result from the widespread establishment of tamarisk, observed at many locations in the west. However, more often than not, significant changes in stream morphology (and habitat) are the result of changes in local land use (e.g., grazing practices) or small instream structures such as check dams and low-water bridges.

*Alteration of Stream Substrate* - Flow diversion, erosion, or trampling by livestock can reduce substrate and species diversity. Substrate embeddedness (increased siltation) can result in a lower diversity of fish and macroinvertebrate species, along with a change in algal assemblages (Cuffney et al.1997). A study of macroinvertebrate communities in the Gore Creek Watershed, Colorado revealed low species abundance at sites with high sediment loads (Wynn et al. 2001). However, many aquatic plants (macrophytes) may prefer finer substrates and, once established in these reaches, act as substrate for other organisms (Gordon et al. 1992). In general, diversity and abundance of aquatic macroinvertebrates have been shown to increase with substrate stability and the presence of organic detritus (Allan 1995).

W.2.3.4. Ungulate Grazing and Trampling

*Livestock Grazing* - Livestock grazing is one of the most pervasive human stressors of natural ecological systems in the western United States. Livestock use is permitted in portions of one SOPN park (Lyndon B. Johnson National Historical Park), occurs on lands adjacent to most SOPN parks, and in the upland watersheds of all network parks. Most parks in the SOPN were grazed by domestic livestock at one time, and many parks have on-going issues associated with the persistent legacies of past livestock grazing and livestock-management practices.

Heavy grazing on uplands compact soils, which reduces infiltration of precipitation and increases the delivery of water and sediment to streams. The combination of increased upland runoff and reduced channel stability within riparian zones contributes to increased stream bank and channel erosion, and has been implicated in the initiation of channel incision at many locations (Brinson et al. 1981, Cooke and Reeves 1976).

Livestock grazing also increases nutrient loading, alteration of riparian vegetation (which changes instream light and temperature regimes), and increases bacterial inputs (Scrimgeour and Kendall 2003, Davies-Colley et al. 2004). These changes directly and indirectly alter benthic

macroinvertebrate communities. Nutrient loading contributes to greater algal growth and a potential subsequent change in species composition. Increased algal growth results in greater invertebrate biomass (Behmer and Hawkins 1986) and a change in community structure (i.e. a change from allochthonous communities to autochthonous communities).

Scrimgeour and Kendall (2003) found a greater total invertebrate biomass at grazed sites vs. non-grazed sites. Non-grazed sites, however, had a greater biomass of shredders (indicative of an allochthonous community) as compared to grazed sites, which had a greater biomass of collectors and scrapers (indicative of an autochthonous community). This is consistent with the expected invertebrate community structure following decreased bank vegetation and increased nutrient loading (Scrimgeour and Kendall 2003). Haefner and Lindahl (1991) studied the effects of grazing at Capitol Reef National Park and found algal growth increased in response to nutrient inputs, followed by selective increases in macroinvertebrate species. Effects of nutrient inputs from livestock urine and feces can also be particularly detrimental to isolated pools which can become anoxic (Haefner and Lindahl 1991). The use of macroinvertebrates as indicators of nutrient related degradation associated with grazing could be a useful tool to assess the magnitude of the impacts on aquatic systems.

*Livestock Trampling* - Trampling of stream banks by livestock causes a loss of bank stability and changes channel morphology because overgrazed streams become wider and shallower (Scrimgeour and Kendall 2003). Increases in turbidity and suspended solids are also associated with livestock trampling (Davies-Colley et al. 2004). Trampled riparian areas are characterized by soil compaction, vegetation removal, and decreased water infiltration rates, which results in increased runoff rates (Trimble and Mendel 1995). A combination of vegetation loss and wider, shallower streams increases light and water temperature and often results in increased algal growth.

Increases in turbidity, erosion, and suspended solids, however, would decrease light penetration and decrease the growth of algae. These contrasting effects on algal communities make it difficult to predict macroinvertebrate community structure without determining which stressors are dominant in a given situation. In either case, macroinvertebrate diversity typically decreases in response to increasing sedimentation (Kaller and Hartman 2004), followed by an increase in generalist species and a loss of specialist species. For example, Weigel et al. (2000) found that stream reaches with minimal trampling impacts contained more specialist macroinvertebrate species than did stream reaches with greater trampling impacts. Also, species that prefer fine sediments as opposed to coarser sediments (e.g. oligochaetes and chironomids) tend to be found in trampled areas (Meadows 2001). Effects of trampling by livestock in streams and pools across the Southern Plains should be similar to those in other areas, although few studies have examined these effects.

W.2.3.5. Recreation

Visitor use in and around park aquatic and riparian resources tend to be spatially concentrated, magnifying the potential impacts to these systems. Documented impacts from recreation include bank erosion, contamination from human waste, trash, and trampling of plants (Carothers et al. 1976).

At some SOPN parks, recreational activities include driving off-road vehicles through canyons and on river banks (e.g., Reservoir Meredith National Recreation Area), both of which can involve stream crossings and driving up stream channels. As with cattle trails, off-road vehicle trails breach stream banks, increasing hydraulic roughness and removing vegetation. At high flows, turbulence created by these features accelerates erosion, creating more turbulence in a positive feedback loop. Trails and road crossings also serve as preferred flow paths for water onto, and off of the flood plain during rising and falling streamflows, causing further erosion (Trimble and Mendel 1995). Finally, because of reduced resistance to flow, un-vegetated trails crossing flood

plain surfaces experience excess erosion during high flows and can trigger channel incision (Cook and Reeves 1976).

Vehicles crossing or driving up streams causes an increase in stream turbidity, total dissolved solids (TDS), total suspended solids (TSS), salinity, and overall erosion (Lane and Sheridan 2002, Sample et al. 1998). Several studies have shown that macroinvertebrate communities respond to these factors. Increased turbidity and the associated decrease in light penetration, result in decreased diversity and/or a complete community shift in both algae and macroinvertebrates (Stevens et al. 1997, Thiere and Schulz 2004). Similarly, increases in TDS and changes in salinity levels can change benthic invertebrate community structure (Leland and Fend 1998). Several studies have demonstrated species-specific responses to TSS, with certain species more resistant than others to high TSS (Thiere and Schulz 2004). Erosion is a direct cause of increases in turbidity, TDS, and TSS, and has been correlated with a decrease in the biointegrity of macroinvertebrate communities where erosion is prevalent (Rothrock et al. 1998). High levels of turbidity, TDS, and TSS inhibit the establishment of light-dependent algae and associated invertebrate assemblages. Sensitive orders such as Ephemeroptera, Trichoptera, and Odonta are found to be less abundant under these conditions (Thiere and Schulz 2004). Instead, more tolerant invertebrate taxa such as dipterans become established (Stevens et al. 1997, Thiere and Schulz 2004).

Off-site roads alter abiotic components of aquatic ecosystems by changing soil density and composition, runoff and sedimentation patterns, light and temperature regimes, and water chemistry (Trombulak and Frissell 2000). Biotic alterations in response to these changes can be seen in riparian vegetation structure, as well as aquatic community structure (Backer et al. 2004). Few studies have examined the direct effects of roads and trails on macroinvertebrate communities. However, macroinvertebrates are sensitive to the effects mentioned above. Kaller and Hartman (2004) found a threshold level of sediment accumulation, above which macroinvertebrate abundance and diversity were reduced significantly. Increased sedimentation also tends to favor macroinvertebrates that prefer habitats characterized by fine substrata such as oligochaetes and chironomids (Meadows 2001). Instream salinity levels are generally greatly increased in the vicinity of roads and certain macroinvertebrate species are more sensitive than others to high levels of road salt (Benbow and Merritt 2004). This sensitivity to road effects makes macroinvertebrate inventories useful for monitoring the status of aquatic systems in national parks where roads have been constructed for visitor access.

W.2.3.6. Altered Fire Regime

Depending on the severity and extent, upland fire events can degrade aquatic and riparian systems due to erosion, increases in suspended and bed-load sediment, and increases in peak flows during floods (Veenhuis 2002, Vieira 2004). Although post-fire impacts may be minimal following low or moderate severity fire, degradation of aquatic and riparian systems following high-severity events can be significant. Erosion rates, for example, following high-severity fire can increase by one or more orders of magnitude (Benavides-Solorio 2003, Moody and Martin 2001).

The structure and function of aquatic and riparian areas are adversely impacted by the sequence of wildfire, increased runoff, erosion and downstream sedimentation. The removal or reduction of the forest canopy, surface vegetation cover and ground cover all contribute to accelerated erosion following severe fire (Cipra et al. 2002). Where present, the loss of forest canopy also reduces shading to riparian areas which can raise water temperatures by 3 to 10 ºC (Amaranthus et al. 1989). A several fold increase in peak flows (due to increased runoff) further amplifies surface and mass erosion (Dennis 1989, Tiedemann et al. 1979). Sediment laden flows often induce sheet wash, rill and gully erosion and can induce mass movements such as debris torrents. As mass movements travel through the channel network, they can cause intense bank

scour, which increases the volume of sediment delivered to downstream areas (Cipra et al. 2002).

Alterations to water chemistry following fire also degrade aquatic and riparian systems. The ash from fires can temporarily increase nutrients, ions, turbidity, pH, and alkalinity while decreasing dissolved oxygen levels (Earl and Blinn 2003). Macroinvertebrate densities are reduced immediately after a fire, but can recover within a year, whereas community structure and diversity are affected over a long period (Earl and Blinn 2003, Vieira et al. 2004). Because of intense flooding after burns and because of instream physical and chemical changes, generalist macroinvertebrate species with successful and rapid larval dispersal mechanisms tend to dominate over more specialized macroinvertebrate species that were present in the pre-fire system (Vieira et al. 2004).

W.2.3.7. Non-Point and Point Contaminant Releases

Organic pollutants from pesticide use in urban and agricultural areas act as stressors on instream communities. Macroinvertebrates in stream reaches containing pesticides have shown similar numbers of individuals, but lower overall diversity and richness than communities in pesticide-free reaches (Thiere and Schulz 2004, Lenat 1984). Certain taxa are more sensitive than others to contaminants (Sibley et al. 1991, Thiere and Schulz 2004, Carsten von der Ohe and Liess 2004, Lenat 1984). The effects of different chemicals used for pest control are variable. For example, chemicals which are less water soluble may be less toxic to macroinvertebrates than they would be if they were available in the water column (Schulz and Liess 2001b). Organic contaminants have been shown to negatively affect macroinvertebrate survival and growth, and increase downstream macroinvertebrate drift (Schulz and Liess 2001a). Information about the effects of pesticides on macroinvertebrates is sparse.

Stresses and impacts to streamflow regime, stream sediments and geomorphology, water quality/chemistry, and biota of SOPN streams are enumerated in Tables 2 through 5, respectively, accompaned by indicators of ecosystem response/condition. For each major stressor identified, indicators of ecosystem condition are summarized in Table 6.

*W.2.4. Benefits of Stream Classification for Long-Term Monitoring*

Indirect effects of climate change and land use practices such as grazing and land-clearing, which degrade upland soil stability and reduce vegetation cover, alter the delivery of water and sediment to receiving streams (Trimble and Mendel 1995). This, in turn, alters the rate, magnitude, and style of channel processes, which ultimately structure and maintain aquatic and riparian ecosystems (Frissell et al. 1986). A hierarchical, process-based approach to geomorphic stream classification offers the possibility of mitigating undesirable human impacts on stream and riparian ecosystems through the design of efficient and representative assessment and monitoring programs (Montgomery and Buffington 1997, Montgomery and MacDonald 2002).

Stream channel classification systems use similarities of form and/or process to discretely organize complex landscape features that display both relatively continuous longitudinal variation (Vannote et al. 1980) and sharp, local discontinuities (Montgomery 1999, Benda et al. 2004). A number of stream classification schemes have been developed (Schumm, 1981 Rosgen 1996). Successful geomorphic classification systems are process-based, applicable across a range of spatial and temporal scales, and capable of assessing probable channel responses to a range of natural and anthropogenic disturbances (Naiman et al. 1992). A process-based classification could be employed by SOPN to determine the sensitivity, or resistance and resilience, of park streams to anthropogenic stressors of concern to park managers, and thus provide a basis for objectively prioritizing and selecting sites for monitoring (Frissel et al.1986).

**Table 2. Stresses and impacts on streamflow regime**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | ↓ Streamflow, Stream Velocities, Depth of Water | Stream Stage / Discharge |
| Groundwater Pumping (△ Baseflow, Streamflow) | ↓ Baseflow, Streamflow, Stream Velocities, Depth of Water | Groundwater Level, Stream Stage / Discharge (Baseflow) |
| △ Local Stream Base Level(s) | ↓ or ↑ Stream Velocities | Local Stream Velocities, Stage |
| Impoundments | ↓ Stream Velocities, Temporal Variations in Streamflow, ↑ Depth of Water | Stream Stage / Discharge (Regulated Dams) |
| Bridges, Ramps, Docks (instream structures) | ↓ and ↑ Stream Velocities, Depth of Water | Local Stream Velocities, Depth Profile |
| Bank Stabilization / Channel Straightening | ↓ and ↑ Stream Velocities, Depth of Water | Local Stream Velocities, Depth Profile |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Baseflow, Streamflow, Stream Velocities, Depth of Water | Groundwater Level, Stream Stage / Discharge |
| Tamarisk & Other Phreatophytes | ↑ Evapotranspiration, ↓ Streamflow, Stream Velocities, Depth of Water | Stream Stage / Discharge |
| Clearing of Emergent Vegetation & Woody Debris | ↑ Stream Velocities | Local Stream Velocities |

| | | |
|---|---|---|
| Removal of Upland Riparian Vegetation | ↓ Energy Dissipation at High Flows | Local Stream Velocities (High Flows) |
| Flood | ↑ Streamflow, Stream Velocities, Depth of Water | Stream Stage / Discharge |
| Drought | ↓ Streamflow, Stream Velocities, Depth of Water | Stream Stage / Discharge |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Evapotranspiration, Baseflow, Streamflow, Stream Velocities, Depth of Water | Groundwater Level, Stream Stage / Discharge |
| Motorized Boating | ↑ Local Stream Velocities | Local Stream Velocities |

**Table 3. Stresses and impacts on stream sediments / geomorphology**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | ↓ Streamflow, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Groundwater Pumping (△ Baseflow, Streamflow) | ↓ Baseflow / Streamflow, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| △ Local Stream Base Level(s) | △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Impoundments | △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Bridges, Ramps, Docks (instream structures) | △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Shoreline Development (buildings & other structures) | Bank Modification, △ Stream Cross-Sectional Geometry, Entrenchment | Stream Geomorphic Parameters[*1] |
| Bank Stabilization / Channel Straightening | △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Dredging / Filling (Riverine Wetlands) | △ Stream Cross-Sectional Geometry, Entrenchment | Stream Geomorphic Parameters[*1] |

| | | |
|---|---|---|
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | △ Baseflow / Streamflow, Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| △ Sediment Load (due to changes in upland or local land use) | △ Suspended Sediment, Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Tamarisk | △ Stream Cross-Sectional Geometry (loss of active channel) | Stream Geomorphic Parameters[*1] |
| Other Exotic / Invasive Riparian Vegetation | ↓ or ↑ Bank Erosion, Sediment Load with Impacts to Stream Geomorphology | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Clearing of Emergent Vegetation & Woody Debris | △ Stream Cross-Sectional Geometry, Longitudinal Profile | Stream Geomorphic Parameters[*1] |
| Removal of Upland Riparian Vegetation | ↑ Bank Erosion, Sediment Load with Impacts to Stream Geomorphology | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Flood | Possible △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Baseflow / Streamflow, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] |

| | | |
|---|---|---|
| Ungulate Grazing / Trampling | Trampling of Riparian Vegetation & Banks, ↑ Sediment Load, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Instream Driving / Vehicle Crossing | △ Stream Cross-Sectional Geometry, ↑ Suspended Sediment, Redistribution of Bed Material | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Motorized Boating | ↑ Suspended Sediment, Redistribution of Bed Material | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Off-Road Vehicle Use | ↑ Erosion, Sediment Load, △ Bed Composition | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Sand & Gravel Mining | ↑ Sediment Load, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition, | Suspended Sediment, Stream Geomorphic Parameters[*1] |
| Altered Fire Regime | △ Sediment Load, Bed Composition | Suspended Sediment, Bed Composition |

*1 Channel cross-section, width/depth, entrenchment, rates of bank erosion and downcutting/aggradation, longitudinal profile, sinuosity, channel pattern, channel location
(migration), and pebble count.

**Table 4. Stresses and impacts on stream water quality / chemistry**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Basic Water Quality Parameters[*1], Nutrients[*2], Suspended Sediment |
| Groundwater Pumping (△ Baseflow, Streamflow) | ↑ Concentration of Nutrients, Organic Carbon, & Suspended Solids, Water Temperature, △ Concentration of Other Dissolved & Suspended Constituents | Basic Water Quality Parameters[*1], Nutrients[*2], Suspended Sediment |
| Impoundments | ↓ and ↑ Suspended Sediment | Suspended Sediment, Turbidity |
| Shoreline Development (buildings & other structures) | ↑ Sediment Load, Water Temperature | Basic Water Quality Parameters[*1], Suspended Sediment |
| Bank Stabilization / Channel Straightening | ↓ Sediment Load | Suspended Sediment, Turbidity |
| Dredging / Filling (Riverine Wetlands) | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, ↓ or ↑ Water Temperature | Basic Water Quality Parameters[*1], Suspended Sediment |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Sediment Load, Concentration of Other Dissolved & Suspended Constituents, Water Temperature | Basic Water Quality Parameters[*1], Suspended Sediment |
| △ Sediment Load (due to changes in upland or local land use) | ↓ or ↑ Suspended Sediment | Suspended Sediment, Turbidity |

| | | |
|---|---|---|
| Non-Point Nutrient & Organic Releases (upland or local land use) | ↑ Nutrients, Organic Carbon, Heavy Metals, Riverine Wetland Eutrophication | Basic Water Quality Parameters[*1], Nutrients[*2], BOD/COD[*3] |
| Permitted Wastewater Discharge to Streams | ↑ Nutrients, Organic Carbon, Heavy Metals, Aquatic Microorganisms, Riverine Wetland Eutrophication | Aquatic Microorganisms[*4], BOD/COD[*3], Nutrients[*2] |
| Point Contaminant Releases (contaminated sites) | ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, and/or Other Toxic Substances (as applicable) | Potential Point Source Contaminants[*5], BOD/COD[*3] |
| Atmospheric Deposition | ↑ Nitrogen and Sulphur Compounds, Mercury & Other Metals, Pesticides (as applicable) | Nutrients[*2], pH, Mercury & Other Metals, Pesticides (as applicable) |
| Tamarisk | ↑ Salinity | Salinity |
| Other Exotic / Invasive Riparian Vegetation | ↓ or ↑ Bank Erosion, Sediment Load | Suspended Sediment, Turbidity |
| Exotic / Invasive Aquatic Vegetation | ↓ or ↑ Dissolved Oxygen, △ Nutrient Cycling | Basic Water Quality Parameters[*1], Nutrients[*2] |
| Removal of Upland Riparian Vegetation | ↓ Interception of Overland Flow (Nutrients & Contaminants) | Basic Water Quality Parameters[*1], Nutrients[*2] |
| Flood | ↑ Nutrient Load, Suspended Sediment | Nutrients[*2], Suspended Sediment, Turbidity |
| Drought | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Basic Water Quality Parameters[*1], Nutrients[*2], Suspended Sediment |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Water Temperature, Algae, Concentration of Dissolved and Suspended Constituents | Basic Water Quality Parameters[*1] |
| Ungulate Grazing / Trampling | ↑ Aquatic Microorganisms, Sediment Load, Nutrients, Organic Carbon | Aquatic Microorganisms[*4], Suspended Sediment, Turbidity, BOD/COD[*3] |

| | | |
|---|---|---|
| Swimming / Wading | ↑ Aquatic Microorganisms, Suspended Sediment | Aquatic Microorganisms*4, Suspended Sediment, Turbidity |
| Instream Driving / Vehicle Crossing | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Suspended Sediment, Turbidity, Petroleum Hydrocarbons |
| Motorized Boating | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Suspended Sediment, Turbidity, Petroleum Hydrocarbons |
| Off-Road Vehicle Use | ↑ Erosion, Sediment Load | Suspended Sediment, Turbidity |
| Sand & Gravel Mining | ↑ Sediment Load | Suspended Sediment, Turbidity |
| Altered Fire Regime | ↓ or ↑ Sediment Load, Nutrients | Suspended Sediment, Turbidity, Nutrients*2 |

*1 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, alkalinity, and turbidity.

*2 Nitrogen and phosphorous.

*3 Biological oxygen demand, chemical oxygen demand.

*4 Bacteria, viruses, and protozoa.

*5 Synthetic organic compounds, petroleum hydrocarbons, heavy metals, pesticides, and other toxic substances, as applicable.

**Table 5. Stresses and impacts on stream biota**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | ↓ Degree of Submergence, Available Habitat, ↑ Concentrations of Dissolved and Suspended Constituents | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Groundwater Pumping (△ Baseflow, Streamflow) | ↓ Baseflow, Degree of Submergence, Available Habitat, ↑ Concentrations of Dissolved and Suspended Constituents | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| △ Local Stream Base Level(s) | △ Habitat with △ Stream Geomorphology | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Impoundments | Impede or Reduce Fish Passage | Composition, Abundance, & Distribution of Fish |
| Bridges, Ramps, Docks (instream structures) | △ Habitat with △ Stream Geomorphology | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Shoreline Development (buildings & other structures) | △ Near-Shore Habitat, Near-Shore Water Quality | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Bank Stabilization / Channel Straightening | Loss of Riparian Vegetation, Bank Habitat | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Dredging / Filling (Riverine Wetlands) | △ Riverine Wetland Habitat, Water Quality | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | | |
|---|---|---|
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | △ Streamflow, Stream Geomorphology, Habitat, Water Quality | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| △ Sediment Load<br>(due to changes in upland or local land use) | △ Bed Composition, ↓ or ↑ Areal Extent of Aquatic / Riverine Wetland Habitat | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Non-Point Nutrient & Organic Releases<br>(upland or local land use) | ↑ Nutrients, Organic Carbon, Heavy Metals, Riverine Wetland Eutrophication | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Permitted Wastewater Discharge to Streams | ↑ Nutrients, Organic Carbon, Heavy Metals, Riverine Wetland Eutrophication | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Point Contaminant Releases<br>(contaminated sites) | ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, and/or Other Toxic Substances (as applicable) | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Atmospheric Deposition | ↑ Nitrogen & Sulphur Compounds, pH, Mercury & Other Metals, Pesticides (as applicable) | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Tamarisk & Other Phreatophytes | ↑ Salinity, ↓ Depth of Water, Areal Extent of Active Channel / Riverine Wetlands | Tamarisk Abundance & Distribution; Composition, Abundance, & Distribution of Native Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, & Herptofauna |

| | | |
|---|---|---|
| Other Exotic / Invasive Riparian Vegetation | Competition with Noninvasive Native Riparian Vegetation | Composition, Abundance, & Distribution of Riverine Wetland Vegetation |
| Exotic / Invasive Aquatic Vegetation | Competition with Noninvasive Native Aquatic Vegetation, △ Available Habitat | Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Clearing of Emergent Vegetation & Woody Debris | Loss of Habitat | Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Removal of Upland Riparian Vegetation | ↓ Cover, △ Habitat | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Exotic / Invasive Periphyton, Fish, or Herptofauna | Competition with Noninvasive Native Periphyton, Fish, and Herptofauna; △ Nutrient Cycling, Dissolved Oxygen | Composition, Abundance, & Distribution of Macroinvertebrates, Fish, & Herptofauna |
| Flood | △ Habitat with △ Stream Geomorphology, △ Water Quality | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Drought | △ Water Quality | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Air & Water Temperatures, Depth of Water, Concentrations of Dissolved and Suspended Constituents, Riverine Wetland Eutrophication | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Stream Fragmentation | Loss of Patch Connectivity | Composition, Abundance, & Distribution of Macroinvertebrates, Fish, & Herptofauna |
| Ungulate Grazing / Trampling | Trampling of Aquatic / Riverine Wetland Vegetation & Banks, ↑ Nutrients, Organic Carbon, Possible Riverine Wetland Eutrophication | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | | |
|---|---|---|
| Swimming / Wading | Trampling of Aquatic / Riverine Wetland Vegetation, Disruption of Habitat, ↑ Suspended Sediment | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Instream Driving / Vehicle Crossing | Damage to Aquatic / Riverine Wetland Vegetation, Disruption of Habitat, ↑ Suspended Sediment | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Motorized Boating | Disruption of Habitat, ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Off-Road Vehicle Use | ↑ Erosion, Suspended Sediment | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Sand & Gravel Mining | Loss of Aquatic / Riverine Wetland Vegetation & Other Habitat, ↑ Sediment Load | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Altered Fire Regime | ↑ Sediment Load, Nutrients | Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

**Table 6. Summary of stresses and indicators of stream ecosystem function and condition**

| Stresses | Indicators |
|---|---|
| Surface Water Diversions (△ Streamflow) | Stream Stage / Discharge; Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*2], Nutrients[*3]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Groundwater Pumping (△ Baseflow, Streamflow) | Groundwater Level, Stream Stage / Discharge (Baseflow); Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*2], Nutrients[*3]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| △ Local Stream Base Level(s) | Local Stream Velocities, Stage; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Impoundments | Stream Stage / Discharge (Regulated Dams); Stream Geomorphic Parameters[*1]; Suspended Sediment, Turbidity; Composition, Abundance, & Distribution of Fish (Fish Passage) |
| Bridges, Ramps, Docks (instream structures) | Local Stream Velocities; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Shoreline Development (buildings & other structures) | Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*1], Suspended Sediment; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Bank Stabilization / Channel Straightening | Local Stream Velocities; Stream Geomorphic Parameters[*1]; Suspended Sediment, Turbidity; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Dredging / Filling (Riverine Wetlands) | Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*1], Suspended Sediment; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | |
|---|---|
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | Groundwater Level, Stream Stage / Discharge; Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*2], Nutrients[*3], Suspended Sediment; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| △ Sediment Load<br>(due to changes in upland or local land use) | Suspended Sediment, Turbidity; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Non-Point Nutrient & Organic Releases<br>(upland or local land use) | Basic Water Quality Parameters[*2], Nutrients[*3], BOD/COD[*4]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Permitted Wastewater Discharge to Streams | Aquatic Microorganisms[*5], BOD/COD[*4], Nutrients[*3]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Point Contaminant Releases<br>(contaminated sites) | Potential Point Source Contaminants[*6], BOD/COD[*4]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Atmospheric Deposition | Nutrients[*3], pH, Mercury & Other Metals, Pesticides (as applicable); Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Tamarisk | Stream Stage / Discharge; Stream Geomorphic Parameters[*1]; Salinity; Tamarisk Abundance & Distribution; Composition, Abundance, & Distribution of Native Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Other Exotic / Invasive Riparian Vegetation | Suspended Sediment, Turbidity, Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Riverine Wetland Vegetation |
| Exotic / Invasive Aquatic Vegetation | Basic Water Quality Parameters[*2], Nutrients[*3]; Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | |
|---|---|
| Clearing of Emergent Vegetation & Woody Debris | Local Stream Velocities; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Removal of Upland Riparian Vegetation | Local Stream Velocities (High Flows); Stream Geomorphic Parameters[*1]; Suspended Sediment; Basic Water Quality Parameters[*2], Nutrients[*3]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Exotic / Invasive Periphyton, Fish, & Herptofauna | Composition, Abundance, & Distribution of Macroinvertebrates, Fish, & Herptofauna |
| Flood | Stream Stage / Discharge; Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*2], Nutrients[*3], Suspended Sediment; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Drought | Stream Stage / Discharge; Basic Water Quality Parameters[*2], Nutrients[*3], Suspended Sediment; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Climate Change (temperature, precipitation, wind) | Groundwater Level, Stream Stage / Discharge; Stream Geomorphic Parameters[*1]; Basic Water Quality Parameters[*2]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Algae |
| Stream Fragmentation | Composition, Abundance, & Distribution of Macroinvertebrates, Fish, & Herptofauna |
| Ungulate Grazing / Trampling | Suspended Sediment, Stream Geomorphic Parameters[*1]; Aquatic Microorganisms[*5], Suspended Sediment, Turbidity, BOD/COD[*4]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Swimming / Wading | Aquatic Microorganisms[*5], Suspended Sediment, Turbidity; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Instream Driving / Vehicle Crossing | Suspended Sediment, Turbidity, Petroleum Hydrocarbons; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | |
|---|---|
| Motorized Boating | Local Stream Velocities; Suspended Sediment, Turbidity, Petroleum Hydrocarbons; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Off-Road Vehicle Use | Suspended Sediment, Suspended Sediment, Turbidity; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Sand & Gravel Mining | Suspended Sediment, Suspended Sediment, Turbidity; Stream Geomorphic Parameters[*1]; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Altered Fire Regime | Suspended Sediment, Turbidity, Nutrients[*3]; Bed Composition; Composition, Abundance, & Distribution of Aquatic / Riverine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

*1 Channel cross-section, width/depth, entrenchment, rates of bank erosion and downcutting/aggradation, longitudinal profile, sinuosity, channel pattern, channel location
(migration), and pebble count.

*2 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, alkalinity, and turbidity.

*3 Nitrogen and phosphorous.

*4 Biological oxygen demand, chemical oxygen demand.

*5 Bacteria, viruses, and protozoa.

*6 Synthetic organic compounds, petroleum hydrocarbons, heavy metals, pesticides, and other toxic substances, as applicable.

## W.3. RESERVOIR ECOSYSTEM MODEL

Reservoirs at Lake Meredith NRA and Chickasaw NRA (Lake Meredith, Lake of the Arbuckles, and Veterans Lake) are man-made lakes, managed by the National Park Service as recreational resources and operated as public drinking water supplies by other entities. The Pedernales River in the vicinity of Lyndon B. Johnson NHP has three small dams on it and the river there has components of both a riverine and lacustrine system.

### *W.3.1. Summary of Drivers, Stressors, Attributes, and Indicators of Reservoir Ecosystem Function and Condition*

Man-made structures (e.g., diversions, dams, and spillways), as well as natural conditions such as climate, atmospheric conditions, geology, landform, time, and upland watershed conditions, are drivers (major forces of change) for Lake Meredith, Lake of the Arbuckles, and Veterans Lake ecosystems (Figure 11).

### *W.3.2. Reservoir Ecosystem Function under Desired Conditions*

Reservoirs are human-engineered habitats and relatively young compared to many ecological processes. Little is known about the dynamics of aquatic organisms and nutrient and mineral cycling in reservoirs, although basic principles of lake ecology are presumed to apply. Habitats of reservoir ecosystems (the pelagial, littoral, and profundal zones), 'resources' influencing the function of reservoir ecosystems (Chapin et al. 1996), are described in this section. The attributes and functioning of SOPN reservoir ecosystems under 'desired' conditions is summarized in Figure 12.

Lakes (reservoirs) are highly valued for the recreational opportunities and esthetic experiences they provide. They have also attracted scientists for ecosystem studies because of their diversity, relative ease of isolating specific subunits, the ability to conduct ecosystem-level manipulations, and more recently to use lakes for documenting changes in the global environment (Davis 1981). Because they are sensitive to inputs from watershed and air sheds, lake ecosystems in most areas of the world are likely to have experienced at least some level of human-induced, ecological change.

This model is intentionally general in order to describe a range of potential conditions at Lake Meredith, Lake of the Arbuckles, and Veterans Lake, including:

Trophic status (oligotrophic, eutrophic, dystrophic…)

Annual mixing pattern (dimictic, polymictic, meromictic)

Morphometry (mean depth – volume/area, maximum depth, shoreline development, mean slope…)

Water Source (stream inflows and outflows, groundwater seepage to and from the reservoir…)

Additionally, responses of reservoir ecosystems may vary considerably in duration depending on the subsystem affected. Frost et al. (1988) emphasize the importance of recognizing variations in scale in studying and understanding lake ecosystems. Hence reservoirs (lakes) may show responses on evolutionary time scales (e.g. predator-prey associations) (DeAngelis et al. 1985) to time scales of seconds (phosphorus cycling) (Norman and Sager 1978). On intermediate scales, the introduction of an exotic crayfish has been shown to alter the littoral community for several years (Lodge and Lorman 1987).

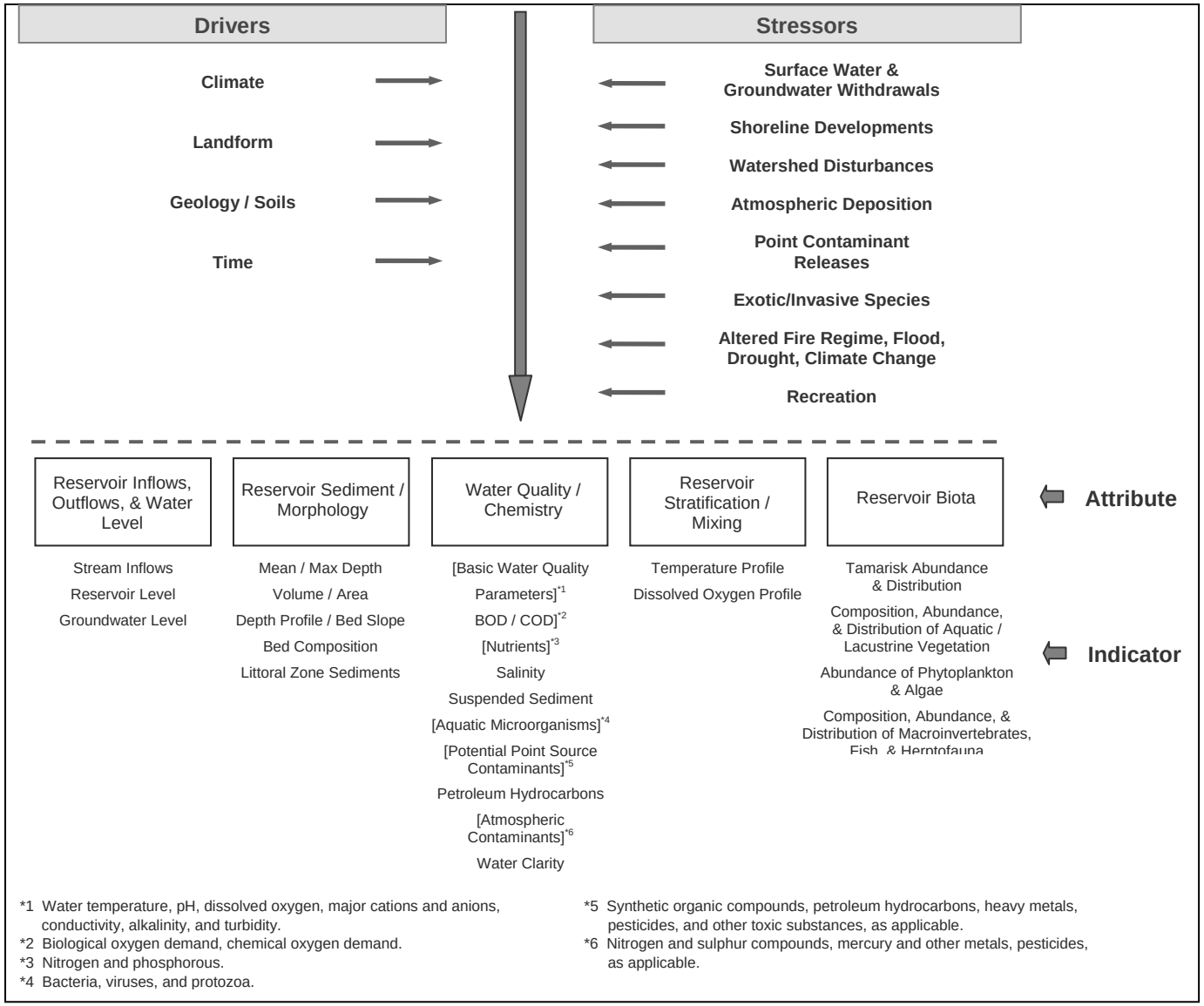



**Figure 11. Overview of drivers, stressors, attributes, and indicators of reservoir ecosystem function and condition.**

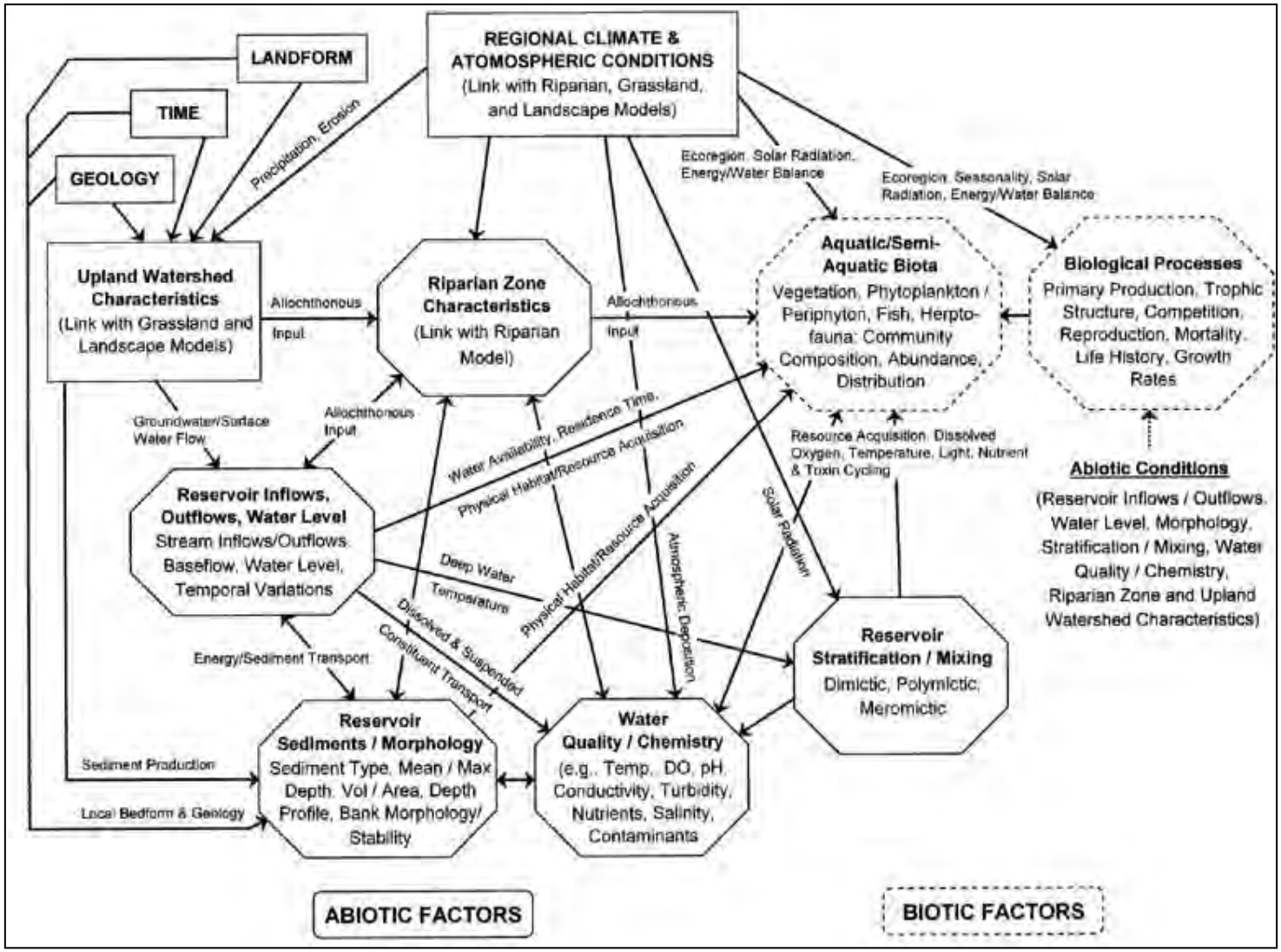



**Figure 12. Desired reservoir ecosystem function.**

W.3.2.1. Major Habitats of Reservoir Ecosystems

The *pelagial zone* has long been the focus of lake ecology studies. This open water habitat supports the plankton community, the phytoplankton and zooplankton, as well as the ichthyoplankton. The phytoplankton are dependent on water motion for maintaining their position in the water column in addition to various adaptation in morphology of the cells to increase their surface area. Hence the phytoplankton will generally be distributed in the pelagial zone to the depth of mixing in the reservoir (in shallow reservoirs to the bottom, in stratified reservoirs to the thermocline) but functionally their effective distribution is a function of light, specifically the attenuation of light with depth. Phytoplankton photosynthesis is considered to prevail to that depth where about 1 percent of surface light remains, known as the compensation depth. Beyond this depth, respiration and decomposition processes exceed any contribution from photosynthesis.

In certain stratified reservoirs of sufficient clarity, the compensation depth may extend below the mixing depth into or below the thermocline. Photosynthetic production of oxygen can then help to create a habitat for cold water fishes in this layer, complementing the warm water habitat of the upper epilimnion. In other reservoirs, the compensation depth can be shallower than the mixing depth producing a light limiting condition for production. The zooplankton, because of their mobility, typically show variations in vertical distribution in a reservoir due to vertical migration in response to diurnal changes in light intensity in the water column. Factors influencing the underwater light regime are thus of considerable ecological importance in the ecosystem.

The *littoral zone* (lacustrine wetlands) has been recognized as a major component of lake ecosystems in recent decades. Wetzel (1979) showed the important role of detritus originating in submersed aquatic vegetation (SAV) of the littoral zone on the overall metabolism of a lake (reservoir). Carpenter and Lodge (1986) stressed the important interactions of the littoral community - between sediment and water and between shoreline and open water. The major producers in this community, SAV, provide habitat and food for fishes, muskrats, waterfowl amphibians and invertebrates. Additionally, algal periphyton can be important contributors to littoral production in certain reservoirs. The littoral zone includes a major nutrient pool that cycles slowly compared to the pelagial zone. It influences water temperature in shallow waters, reduces water movement, and through self-shading increases light attenuation. Cole (1994) notes that the littoral community often has the highest biodiversity and biological production in a lake (reservoir) ecosystem.

The aerial extent of development of the littoral community is a function of the substrate, nutrient levels, and bottom slope of the nearshore environment. The depth distribution is a function of light attenuation and ultimately pressure, at least for angiosperm SAV. Hence factors decreasing light availability play a major role in the degradation of this community (Sager et al. 1996). Nutrients are also important for the growth of the SAV that reach their maximum growth and biomass at roughly intermediate conditions between oligotrophic and eutrophic status (Wetzel 1979). Nutrient limitation in sediments and water seems to be in effect in oligotrophic reservoirs, while the light shading effect of increased phytoplankton biomass can limit depth distribution and growth in eutrophic reservoirs (Wetzel 1983).

The *profundal zone* includes the deep water, bottom sediment environment typically found in stratified lakes (reservoirs) where it is dark and cold. Habitat diversity is low. Processes of organic matter sedimentation and decomposition produce a physically uniform texture in bottom sediments, though the qualitative composition includes a range of inorganic and organic substances. In eutrophic reservoirs, the hypolimnetic water and sediments will have varying degrees of oxygen depletion while in oligotrophic reservoirs, oxygen depletion is minimal in the hypolimnion, though oxygen depletion can occur in the pore water of the organically richer sediments.

In unstratified reservoirs of moderate depth, light may not reach the profundal sediments, but with full mixing of the water column, bottom temperatures and oxygen levels will be comparable to the surface waters. Higher water temperatures, consequently, can have a positive effect on metabolism and growth on the benthos in such reservoirs. In shallow reservoirs, the littoral zone may prevail throughout the basin and a profundal zone is lacking. Maximum depth and trophic status thus are important influences on the development of sediment habitat among reservoirs.

In eutrophic reservoirs, the profundal benthos adapt in various ways to the oxygen stress and generally include at least a few macroinvertebrates. In oligotrophic reservoirs the fauna associated with the profundal habitat is generally more diverse, even though biomass and production may be lower than in eutrophic reservoirs. The profundal zone in oligotrophic reservoirs may include some of the same taxa found in eutrophic reservoirs, in addition to other species.

W.3.2.2. Natural Processes

Hutchinson (1969) used the phrase “trophic equilibrium” to describe the close linkage between a lake (reservoir) and its watershed. The linkage is based on the geological character of the watershed, the fertility of the soil and bedrock, and the trophic status of the reservoir that, through transport, receives nutrients from the watershed. In the natural state and over the long term, this linkage would achieve an equilibrium condition. Major events such as extreme precipitation and runoff, fire, and erosion, foster increases in nutrient loading or hydrological washout, leading to changes in the reservoir of varying duration. Reservoirs are quite sensitive to events and process external to their basins. Features of the reservoir itself, such as basin morphometry, water clarity, and food chain structure, interact with external influences to produce reservoir ecosystem features.

*W.3.3. Natural and Anthropogenic Stresses and Reservoir Ecosystem Response*

Significant changes in any of the four interactive controls – climate, resource supply, major biotic functional groups, or disturbance regime (Chapin et al. 1996) – are predicted to result in a new ecosystem with different characteristics than the original system. This section describes predominant anthropogenic disturbance regimes and specific stressors and responses of reservoir ecosystems at Lake Meredith NRA and Chickasaw NRA.

W.3.3.1. Anthropogenic Influences

*Watershed Disturbances* - Watershed disturbances such as agriculture, urban development, logging and fire are major influences on reservoir ecosystems (Scrimgeour et al. 2001, Garrison and Wakeman 2000). Loss of protective vegetative cover on soil leads to increased loading of nutrients and sediments over the natural loads which stimulate increased growth of phytoplankton and submersed aquatic vegetation (SAV). These eutrophication processes can lead to excessive growth of nuisance algae, loss of SAV in the littoral community due to increased light attenuation, and altered food chain processes and efficiencies owing to less palatable phytoplankton species (Richman and Dodson 1983, Sager and Richman 1991, Kemp et al. 2001)

*Shoreline Disturbances* - Shoreline disturbances such as clearing emergent and submersed vegetation and removing woody debris to create swimming areas can lead to a loss of aquatic habitat, decreased amphibian populations (Woodford and Meyer 2003), reduction in fish growth rates (Schindler et al. 2000), and decreased water quality (Garrison and Wakeman 2000).

*Atmospheric Deposition* - Atmospheric deposition of contaminants illustrates the broad extent to which external factors affect reservoir ecosystems. The watershed area for a given reservoir is, in most cases, small in comparison to the air shed. Substances can be transported great distances through the atmosphere before falling on the reservoir or upstream tributaries. Mercury is a problem in water bodies throughout the United States. Following deposition in the reservoir,

inorganic mercury undergoes a transformation to methyl mercury, the form in which it bioaccumulates in the food chain. Animals, including humans and wildlife (such as loons and eagles) that eat contaminated fish, are susceptible to central nervous system damage. The affect of mercury on human fetuses and newborn infants is of prime concern (ATSDR 1999). In the 1990s, certain regions experienced a decline in mercury deposition rates that was followed by gradual declines in lake water and fish (Watras et al. 2000).

Deposition of sulfur and nitrogen oxides produced by combustion of fossil fuels (coal-fired power plants, automobiles and other fuel burning processes) causes acidification of lakes (reservoirs). Atmospheric transport of sulfur and nitrogen oxides may occur over great distances, as well as nearby sources. Not all lakes respond equally. The buffering capacity of lakes (reservoirs) is determined by the geological setting. Other factors, such as watershed gradient, vegetative cover, and food web structure, play a role in reservoir response.

Acidification of lakes (reservoirs) by atmospheric deposition has broad ranging ecological affects, in addition to its influence on the methylization of mercury. The Clean Air Act Amendment of 1990 called for a decrease in sulfur dioxide emissions. Some acidified lakes are now showing recovery, others are not.

*Recreation* - Recreation activities are increasingly regarded as a major influence on lake (reservoir) ecosystems. Considerable pressure from fishing and boating can lead to impacts on the age and size structure of fish populations and the food web (Reed-Andersen et al. 2000a; Landres et al. 2001, Harig and Bain 1998). Exotic and invasive species can result from transporting boats from lake to lake, inadvertently carrying entangled plant material and associated biota (Johnson 2001) such as zebra mussels (*Dreissena polymorpha*) (Kraft et al. 2002, Reed-Andersen et al. 2000b, Engel 1990). Similarly, exotic/invasive organisms are sometimes carried as bait for fishing and subsequently released (Lodge and Lorman 1987, WASAL 2003). In most cases, successful invasive species have impacts similar to exotic species - elimination of native species through predation and/or competition, alteration of habitats, and modification of food webs.

*Climate Change* - Climate Change could become one of the most serious anthropogenic influences on ecosystems of all types. In an increasing number of scenarios and predictions being reported concerning the effects of climate change on reservoirs, nearly all communities and processes show some response via effects of altered temperature regimes, the alteration of hydrologic patterns, and interactions with numerous other stressors. Geographic location may be an important determinant of temperature response.

W.3.3.2. Specific Stressors

*Nutrient Loading* - Inputs to lakes (reservoirs) of the key nutrients nitrogen, and especially phosphorus, are generally considered major influences on lake ecosystems. The lake (reservoir) response to changes in nutrient inputs is often fast, consisting of a pulse in growth of the primary producers, especially phytoplankton. Algal turnover rates are typically high, and the uptake and turnover rate of phosphorus by algae is even faster (Norman and Sager 1978). Movement of this growth pulse through the food chain is much slower for organisms higher in the food chain. A sustained increase in nutrient loading will ultimately have some effect in the higher trophic levels. Anthropogenic disturbances in the watershed can increase nutrient loading, most of which is originate as non-point sources (Bennett et al. 1999, Klump et al. 1996, Carpenter et al. 1998). Eutrophication leads to changes in phytoplankton species composition, size structure, and growth rates, all of which have relevance to the pelagial food web. The increase in algal biomass affects water clarity and the depth distribution of photosynthesis. The depth distribution, and subsequently the aerial extent of the littoral community, are generally reduced as well. Other effects of eutrophication include impairment of esthetics and recreational values, loss of deep-water habitats, and hypolimnetic oxygen depletion.

*Sediment Loading* - The loading of suspended sediments and detritus from the watershed is a function of soil temperature, moisture, hydrology, and watershed morphology (Dillon and Molot 1997). In the absence of anthropogenic influences sediment loading may vary considerably, increasing as a function of natural catastrophes such as fire and floods and herbivory, which enhance soil erosion. Due to urban development, agriculture, logging, fire and other anthropogenic activities, the watershed generally discharges an increased load of sediment and detritus to the lake (reservoir). The impacts of increased levels of suspended solids include increased light extinction, exacerbating the effects of increased nutrient loading on the penetration of light due to increased algal populations (Millard and Sager 1994).

*Metals/Toxic Loading* - Mercury contamination in lake (reservoir) ecosystems experiencing aerial deposition can be found in most organisms and habitats of lakes (Boening 2000, Mackay and Toose 2003). In fish, mercury concentrations vary directly with size and age, indicating bioaccumulation through the food web (Glass 2001). As a result, fish of standard size at the top of the food chain (apex predators) are used for comparison purposes in assessing mercury contamination in lakes (Kallemeyn et al. 2003). Effects of mercury contamination may extended from thelake (reservoir) ecosystem through fish-eating birds such as eagles, osprey (*Pandion haliaetus*) and loons (*Gavia spp.*), and a range of mammals, including humans (Mackay and Toose 2003).

Physiological effects of mercury relate to the fact that it accumulates in nervous system tissue. In humans, mercury exposure in pregnant women can lead to neurodevelopment effects in fetuses and children (Vahter et al. 2002). Consumption of contaminated game fish must therefore be closely controlled. In birds and other wildlife, physiological effects are difficult to ascertain in the field because of interacting effects of food, predation and the presence of other types of contaminants (Karasov and Meyer 2000). In general, Boening (2000) notes that fish exposed to sublethal concentrations show a variety of physiological and reproductive abnormalities and that birds fed inorganic mercury showed a reduction in food intake and poor growth. Boening (2000) also states that the form of mercury retained in birds depends on the species, location, and target organ.

Indicators of critical mercury concentrations have been recommended. Scheuhammer and Bond (1991) suggest feather concentrations of 20ug/g as a toxic effect threshold. Barr (1986) reported impaired loon reproduction when mercury residues in forage fish exceeded 0.3ug/g. Atmospheric deposition can also be a significant source of organochlorine compounds (PCBs and PBDEs) and other contaminants to lakes (reservoirs). Lake Meredith is included on the 303(d) list of impaired water bodies in connection with mercury contamination identfied in fish tissues.

*Acid Deposition* - Sulfur and nitrogen oxides discharged to the atmosphere react with water vapor to form sulfuric and nitric acids that are deposited on the earth as acid rain, snow, or fog. Effects on lake (reservoir) ecosystems depend on the buffering or acid neutralizing capacity (ANC) of the lake. Soft water lakes of low ANC (< 100 mueq/L) (Stoddard et al. 1998) have experienced declines in diversity of flora and fauna through reproductive failure or direct mortality. The Clean Air Act of 1970 and Amendment of 1990 were followed by emission reductions in North America and Europe that resulted in decreased sulfur depositions of up to 50 percent (Skjelkvale et al. 2001). On a broad scale, Skjelkvale et al. (2001) observed downward trends in lake sulfate concentrations from 1989-1998 in all regions of the United States, with low ANC sites showing the highest rates of recovery.

*Exotic Species* - Exotic, invasive species may be characterized by elevated fecundity, rapid growth and early maturity - typical traits of r-selected species where physiological tolerance is not a requirement for success (McMahon 2000). Their impact on lake (reservoir) ecosystems is one of a trend towards homogenization of flora and fauna through direct processes of competition for food and space, predation and grazing, and alterations of food web structure (Rahel 2002).

Prevention seems to be the only effective solution. Once established, most are extremely difficult to remove.

*Fishing and Boating* - Aquatic resources of the national parks generally receive considerable recreational pressure from visitors. Lakes and streams are prized for their remoteness and esthetics, but subjected to a range of stresses, largely from fishing and boating. Fish stocking of native and non-native species to meet public demand may compromise some ecological values of SOPN reservoirs (Landres et al. 2001).

*Temperature and Precipitation Changes* - It is beyond the scope of this report to review the full spectrum of scenarios and predictions offered in relation to lake (reservoir) ecosystem responses to climate change. Some may wonder how managers can deal with this global phenomenon. Yet awareness of expected effects of climate change may be important when interpreting observations of changes in reservoir ecosystem features. General scenarios include change towards warmer and drier climates in the century ahead (Davis et al. 2000). Translating this generalization into specific effects is not easy given the complex interactions of acidification, climate warming, and increased ultraviolet light exposure as a result of stratospheric ozone depletion (e.g., Schindler 1999).

Magnuson et al. (2000) noted a recent trend toward shorter periods of ice cover in lakes and rivers of the northern hemisphere. If so, lakes (reservoirs) will be subject to higher surface water temperatures at earlier times in the spring and later in the fall. The potential effects are many, including changes in the timing of events such as fish spawning and hatching in relation to plankton (food source) availability, the extent of oxygen depletion (during periods of extended summer stratification), effects on cold-water habitats/fish, and warm water species with limited ability to acclimate to higher temperatures.

Planning for ecosystem change may be the best strategy (e.g., WASAL 2003, Magnuson et al. in press).

Stresses and impacts on reservoir inflows/outflows and reservoir levels, reservoir sediments/ morphology, water quality/chemistry (including palustrine wetlands), reservoir stratification/mixing, and reservoir biota are enumerated in Tables 7 through 11, respectively, accompaned by indicators of ecosystem response/condition. For each major stressor identified, indicators of ecosystem condition are summarized in Table 12.

**Table 7. Stresses and impacts on reservoir inflows, outflows, and water level**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (from reservoir or upstream tributaries) | ↓ Streamflow (Upstream Tributaries) or Direct Lowering of Reservoir Level | Stream Discharge (Upstream Tributaries), Reservoir Level |
| Groundwater Pumping | ↓ Baseflow to Reservoir & Upstream Tributaries, Streamflow (Upstream Tributaries), Reservoir Level | Groundwater Level, Stream Discharge (Baseflow to Upstream Tributaries), Reservoir Level |
| Shoreline Development (buildings & other structures) | ↑ Overland Flow, Reservoir Level | Reservoir Level |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Baseflow to Reservoir & Upstream Tributaries, Streamflow (Runoff), Reservoir Level | Stream Discharge (Upstream Tributaries), Reservoir Level |
| Tamarisk & Other Phreatophytes | ↑ Evapotranspiration, ↓ Reservoir Level | Reservoir Level |
| Flood | ↑ Streamflow (Upstream Tributaries), Reservoir Level | Stream Discharge (Upstream Tributaries), Reservoir Level |
| Drought | ↑ Evaporation / Evapotranspiration, ↓ Streamflow (Upstream Tributaries), Reservoir Level | Stream Discharge (Upstream Tributaries), Reservoir Level |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Evaporation / Evapotranspiration, Baseflow to Reservoir & Upstream Tributaries, Streamflow (Upstream Tributaries), Reservoir Level | Groundwater Level, Stream Discharge (Baseflow to Upstream Tributaries), Reservoir Level |

**Table 8. Stresses and impacts on reservoir sediments / morphology**

| Stresses | Effects | Indicators |
|---|---|---|
| Shoreline Development (buildings & other structures) | Bank Modification | Bed Composition, Reservoir Morphometry[*1] |
| Bank Stabilization / Channel Straightening | △ Bank Morphology / Sediments | Bed Composition, Reservoir Morphometry[*1] |
| Bank Instability | △ Bank Morphology | Reservoir Morphometry[*1] |
| Dredging / Filling (Lacustrine Wetlands) | △ Wetland Morphology | Reservoir Morphometry[*1] |
| △ Sediment Load (due to changes in upland or local land use) | ↓ or ↑ Deposition, △ Reservoir Morphology / Bed Composition | Bed Composition, Reservoir Morphometry[*1] |
| Tamarisk & Other Phreatophytes | ↑ Evapotranspiration, ↓ Reservoir Level, Areal Extent / Location of Littoral Zone | Reservoir Morphometry [*1] |
| Other Exotic / Invasive Riparian Vegetation | ↓ or ↑ Bank Erosion, Sediment Load, △ Reservoir Morphology / Bed Composition | Bed Composition, Reservoir Morphometry[*1] |
| Removal of Upland Riparian Vegetation | ↑ Bank Erosion, Sediment Load, △ Reservoir Morphology / Bed Composition | Bed Composition, Reservoir Morphometry[*1] |
| Flooding | ↑ Deposition / Scouring | Bed Composition, Reservoir Morphometry[*1] |
| Removal of Riparian Vegetation | ↑ Bank Erosion, Deposition | Bed Composition (Littoral Zone), Reservoir Morphometry[*1] |
| Ungulate Grazing / Trampling | Trampling of Riparian Vegetation & Banks, ↑ Bank Erosion, Deposition | Bed Composition (Littoral Zone), Reservoir Morphometry[*1] |
| Off-Road Vehicle Use | ↑ Bank Erosion, Sediment Deposition | Bed Composition (Littoral Zone), Reservoir Morphometry[*1] |

| | | |
|---|---|---|
| Altered Fire Regime | △ Sediment Load / Deposition | Bed Composition, Reservoir Morphometry[*1] |

*1 Reservoir mean/maximum depth, volume/area, depth profile/bed slope.

**Table 9. Stresses and impacts on reservoir water quality / chemistry**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (from reservoir or upstream tributaries) | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Temperature Profile |
| Groundwater Pumping | ↑ Concentration of Nutrients, Organic Carbon, & Suspended Solids, Water Temperature, △ Concentration of Other Dissolved & Suspended Constituents | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Temperature Profile |
| Shoreline Development (buildings & other structures) | ↑ Sediment Load, Water Temperature | Suspended Sediment, Water Clarity, Basic Water Quality Parameters[*4], Temperature Profile |
| Bank Stabilization | ↓ Sediment Load | Suspended Sediment, Water Clarity |
| Bank Instability | ↑ Sediment Load | Suspended Sediment, Water Clarity |
| Dredging / Filling (Palustrine Wetlands) | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, ↓ or ↑ Water Temperature / Gradient | Suspended Sediment, Water Clarity, Temperature Profile |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Sediment Load, Concentration of Other Dissolved & Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Temperature Profile |
| △ Sediment Load (due to changes in upland or local land use) | ↓ or ↑ Suspended Sediment | Suspended Sediment, Water Clarity |

| | | |
|---|---|---|
| Non-Point Nutrient & Organic Releases (upland or local land use) | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Eutrophication | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4] |
| Permitted Wastewater Discharge to Upland Tributaries | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Eutrophication, Aquatic Microorganisms | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Aquatic Microorganisms[*5] |
| Point Contaminant Releases (contaminated sites) | ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, & Other Toxic Substances (as applicable) | Potential Point Source Contaminants[*6], BOD/COD[*2] |
| Atmospheric Deposition | ↑ Nitrogen & Sulphur Compounds, Mercury & Other Metals, Pesticides (as applicable) | Nutrients[*1], pH, Mercury & Other Metals, Pesticides (as applicable) |
| Tamarisk | ↑ Salinity | Salinity |
| Other Exotic / Invasive Riparian Vegetation | ↓ or ↑ Bank Erosion, Sediment Load | Suspended Sediment, Water Clarity |
| Exotic / Invasive Aquatic Vegetation | ↓ or ↑ Dissolved Oxygen, △ Nutrient Cycling | Basic Water Quality Parameters[*4], Nutrients[*1] |
| Removal of Upland Riparian Vegetation | ↓ Interception of Overland Flow (Nutrients, Contaminants, Sediments) | Basic Water Quality Parameters[*4], Nutrients[*1], Suspended Sediment, Water Clarity |
| Flood | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, ↓ Water Temperature | Nutrients[*1], Suspended Sediment, Water Clarity, Basic Water Quality Parameters[*4] |
| Drought | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Nutrients[*1], Suspended Sediment, Water Clarity, Basic Water Quality Parameters[*4] |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Nutrient Load, Suspended Sediment, Concentration of Other Dissolved & Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Temperature Profile |

| | | |
|---|---|---|
| Ungulate Grazing / Trampling | ↑ Nutrient Loading, Rate of Organic Carbon Input, Aquatic Microorganisms | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Suspended Sediment, Water Clarity, Aquatic Microorganisms[*5] |
| Swimming / Wading | ↑ Suspended Sediment, Aquatic Microorganisms | Suspended Sediment, Water Clarity, Aquatic Microorganisms[*5] |
| Motorized Boating | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Suspended Sediment, Water Clarity, Petroleum Hydrocarbons |
| Off-Road Vehicle Use | ↑ Bank Erosion, Deposition | Suspended Sediment, Water Clarity |
| Altered Fire Regime | ↓ or ↑ Nutrient Load, Rate of Organic Carbon Input, Suspended Sediment | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Suspended Sediment |

*1 Nitrogen and phosphorous.

*2 Biological oxygen demand, chemical oxygen demand.

*3 Dissolve oxygen profile.

*4 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, alkalinity, and turbidity.

*5 Bacteria, viruses, and protozoa.

*6 Synthetic organic compounds, petroleum hydrocarbons, heavy metals, pesticides, and other toxic substances, as applicable.

**Table 10. Stresses and impacts on reservoir stratification / mixing**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions<br>(from reservoir or upstream tributaries) | ↑ Water Temperature, △ Water Temperature & Dissolved Oxygen Gradients | Temperature Profile, DO Profile[*1] |
| Groundwater Pumping | ↑ Water Temperature, ↓ Water Temperature Gradient, △ Dissolved Oxygen Gradient | Temperature Profile, DO Profile[*1] |
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↑ Water Temperature, △ Water Temperature & Dissolved Oxygen Gradients | Temperature Profile, DO Profile[*1] |
| Climate Change<br>(temperature, precipitation, wind) | ↓ or ↑ Air & Water Temperatures, △ Water Temperature & Dissolved Oxygen Gradients | Temperature Profile, DO Profile[*1] |

*1 Dissolve oxygen profile.

**Table 11. Stresses and impacts on reservoir biota**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (from reservoir or upstream tributaries) | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature, Phytoplankton, Algae, Light Extinction, ↓ Depth Submergence, △ Areal Extent / Location of Littoral Zone | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Groundwater Pumping | ↑ Concentration of Nutrients, Organic Carbon, Suspended Solids, Water Temperature, Phytoplankton, Algae, Light Extinction, ↓ Depth Submergence, △ Areal Extent / Location of Littoral Zone | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Shoreline Development (buildings & other structures) | Loss of Near-Shore Habitat (Bank Modification), ↓ Amphibians, Waterfowl | Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| Bank Stabilization | Loss of Bank Habitat, ↓ Amphibians, Waterfowl | Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| Bank Instability | Loss of Bank Habitat, ↓ Amphibians, Waterfowl | Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| Dredging / Filling (Lacustrine Wetlands) | Loss or Alteration of Lacustrine Wetland Habitat | Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↑ Nutrient Load, Rate of Organic Carbon Input, Sediment Load, Concentration of Other Dissolved & Suspended Constituents, Water Temperature, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |

| | | |
|---|---|---|
| △ Sediment Load (due to changes in upland or local land use) | ↓ or ↑ Suspended Sediment, Deposition, Areal Extent / Location of Littoral Zone, Light Extinction | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Non-Point Nutrient & Organic Releases (upland or local land use) | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Eutrophication, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Permitted Wastewater Discharge to Streams | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Aquatic Microorganisms, Eutrophication, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Point Contaminant Releases (contaminated sites) | ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, & Other Toxic Substances (as applicable) | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Atmospheric Deposition | ↑ Nitrogen & Sulphur Compounds, pH, Mercury & Other Metals, Pesticides (as applicable) | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Tamarisk | ↑ Salinity | Tamarisk Abundance & Distribution; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Other Exotic / Invasive Riparian Vegetation | Competition with Noninvasive Native Lacustrine Wetland Vegetation, ↓ or ↑ Bank Erosion, Sediment Load, △ Reservoir Morphology / Bed Composition, Lacustrine Wetland Habitat | Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Exotic / Invasive Aquatic Vegetation | Competition with Noninvasive Native Aquatic Vegetation, △ Aquatic Habitat | Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | | |
|---|---|---|
| Clearing of Emergent / Aquatic Vegetation & Woody Debris | Loss of Aquatic Habitat, ↓ Amphibians, Waterfowl, Fish Growth Rates, △ Water Quality | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Removal of Upland Riparian Vegetation | △ Sediment Load, Water Quality | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Exotic / Invasive Periphyton, Fish, or Herptofauna | Competition with Noninvasive Native Periphyton, Fish, and / or Herptofauna; △ Nutrient Cycling, Dissolved Oxygen | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Flood | △ Sediment Load, Water Quality, Water Temperature | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Drought | △ Water Quality, Water Temperature | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Air & Water Temperatures, Reservoir Level, Nutrient Load, Sediment Load, Concentrations of Other Dissolved & Suspended Constituents | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Ungulate Grazing / Trampling | ↑ Nutrient Load, Rate of Organic Carbon Input, Sediment Load, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Swimming / Wading | Trampling of Aquatic / Lacustrine Wetland Vegetation, Loss of Habitat, ↑ Suspended Sediment | Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Motorized Boating | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | | |
|---|---|---|
| Off-Road Vehicle Use | ↑ Bank Erosion, Deposition, Light Extinction, △ Lacustrine Wetland Habitat | Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Altered Fire Regime | ↓ or ↑ Nutrient Load, Rate of Organic Carbon Input, Suspended Sediment, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |

**Table 12. Summary of stresses and indicators of reservoir ecosystem function and condition.**

| Stresses | Indicators |
|---|---|
| Surface Water Diversions<br>(from reservoir or upstream tributaries) | Stream Discharge (Upstream Tributaries), Reservoir Level; Temperature Profile; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Groundwater Pumping | Groundwater Level, Stream Discharge (Baseflow to Upstream Tributaries), Reservoir Level; Temperature Profile; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Shoreline Development<br>(buildings & other structures) | Reservoir Level; Bed Composition, Reservoir Morphometry[*1]; Suspended Sediment, Water Clarity, Basic Water Quality Parameters[*4]; Temperature Profile; Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates,<br>& Herptofauna |
| Bank Stabilization | Bed Composition, Reservoir Morphometry[*1]; Suspended Sediment, Water Clarity; Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| Bank Instability | Reservoir Morphometry[*1]; Suspended Sediment, Water Clarity; Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| Dredging / Filling<br>(Lacustrine Wetlands) | Reservoir Morphometry[*1]; Suspended Sediment, Water Clarity, Temperature Profile; Composition, Abundance, & Distribution of Littoral Zone Vegetation, Macroinvertebrates, & Herptofauna |
| △ Infiltration / Runoff Rates<br>(due to changes in upland or<br>local land use – e.g., urbanization or agricultural development) | Stream Discharge (Upstream Tributaries), Reservoir Level; Temperature Profile; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |

| | |
|---|---|
| △ Sediment Load<br>(due to changes in upland<br>or local land use) | Bed Composition, Reservoir Morphometry[*5]; Suspended Sediment, Water Clarity; Composition, Abundance, & Distribution<br>of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Non-Point Nutrient & Organic Releases<br>(upland or local land use) | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution<br>of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Permitted Wastewater Discharge to Streams | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4], Aquatic Microorganisms[*6]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Point Contaminant Releases<br>(contaminated sites) | Potential Point Source Contaminants[*7], BOD/COD[*2]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Atmospheric Deposition | Nutrients[*1], pH, Mercury & Other Metals, Pesticides (as applicable); Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Tamarisk | Tamarisk Abundance & Distribution; Reservoir Level; Stream Geomorphic Parameters[*5]; Salinity; Composition, Abundance,<br>& Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Other Exotic / Invasive Riparian Vegetation | Suspended Sediment, Water Clarity; Bed Composition, Reservoir Morphometry[*5]; Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Exotic / Invasive Aquatic Vegetation | Basic Water Quality Parameters[*4], Nutrients[*1]; Composition, Abundance, & Distribution of Aquatic Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Clearing of Emergent / Aquatic Vegetation & Submerged Woody Debris | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation (and Woody Debris), Macroinvertebrates, Fish, & Herptofauna |
| Removal of Upland Riparian Vegetation | Suspended Sediment, Water Clarity; Bed Composition (Littoral Zone), Reservoir Morphometry[*5]; Basic Water Quality Parameters[*4], Nutrients[*1]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |

| | |
|---|---|
| Exotic / Invasive Periphyton, Fish, or Herptofauna | Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Macroinvertebrates, Fish, & Herptofauna |
| Flood | Stream Discharge (Upstream Tributaries), Reservoir Level; Bed Composition, Reservoir Morphometry[*5]; Suspended Sediment, Water Clarity, Nutrients[*1], Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Drought | Stream Discharge (Upstream Tributaries), Reservoir Level; Nutrients[*1], Suspended Sediment, Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Climate Change (temperature, precipitation, wind) | Groundwater Level, Stream Discharge (Baseflow to Upstream Tributaries), Reservoir Level; Temperature Profile; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Water Clarity, Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Ungulate Grazing / Trampling | Bed Composition (Littoral Zone), Reservoir Morphometry[*5]; Aquatic Microorganisms[*6], Nutrients[*1], BOD/COD[*2], DO Profile[*3], Suspended Sediment, Water Clarity; Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |
| Swimming / Wading | Aquatic Microorganisms[*6], Suspended Sediment, Water Clarity; Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Motorized Boating | Suspended Sediment, Water Clarity, Petroleum Hydrocarbons; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna |
| Off-Road Vehicle Use | Suspended Sediment, Water Clarity; Bed Composition (Littoral Zone), Reservoir Morphometry[*5]; Composition, Abundance, & Distribution of Lacustrine Wetland Vegetation, Macroinvertebrates, & Herptofauna |
| Altered Fire Regime | Suspended Sediment, Water Clarity; Bed Composition, Reservoir Morphometry[*5]; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4]; Composition, Abundance, & Distribution of Aquatic / Lacustrine Wetland Vegetation, Macroinvertebrates, Fish, & Herptofauna; Abundance of Phytoplankton & Algae |

*1 Nitrogen and phosphorous.

*2 Biological oxygen demand, chemical oxygen demand.

* 3 Dissolve oxygen profile.

*4 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, alkalinity, and turbidity.

*5 Reservoir mean / maximum depth, volume / area, depth profile / bed slope.

*6 Bacteria, viruses, and protozoa.

*7 Synthetic organic compounds, petroleum hydrocarbons, heavy metals, pesticides, and other toxic substances, as applicable

## W.4. RIPARIAN ECOSYSTEM MODEL

The term riparian is derived from the Latin word *Riparius*, meaning the banks of a river or stream. Riparian zones occupy landscape positions that are transitional between upland and aquatic ecosystems and as a result are more physically dynamic and biologically diverse than surrounding uplands. Because of their unique landscape position, and tight linkages between fluvial and upland disturbance processes, riparian ecosystems are potentially sensitive indicators of landscape-level environmental change (Naiman et al. 1988). Riparian ecosystems are directly influenced by streams through enhanced water supply, flooding, and erosional and depositional processes (Brinson et al. 1981). At the same time, upland disturbance processes, across a range of scales, impose direct and indirect effects on riparian ecosystems. Debris flows and landslide disturbances impinge directly on narrow riparian zones on a local scale. At larger scales, the indirect effects of climate change and land use practices such as grazing and land-clearing, which degrade upland soil stability and reduce riparian vegetation cover, is to alter the delivery of water and sediment to receiving streams (Trimble and Mendel 1995).

### *W.4.1. Summary of Drivers, Stressors, Attributes, and Indicators of Riparian Ecosystem Function and Condition*

Regional climate, atmospheric conditions, geology, landform, time, and upland watershed characteristics are drivers (major forces of change) for riparian ecosystems of the SOPN (Figure 13).

Due to the overriding importance of surface flow and groundwater dynamics on the establishment and survival of riparian plants, little work has focused on the effects of precipitation events as a driver of riparian vegetation dynamics. However, successful cottonwood recruitment has been correlated with wet years (Baker 1990), and workers on the San Pedro River in southern Arizona have shown correlations between precipitation and the richness and cover of some herbaceous riparian plant guilds (Bagstad et al. in press).

### *W.4.2. Riparian Ecosystem Function under Natural/Desired Conditions*

Floods, alluvial groundwater, and riparian zone soils/morphology, major ‘soil-resources’ influencing the function of riparian ecosystems (Chapin et al. 1996), are described in this section, followed by a discussion of riparian biotic functional groups (vegetation, invertebrates, and vertebrates) and riparian ecosystem dynamics under natural/desired (sustainable) conditions. The attributes and functioning of SOPN riparian ecosystems under natural/desired conditions are summarized in Figure 14.

#### W.4.2.1. Riparian Water Resources

*Floods* - The reproductive traits of early successional riparian trees are tightly linked with fluvial disturbances. Seeds of *Populus* spp. and *Salix* spp. germinate and grow on moist, freshly deposited alluvial sediments following floods of appropriate timing, magnitude, and rate of recession (Mahoney and Rood 1998, Stromberg et al. 1991, Scott et al. 1997, Auble and Scott 1998, Cooper et al. 2003). The physical disturbance and increased moisture availability provided by floods is also positively associated with species richness and cover of herbaceous species in riparian zones. Whereas some studies have reported reduced diversity of riparian herbs following flooding (Smith et al. 1998), flood-related increases in the cover and diversity of annual and some perennial riparian herbs along the San Pedro River, Arizona, were attributed to the creation of safe sites for germination, increased water availability, and the possible transport of seeds and vegetative propagules by flood waters (Bagstad et al. in press). Flood transport of seeds, or hydrochory, may play an important role in maintaining high species diversity in riparian landscapes by preferentially delivering seeds of species, or groups of species, to specific riparian landscape positions at times suitable for establishment and growth.

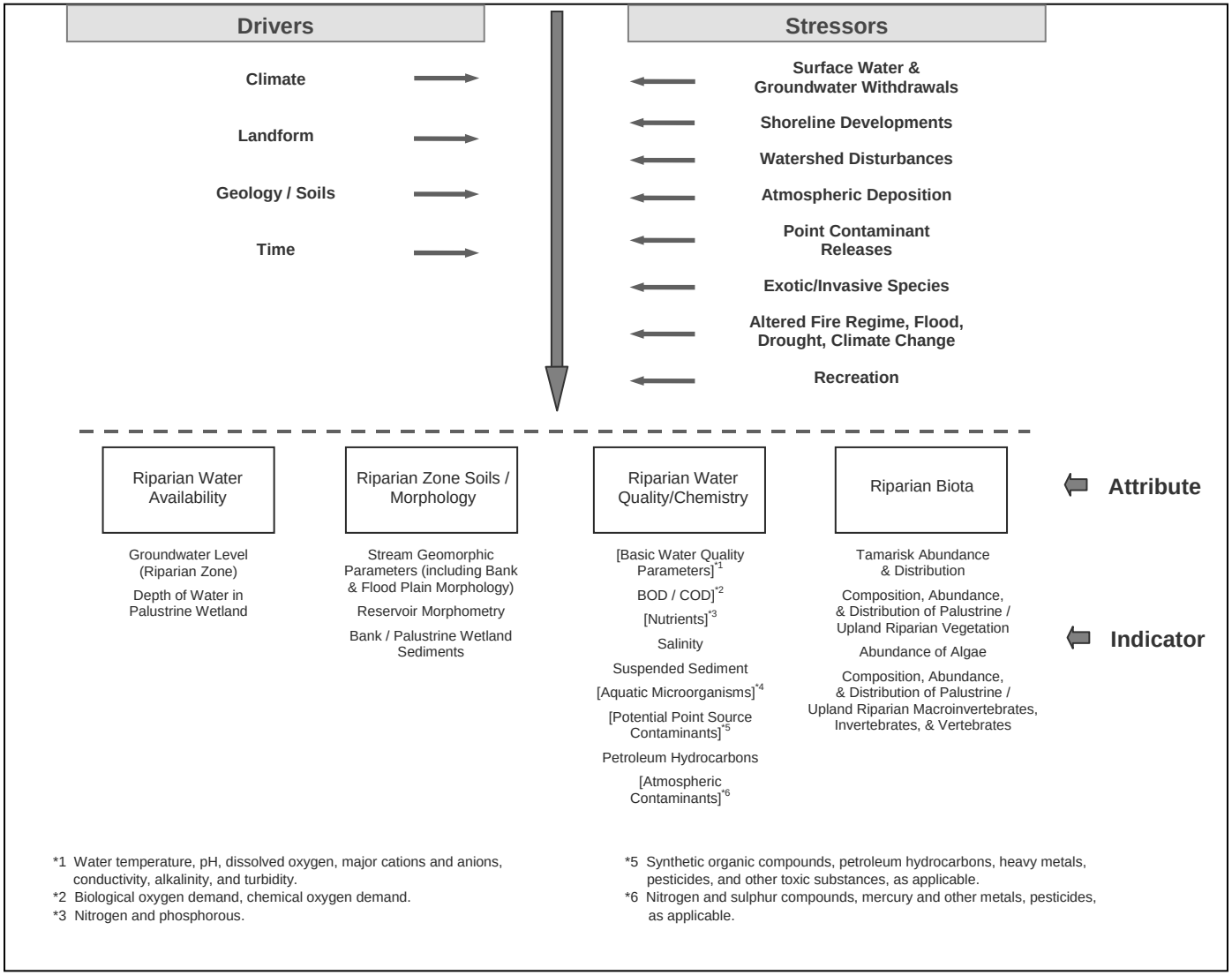



**Figure 13. Overview of drivers, stressors, attributes, and indicators of riparian ecosystem function and condition.**

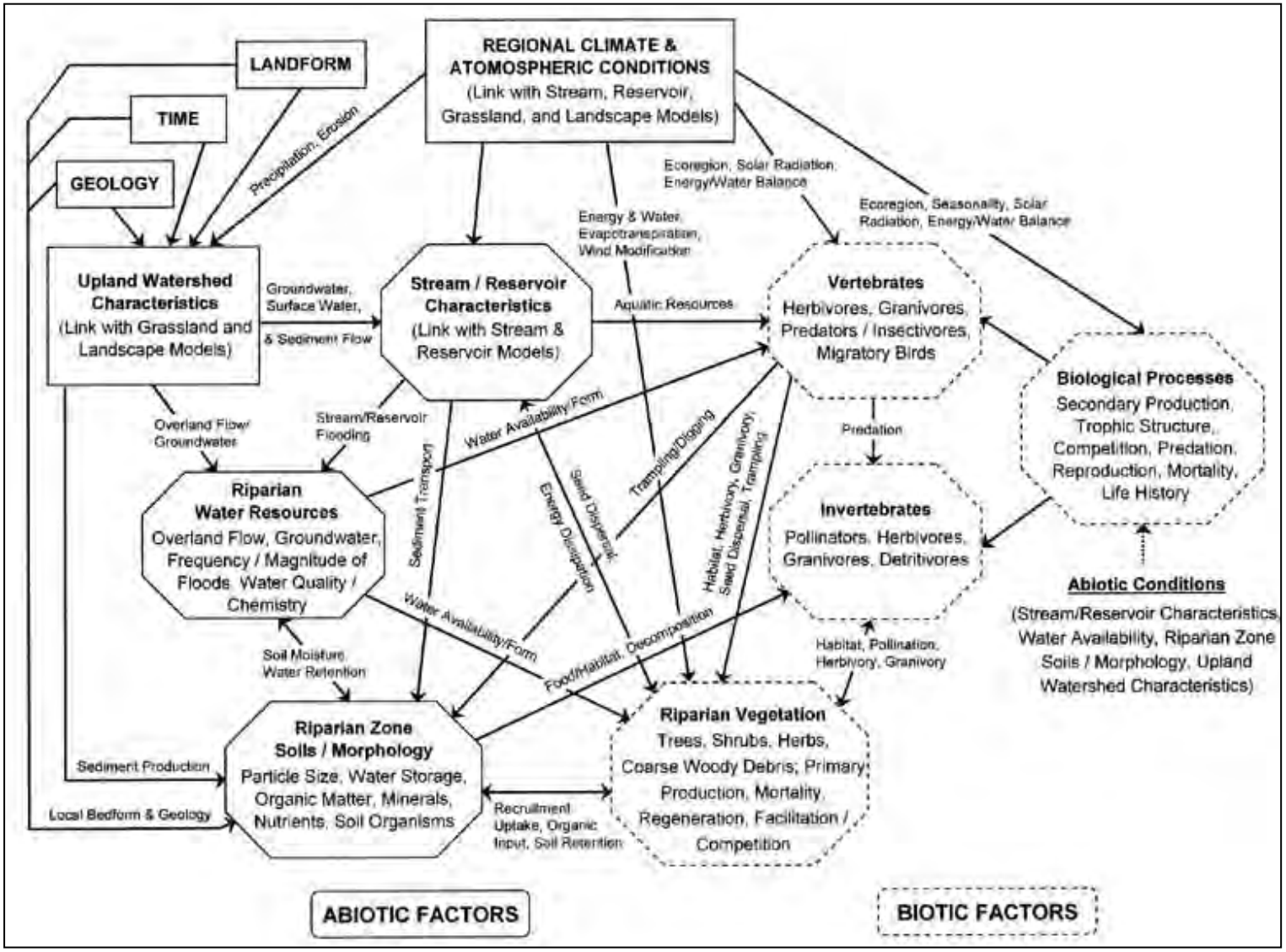



**Figure 14. Natural/desired riparian ecosystem function. Modified from Scott et al. (2005).**

*Alluvial Groundwater* - Water from surface flow and associated shallow alluvial aquifers is essential to the persistence of most low-elevation woody riparian species in the western U.S. Thus, an integrated understanding of surface and alluvial groundwater flows, and their interactions, is fundamental to understanding the establishment and survival processes of existing riparian and wetland ecosystems (Winter 1999, Woessner 2000). On coarse substrates in dry regions, early establishment and growth of *Populus* spp. seedlings, and other woody riparian pioneer species, may require groundwater within 1-2 m of the establishment surface (McBride and Strahan 1984, Mahoney and Rood 1992, Segelquist et al. 1993, Stromberg et al. 1996), but lenses of finer alluvial material may allow seedlings to survive the first few growing seasons without making contact with groundwater (Cooper et al. 1999). Following initial establishment, root growth allows young trees to survive gradual groundwater declines. Depth to groundwater may increase as a result of subsequent floodplain accretion or channel incision (Everitt 1968, Hereford 1986), and *Populus* species have been observed at sites where depth to groundwater is 7 - 9 m (Robinson 1958). However, mature native riparian species such as *Populus*, *Salix* and *Tamarix* are typically found in riparian settings where depth to water is < 4 m (Meinzer 1927, Busch et al. 1992, Scott et al. 1997, Stromberg et al. 1997, Horton et al. 2001a).

Alluvial groundwater is the principle source of water for riparian trees (Busch et al. 1992, Snyder and Williams 2000). Even relatively modest fluctuations or declines (1.5-3 meters) can induce lethal moisture stress (Scott et al. 1999, Shafroth et al. 2000). Seasonal groundwater declines of 2.5-3 meters, in a dry year, along the free-flowing Hasayampa River, Arizona, produced moisture stress in the native riparian cottonwood (*Populus fremontii*), and willow (*Salix gooddingii*) and non-native tamarisk (*Tamarix ramosissima*). All species responded to this stress with lowered shoot water potentials, decreased leaf gas exchange rates, increased canopy die-back, and some tree mortality. Compared to native riparian trees, however, tamarisk had much higher rates of leaf gas exchange and stem growth under shallow groundwater conditions, and exhibited less crown die-back and mortality when groundwater declined. The combination of high leaf gas exchange rates and stem growth when water is available, and greater moisture stress tolerance under dry conditions, help explain the competitive success of tamarisk in southwestern riparian ecosystems, particularly those subject to large within and across-year fluctuations in water availability (Horton 2001b).

W.4.2.2. Riparian Zone Soils/Morphology

*Floodplain Soils* - The soils of a riparian ecosystem differ from those of both upland systems and permanently flooded bottomlands. Shallow alluvial groundwater is a unique and important functional feature of riparian floodplain soils, and is tightly linked to surface water dynamics. Native and non-native woody phreatophytes, like cottonwood, willow and Tamarisk are dependent, to varying degrees, upon shallow alluvial groundwater sources, and spatially complex moisture gradients resulting from floodplain topographic diversity and surface and groundwater dynamics. These factors influence the diversity of herbaceous riparian plants and soil organisms (Meinzer 1927, Scott et al. 1997, Stromberg et al. 1997, Pollock et al. 1998, Horton et al. 2001a, Bagstad et al. in press, Beauchamp 2004).

Because of their dynamic nature, floodplain soils in drier regions of the United States are typically young and poorly developed, often lacking the distinct horizons of soil formed by the interaction of weathering processes and living organisms over time. Many of these soils lack an aquic moisture regime, which requires that soils be saturated long enough to become anoxic and to develop distinctive redoximorphic features such as gleying (Brady 1974). The combination of fine-textured soils, high organic matter and nutrient content, alternating periods of wetting and drying, and anaerobic versus aerobic conditions which make floodplain soils in more humid regions biogeochemically dynamic, are generally lacking in western floodplain soils (Mitsch and Gosselink 1993). In drier riparian ecosystems, nutrient availability is more closely related to nutrient flux in streamflow than soil stores, although these fluxes are poorly understood (Schade et al. 2002). Freshly deposited alluvial sands are typically low in nitrogen and riparian plants colonizing these

surfaces are nitrogen-limited (Adair and Binkley 2002). In general, the periodic wetting and drying of riparian soils is considered important in the release of nutrients from leaf litter in riparian environments (Mitsch and Gosselink 1993).

Soil biota represent another broadly defined group of organisms that is an important contributor to the structure and functioning of riparian ecosystems. Most of the ecosystem soil processes (i.e., nutrient cycling, water infiltration and storage, soil aggregate stability, water and nutrient uptake by plants) are mediated by soil organisms (Skujins 1984; Whitford 1996, 2002; Lavelle 1997; Wardle 2002). Although the general significance of soil biota for ecosystem processes (particularly nutrient cycling) has long been acknowledged, there is increasing recognition that this diverse group of organisms must be considered more explicitly in order to develop a better understanding of the structure and functioning of terrestrial (Wardle 2002, Reynolds et al. 2003) and riparian ecosystems. Because of their intimate association with other components of riparian ecosystems, soil organisms are included in Figure 13 as a component of floodplain soils.

Soil biota include microfloral components (bacteria, algae, and fungi), microfaunal components (nematodes, microarthropods, and protozoans), and macrofaunal components (earthworms, ants, termites, and larval stages of several insect families) that are involved in a variety of processes essential for litter decomposition and nutrient cycling. Functioning of these belowground processes is dependent on the amounts and types of organic-matter inputs from vegetation and soil conditions such as moisture availability (which is strongly influenced by surface and groundwater dynamics), soil structure, soil aeration, and soil temperature (Whitford 1996, 2002; Mitsch and Gosselink 1993).

Mycorrhizal fungi, which form symbiotic associations with roots of many plant species, are another important element of the soil biota. The mycorrhizal symbiosis is one in which the fungal partner provides nutritional benefits to the host plant, and the plant provides carbohydrates to the fungi (Smith and Read 1997). Roots colonized by mycorrhizal fungi acquire phosphorus, zinc, and possibly copper and nitrogen more efficiently than uncolonized roots. There is also evidence that mycorrhizae can increase water uptake in plants due to greater soil volume accessed by colonized roots (Smith and Read 1997). Arbuscular mycorrhizal fungal communities have been described for a number of ecosystems, however comparatively little is known about the structure and composition of these communities in riparian ecosystems. Recent work in cottonwood/willow forests along regulated and unregulated reaches of the Verde River, Arizona, indicates that fungal colonization rates and diversity increases with increases in the diversity of perennial species and decreased with increases in stand age, as well as distance from and elevation above the channel. Stand age, soil moisture and soil texture appeared to be important environmental determinants of fungal community structure, and whereas most species found in these riparian settings are also found in adjacent uplands, diversity was higher in the riparian zone and two species were restricted to these sites (Beauchamp 2004).

Some species common to riparian ecosystems have been identified as mycorrhizal when inspected by botanists (Trappe 1981). Families with a high frequency of mycorrhizal colonization among inspected species included the Asteraceae, Fabaceae, Rosaceae, Poaceae, and Solanaceae. The Brassicaceae stands out as a relatively common riparian plant family in which most inspected species were nonmycorrhizal (Trappe 1981).

*Riparian Zone Morphology* - Flood plains represent one of a number of river-deposited features and are typically composed of vertically stacked fine grained layers left by discrete floods. By definition, flood plains are level surfaces constructed by a river under prevailing climatic conditions, and are frequently inundated by high flows (Leopold 1994). Riparian vegetation establishment and succession is intimately linked to the lateral and vertical accretion of sediments that lead to floodplain formation across a range of channel forms (Schumm and Lichty 1963, Hereford 1984, Bradley and Smith 1986, Boggs and Weaver 1994). This linkage between fluvial

geomorphic processes and riparian vegetation dynamics creates the topographic diversity, soil moisture gradients, fluvial disturbance patches, and distinctive microclimates that characterize riparian ecosystems. The spatial extent of floodplains along streams of the Southern Plains is highly variable and dependent on geomorphic setting. Along channels confined by colluvial materials or bed rock, floodplain deposits may be narrow and discontinuous, or even non-existent. In contrast, channels in large alluvial basins may have large, spatially extensive flood plains.

W.4.2.3. Riparian Vegetation

At a broad level, vegetation is generally recognized as *the* dominant functional type in riparian ecosystems. In addition to conducting photosynthesis, the aboveground structure of vascular plants increases roughness and thus protects floodplain soils from erosion and enhances the deposition and retention of nutrient-rich sediments during floods. Litter from plants reduces the erosive impacts of rainfall on soil surfaces and provides inputs to soil organic matter for nutrient cycling. Aboveground structures of riparian plants modify the physical environment by shading and litter deposition, strongly affecting spatial and temporal patterns of soil-resource availability for other organisms. Vegetation structure helps create gradients of moisture and temperature that are important to maintaining biotic diversity. Roots stabilize soils and stream-banks are conduits for resource acquisition and redistribution, and provide organic-matter inputs to soil food webs. Vegetation also provides fuel for fire, as well as resources and habitat structure for belowground and aboveground consumers and decomposers ranging from fungi and bacteria to birds and mammals (Brinson et al. 1981, Whitford 2002, Wardle 2002). Finally, carbon storage and the mediation of earth-atmosphere energy/water balances are additional ecosystem functions performed by vegetation that are increasingly important with respect to global-change processes (Breshears and Allen 2002, Asner et al. 2003).

A large number of vegetation attributes affects the manner and extent to which these functions are performed. Size, biomass, photosynthetic rate, relative and absolute growth rates, tissue chemistry, stem basal area, canopy cover, vertical canopy structure, spatial arrangement and contiguity, leaf area, leaf longevity, and plant life-span are some of the more important vegetation attributes for ecosystem functioning (Chapin 1993). Root distribution, reproductive traits, moisture requirements, and phenology are additional functional attributes of vegetation that are particularly important in riparian ecosystems. With respect to disturbance interactions, important functional attributes include palatability, flammability, and mode of post-disturbance regeneration.

Woody trees and shrubs are the defining structural and functional elements of riparian ecosystems, especially in dry landscapes (Mitsch and Gosselink 1993). The two most frequently occurring native tree genera in riparian ecosystems of the western U.S. are *Populus* and *Salix*. The non-native trees, tamarisk (*Tamarix*) and Russian-olive (*Elaeagnus*), represent the third and forth most frequently occurring riparian genera (Friedman et al. in press).

Provision of habitat for a diverse array of secondary consumer and decomposer communities is an important functional attribute of riparian vegetation. Undisturbed riparian ecosystems are recognized as being especially diverse biologically. The importance of riparian ecosystems in this regard is attributed to a unique combination of physical and biological characteristics, including: (1) a predominance of woody plants; (2) at least a seasonal presence of surface water and high soil moisture; (3) an interspersion of diverse structural elements that create high habitat patch diversity; and (4) a linear form with high connectivity, that provides for uniform, protected pathways for migration and movements between different habitat types (Brinson et al. 1981).

Many of the functional attributes described above differ greatly among vegetative life forms. For example, there are relatively large differences among riparian trees, shrubs and herbs in terms of canopy height, architecture and spatial arrangement, as well as in their responses to climate, fire and herbivory. As a consequence, ecosystems characterized by different proportions of trees,

shrubs, herbs, and grasses can be expected to differ greatly in terms of associated ecosystem processes including nutrient cycling, hydrologic regimes, disturbance regimes, and wildlife-habitat relationships. Likewise, temporal shifts in the relative abundance and spatial configuration of vegetative life forms can significantly affect the functioning of an array of ecosystem processes.

W.4.2.4. Riparian Zone Invertebrates and Vertebrates

The presence of water, nutrient-rich soils, and the interspersion of a variety of successional aquatic and terrestrial biotic communities make riparian zones more productive and biologically diverse than surrounding uplands (Lugo et al. 1990; Knutson et al. 1996). The physical and biotic components of riparian ecosystems have important influence on the biota of stream ecosystems, but here we focus on non-aquatic invertebrate and vertebrate communities. Vertebrate and invertebrate communities are significant contributors to the biological diversity of aquatic and riparian ecosystems (e.g., Stevens et al. 1977, Brode and Bury 1984, Falck et al. 2003, Fleishman et al. 1999). There are numerous ways in which above-ground, consumers can directly or indirectly affect the structure and functioning of riparian ecosystems. Activities associated with herbivory, trampling, and ponding are among those that have the greatest ecosystem-level consequences for riparian and aquatic ecosystems due to their many effects on vegetation structure and floodplain soil processes. Processes of competition and predation can likewise have important ecosystem-level consequences by altering the structure of consumer food webs, but these processes are not reviewed here.

Herbivory can have numerous direct and indirect effects on ecosystem properties. Native herbivores in riparian ecosystems of the region include insects (grasshoppers and others) and mammals such as beaver (*Castor canadensis*), mice, voles, and deer. Herbivorous insects and small to medium-sized mammals can have significant effects on riparian and wetland vegetation structure, reproductive patterns, and ecosystem processes such as decomposition and nutrient cycling (Wallace and O'Hop 1985, Scott and Haskins 1987, Anderson and Cooper 2000). Perhaps the greatest ecosystem-level consequences for riparian ecosystems are those associated with biophysical alterations, such as dam building by beaver and structural habitat modifications resulting from herbivory and trampling, caused by large-bodied browsers and grazers, including deer and domestic livestock. At certain levels, these activities contribute to the overall biodiversity of riparian ecosystems by creating a dynamic mosaic of different habitat patch types (Naiman and Rogers 1997). However, chronic, high densities of large-bodied browsers and grazers may ultimately lead to habitat simplification and loss of biodiversity (Kauffman and Krueger 1984, Taylor 1986, Scott et al. 2003).

Large herbivores can affect individual plants both directly and indirectly through a variety of mechanisms. Direct impacts include altered physiological function and morphology attributable to defoliation and trampling (Briske 1991, Briske and Richards 1995). Defoliation and trampling by large herbivores may indirectly influence plant performance as a consequence of altered microenvironmental conditions, soil properties (Thurow 1991), mycorrhizal relations (Bethlenfalvay and Dakessian 1984), competitive relations, and through effects on ecosystem processes such as nutrient cycling and channel and floodplain formation. Seed dispersal is yet another indirect mechanism by which large herbivores and other animals may affect vegetation structure. Through time, combined direct and indirect impacts can result in altered plant population dynamics (e.g., altered rates of reproduction, recruitment, and mortality) and consequent changes in plant community composition, structure, and distribution (Brinson et al. 1991, Naiman and Rogers 1997). Due to strong interactions of vegetation with nutrient cycling, hydrologic processes, disturbance regimes, and geomorphic processes, herbivore-driven changes in vegetation structure can have cascading effects on multiple ecosystem processes and properties.

Large herbivores can also affect the productivity and composition of plant communities through numerous indirect and direct effects on nutrient cycling in upland (Archer and Smeins 1991) and

riparian systems. Herbivore-driven shifts in plant community structure can affect nutrient cycles by altering the capacity of vegetation to capture and retain soil and water resources (Whitford 2002) and by altering the quantity and quality of organic-matter inputs (Bardgett and Wardle 2003). Herbivory removes foliage and directly diverts nutrients from litter and physiological processes of intra-plant cycling. Nutrients acquired from foliage may be incorporated in animal biomass or spatially redistributed across the landscape in urine and dung. Where excreta are deposited, productivity may be enhanced if nutrients contained in the excreta are accessible to nearby plants. In other portions of the landscape, productivity may be reduced due to the removal of nutrients in the form of foliage.

W.4.2.5. Riparian Ecosystem Dynamics

Within riparian corridors, the availability of water and nutrient rich soils, along with relatively frequent fluvial disturbance, contribute to high rates of productivity and confer both resistance and resilience to natural disturbance processes (Stromberg et al. 1993). In addition, uniquely high levels of biological diversity associated with riparian ecosystems are attributed to variation in the frequency and intensity of flooding, larger-scale variations in climate as streams traverse elevational gradients, smaller-scale topographic diversity and related soil and moisture gradients, and upland disturbance processes, which together, produce a diverse array of habitat patch types (Naiman et al. 1993).

Early successional woody riparian species like cottonwood and willow, as well as a host of herbaceous species, are disturbance-dependent, requiring bare, moist stream deposits for seed germination and establishment. Thus, models of riparian ecosystem dynamics begin with un-vegetated alluvial landforms which are typically colonized by cottonwood, willow species, and grasses. These early successional vegetation patches are either replaced by later successional riparian or upland species, or returned to bare alluvium by intense fluvial disturbance (Johnson 1994, Friedman et al. 1997, Richter and Richter 2000).

Two physical environmental gradients have been shown to influence riparian ecosystems at different scales; longitudinal, or up/down valley gradients, and transverse, or cross-valley gradients. Longitudinal-scale variables including elevation, valley slope, valley width, and lithology, influence riparian ecosystem dynamics at larger spatial scales. Whereas smaller, transverse-scale variables include depth to the water table, flood frequency, flood intensity, and substrate texture (Bendix 1994). We briefly illustrate the influence of these factors on riparian ecosystem dynamics and diversity.

*W. 4.3. Natural and Anthropogenic Stresses and Riparian Ecosystem Response*

Significant changes in any of the four interactive controls (Chapin et al. 1996) are predicted to result in a new ecosystem with different characteristics than the original system. Major changes in flow regime can be expected to greatly affect vegetation establishment and survival patterns, productivity, and competitive interactions among species, and thus cause significant changes in the structure and functioning of riparian plant communities and higher trophic levels. Changes in vegetation composition and structure can affect the ecosystem's disturbance regime (e.g., through altered fire frequency and intensity). These factors, in combination with processes, can result in an altered system which is fundamentally different from the original riparian system in terms of composition, structure, functioning, and dynamics.

This section describes predominant natural and anthropogenic stressors affecting the structure and functioning of riparian ecosystems of the Southern Plains, and presents conceptual models of degradational processes related to those stressors.

W.4.3.1. Streamflow Alteration

*Flow Depletion* - Flow depletions resulting from the diversion of streamflow, can have a range of effects on aquatic and riparian ecosystems. When depletions are small and incremental, effects on riparian ecosystems may be subtle, involving reduced over-bank flooding, loss of species richness, reduced site productivity, structural simplification, such as reduced tree height and density, reductions in the creation of new riparian vegetation patches, and increased susceptibility to fires. However, significant depletions of surface and groundwater can lead to dewatering of the channel and floodplain, resulting in the mortality of riparian vegetation and encroachment of upland vegetation and/or non-native weeds. This terrestrialization of the riparian zone is a common transition pattern in riparian ecosystems and the predicted outcome of reductions in flow variability and/or flow volume (Auble et al. 1997, and *in press*). The degree of terrestrialization may signal the extent to which riparian ecosystems have been altered by water management activities (Innis et al. 2000). Decreased bank stability associated with the loss of riparian vegetation makes these sites prone to channel incision and ultimately the loss of flood plain soils, site conditions that typically support riparian and aquatic ecosystems (Rood and Mahoney 1990, Kondolf and Curry 1986).

*Altered Flow Variability* - Physical changes resulting from flow alteration downstream of large dams typically degrades the biotic integrity of riparian ecosystems by altering habitats and competitive interactions in favor of non-native riparian species. The loss of ecological integrity resulting from streamflow alteration is illustrated by a widespread degradational process involving the conversion of riparian cottonwood-willow forest to woodlands dominated by the non-native riparian tree, *Tamarix ramosissima*. This represents a common transition in riparian zones throughout the western US (Friedman et al., in press). The mechanisms apparently responsible for such transitions involve reductions in streamflow and channel narrowing resulting from reduced sediment transport. Establishment of relatively dense stands of tamarisk on un-vegetated portions of the formerly active channel facilitates narrowing through the vertical accretion of sediments and flood plain formation. Although climate-related fluctuations in precipitation have been implicated as a principle cause of channel narrowing along some un-dammed rivers (Hereford 1984), damming and diversion of streamflow have facilitated transitions to tamarisk in many cases. In fact, both climate and flow regulation have likely acted in concert, to varying degrees on different streams, to produce this transition (Alred and Schmidt 1999, Grams and Schmidt 2002). High salinity levels, either natural or human-induced (e.g., by irrigation return flows), may also favor the establishment of tamarisk over native species (Shafroth et al. 1995). This conversion may also be self-promoting to the degree that tamarisk increases the frequency and intensity of fires, and re-sprouts more effectively following fire than native riparian species like cottonwood (Ohmart and Anderson 1982, Busch and Smith 1995).

*Floods* - High magnitude floods can produce dramatic, long-term transformations in riparian ecosystem structure and functioning by inducing widespread geomorphic changes and plant mortality that may in turn initiate extended episodes of establishment of relatively long-lived alternative riparian species (Schumm and Lichty 1963). That is, individual floods may influence the reproductive patterns of riparian species for decades following a flood event. Along numerous western streams, channel narrowing and floodplain formation since the 1940's, has been accompanied by the establishment of extensive stands of saltcedar (primarily *Tamarix ramosissima*; Burkham 1972, Hereford 1984). The degree to which saltcedar has facilitated such narrowing is the nexus of a long-standing debate (Graf 1978, Everitt 1980). However, the regional nature of channel narrowing and floodplain construction has led Hereford (1987) to conclude that this channel-change process is primarily due to the control of larger-scale factors such as climate.

*Drought* - The effects of regional climatic drought on riparian ecosystems are expressed most directly through reduced surface flows and depletion of alluvial groundwater aquifers. Thus, the stress effects of naturally occurring drought mimic those produced by anthropogenic stressors

such as damming and diversion of streamflow, groundwater pumping, and channel incision resulting from altered flows of water and sediments, bank stabilization, and in-stream gravel mining (Bravard et al. 1997, Kondolf 1994, 1997, Rood et al. 1995, Stromberg et al. 1996, 1997, Scott et al. 2000).

The response of any plant to gradually increasing water stress involves progressive and integrated physiological and morphological responses, beginning with stomatal closure, reduced leaf and canopy development, and ending with death (Bradford and Hsiao 1982, Braatne et al. 1992). Mild water stress can reduce plant productivity by limiting $CO_2$ assimilation through stomatal closure, lowering net photosynthesis, and through the death of leaves and fine roots. Under more severe drought conditions, trees exhibit reduced radial stem increments, wilting and abscission of leaves, and branch death. Tree mortality may follow directly or secondarily as the result of insects or other pathogens (Albertson and Weaver 1945). Because these changes occur at different levels of water stress and on different time scales, accurate quantification of longer-term water stress is problematic (Pallardy et al. 1991).

Despite widespread occurrence in semiarid landscapes, riparian cottonwood species are susceptible to drought-induced cavitation of xylem vessels (Tyree et al. 1994), and suffer higher mortality during drought than several eastern deciduous forest species (Kaylor et al. 1935, Albertson and Weaver 1945) or non-native tamarisk (Busch and Smith 1995, Cleverly et al. 1997, Horton 2001a, b). In water stressed cottonwood species, Smith et al. (1991) found significantly reduced stomatal conductance and reduced midday leaf water potential ($\Psi_l$) for *Populus trichocarpa* compared with non-stressed trees. These trends were particularly pronounced for juvenile trees. Busch and Smith (1995) found moderately higher rates of stomatal conductance and transpiration and slightly higher predawn and midday $\Psi_l$ in comparing *Populus fremontii* and *Salix gooddingii* from a gaining reach with those from a losing reach of the Bill Williams River, Arizona. Riparian *Populus* can exhibit morphological and growth responses to chronic water stress, including reduced leaf size, increased leaf thickness, reduced leaf area, reduced annual stem elongation, and reduced radial stem increments (Smith et al. 1991, Stromberg and Patten 1991, Busch and Smith 1995). Under conditions of acute water stress associated with severe climatic drought or water table declines, *Populus* display more extreme morphological responses such as crown die-back (branch sacrifice), and ultimately stand mortality (Ellison and Woolfolk 1937, Albertson and Weaver 1945, Stromberg 1993, Rood et al. 1995, Rood et al. 2000).

*Availability of Alluvial Groundwater* - The rate, depth, and duration of alluvial groundwater declines and the water holding characteristics of the soil interact with atmospheric water demand (i.e., temperature, humidity, wind speed) to influence the intensity and duration of water stress in groundwater-dependent plants. The few studies that quantitatively link alluvial groundwater dynamics to riparian vegetation response suggest that along rivers in semi-arid regions: (1) woody riparian trees are sensitive to seasonal or longer-term alluvial groundwater declines (Groeneveld and Griepentrog 1985, Stromberg et al. 1996), (2) they exhibit moisture stress responses ranging from short-term physiological adjustments to stand-wide mortality (Busch et al. 1995, Scott et al. 1999, Shafroth et al. 2000, Horton 2001a,b), (3) stress responses can be deferred by short-term increases in streamflow and corresponding rises in the groundwater (Cooper et al. 2003), (4) tree physiological condition deteriorates rapidly when groundwater declines cross a threshold depth ranging from 5-10 feet (1.5-3 m) (Scott et al. 1999, Shafroth et al. 2000, Horton 2001a), (5) non-native tamarisk is more tolerant of groundwater-induced moisture stress than native cottonwoods and willows (Busch and Smith 1995, Cleverly et al. 1997, Shafroth et al. 2000, Horton 2001b), and (6) the intensity of physiological responses appears to be conditioned by the influence of the historical, site-specific groundwater regime on root architecture (Shafroth et al. 2000, Scott et al. 2000).

W.4.3.2. Alteration of Riparian Zone Soils/Morphology

Abrupt changes in stream channel patterns, from straight through braided forms, can occur in response to a range of factors, as critical geomorphic thresholds are exceeded by changes in external variables such as stream power, channel gradient, and sediment transport (Schumm and Kahn 1972), accompanied by changes in riparian zone morphology. Such channel pattern-shifts can be triggered by episodic events, which may have long-lasting effects on stream and valley morphology, erosional and depositional processes, and riparian and aquatic ecosystems. Rare, large floods have eroded flood plains and terraces and transformed meandering channels near the threshold of pattern-change to a braided pattern. Subsequent channel narrowing and re-establishment of a meandering channel form can then occur through the process of flood plain construction and the establishment of riparian vegetation on portions of the former channel bed (Schumm and Lichty 1963, Friedman et al. 1996). Channel narrowing can also result from the widespread establishment of tamarisk. However, more often than not, significant changes in stream morphology, which give rise to changes in riparian zone morphology, are the result of changes in local land use (e.g., grazing practices) or small instream structures such as check dams and low-water bridges.

Vertically aggraded floodplains progressively become disconnected from surface flows in adjacent channels, and may be abandoned if the regional climate becomes drier. Abandoned flood plains are referred to as terraces. Remnant terrace sequences from across the arid and semi-arid western United States record several climatically driven valley cut-and-fill cycles during the Holocene period (within the last 10,000 years). These changes have dramatic effects on rivers and their floodplains. Geologic evidence indicates that during relatively cool, wet periods, valleys fill by deposition of alluvial (river-derived) sediments. When a period of deposition is followed by a relative dry period, the channel incises into the alluvium, abandoning the previously constructed floodplain as a terrace. Whereas valley deposition or aggradation is a slow process (thousands of years), corresponding valley erosion and floodplain abandonment is rapid (tens to hundreds of years) (Leopold 1994).

W.4.3.3. Ungulate Grazing and Trampling

Because of the presence of water and shade, riparian areas are often subject to more intense grazing pressure than adjacent uplands (Platts 1991). Long-term grazing by livestock and other large herbivores can have profound on-site impacts on riparian ecosystems including the removal of plant biomass, alteration of plant population age structures, and simplification of plant compositional and structural diversity (Szaro and Pace 1983, Kauffman and Kruger 1984, Schultz and Leininger 1990). These changes in turn are related to reduced abundance and diversity of riparian-dependent species, including birds (Taylor 1986, Dobkin et al. 1998, Scott et al. 2003). Within riparian zones, grazing reduces the erosional resistance of alluvial surfaces by reducing vegetation cover. Trampling directly erodes and destabilizes alluvial surfaces, making them prone to further erosion during high flows (Trimble and Mendel 1995).

The riparian plant community controls the amount of light reaching the stream surface, and strongly influences nutrient cycling and transport, organic matter input, bank stability, and stream channel morphology, as well as subsurface flow to streams (Gregory et al. 1991). If vegetation is reduced, light and temperature increase, which may result in greater algal growth.

Stresses and impacts on the availability of water in riparian zones, riparian zone soils and morphology, riparian water quality/chemistry (including palustrine wetlands), and riparian zone biota in SOPN parks are enumerated in Tables 13 through 16, respectively, accompaned by indicators of ecosystem response/condition. For each major stressor identified, indicators of ecosystem condition are summarized in Table 17.

**Table 13. Stresses and impacts on the availability of water in the riparian zone**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | ↓ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Groundwater Pumping (△ Baseflow, Streamflow) | ↓ Groundwater Level (Regional), Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| △ Local Stream Base Level(s) | ↓ or ↑ Stream Stage, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Impoundments | ↑ Stream Stage, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Shoreline Development (buildings & other structures) | ↑ Overland Flow, Stream Stage / Reservoir Level, Depth of Water in Palustrine Wetlands | Depth of Water in Palustrine Wetland |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Groundwater Level (Regional), Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Tamarisk & Other Phreatophytes | ↑ Evapotranspiration, ↓ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Removal of Upland Riparian Vegetation | ↓ Evapotranspiration, ↑ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Flood | ↑ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |

| | | |
|---|---|---|
| Drought | ↓ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Climate Change (temperature, precipitation, wind) | ↓ or ↑ Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |
| Fragmentation (including stream downcutting & floodplain / palustrine wetland abandonment) | ↓ Frequency of Flooding, Exchange of Surface Water in Fragmented Palustrine Wetlands; (where stream is downcut) ↓ Riparian Water Table / Depth of Water in Palustrine Wetlands | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland |

**Table 14. Stresses and impacts on riparian zone soils / morphology**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (△ Streamflow) | Stream Riparian: ↓ Streamflow, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| Groundwater Pumping (△ Baseflow, Streamflow) | Stream Riparian: ↓ Baseflow / Streamflow, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| △ Local Stream Base Level(s) | Stream Riparian: △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| Impoundments | Stream Riparian: △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| Shoreline Development (buildings & other structures) | Stream or Reservoir Riparian: Bank Modification | Stream Geomorphic Parameters[*1] (including Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) |
| Bank Stabilization / Channel Straightening | Stream Riparian: △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition<br>Reservoir Riparian: △ Bank Morphology, Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] & Bank Composition |
| Bank Instability | Reservoir Riparian: △ Bank Morphology | Reservoir Morphometry[*2] (Bank Slope) |
| Dredging / Filling (palustrine wetlands) | Stream Riparian: △ Palustrine Wetland Morphology<br>Reservoir Riparian: △ Palustrine Wetland Morphology | Stream Geomorphic Parameters[*1] (including Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) |

| | | |
|---|---|---|
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | Stream Riparian: △ Baseflow / Streamflow, Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Bed Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| △ Sediment Load<br>(due to changes in upland or local land use) | Stream Riparian: △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition<br>Reservoir Riparian: △ Deposition, Reservoir Morphology / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) & Bed Composition |
| Tamarisk | Stream Riparian: △ Stream Cross-Sectional Geometry (loss of active channel)<br>Reservoir Riparian: △ Reservoir Morphology (decreased deep water habitat) | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) |
| Other Exotic / Invasive Riparian Vegetation | Stream or Reservoir Riparian: ↓ or ↑ Bank Erosion, Sediment Load, △ Stream Geomorphology / Reservoir Morphology | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) & Bank Composition |
| Removal of Upland Riparian Vegetation | Stream or Reservoir Riparian: ↑ Bank Erosion, Sediment Load, △ Stream Geomorphology / Reservoir Morphology | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*2] (including Palustrine Wetlands) & Bank Composition |
| Flood | Stream Riparian: Possible △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| Climate Change<br>(temperature, precipitation, wind) | Stream Riparian: △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |

| | | |
|---|---|---|
| Ungulate Grazing / Trampling | Stream Riparian: Trampling of Riparian Vegetation & Banks,<br>↑ Sediment Load, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition<br>Reservoir Riparian: Trampling of Riparian Vegetation & Banks,<br>↑ Sediment Load, △ Bank Morphology, Bank Composition | Stream Geomorphic Parameters*1 (including Bank & Floodplain Morphology) or Reservoir Morphometry*2 (including Palustrine Wetlands) & Bank Composition |
| Instream Driving / Vehicle Crossing | Stream Riparian: △ Stream Cross-Sectional Geometry, ↑ Suspended Sediment, Redistribution of Floodplain / Bank Material | Stream Geomorphic Parameters*1 (including Bank & Floodplain Morphology) |
| Off-Road Vehicle Use | Stream Riparian: ↑ Erosion, Sediment Load, △ Floodplain / Bank Composition<br>Reservoir Riparian: ↑ Erosion, Sediment Load, △ Bank Morphology, Bank Composition | Stream Geomorphic Parameters*1 (including Bank & Floodplain Morphology) or Reservoir Morphometry*2 & Bank Composition |
| Sand & Gravel Mining | Stream Riparian: ↑ Sediment Load, △ Stream Cross-Sectional Geometry, Entrenchment, Longitudinal Profile, Sinuosity, Channel Pattern / Location, Floodplain / Bank Composition | Stream Geomorphic Parameters*1 |
| Altered Fire Regime | Stream Riparian: △ Sediment Load, Floodplain / Bank Composition<br>Reservoir Riparian: △ Sediment Load, Bank Composition | Floodplain / Bank Composition |

*1 Channel cross-section, width/depth, entrenchment, rates of bank erosion and downcutting/aggradation, longitudinal profile, sinuosity, channel pattern, channel location (lateral migration), and pebble count.

*2 Reservoir mean/maximum depth, volume/area, depth profile/bed slope.

**Table 15. Stresses and impacts on riparian zone water quality / chemistry**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (from streams, reservoirs, or upstream tributaries to reservoirs) | Stream or Reservoir Riparian: ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Groundwater Pumping | Stream or Reservoir Riparian: ↑ Concentration of Nutrients, Organic Carbon, & Suspended Solids, Water Temperature, △ Concentration of Other Dissolved & Suspended Constituents | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Impoundments | Stream Riparian: ↓ and ↑ Suspended Sediment, Water Temperature | Suspended Sediment, Turbidity, Water Temperature [Palustrine Wetlands] |
| Shoreline Development (buildings & other structures) | Stream or Reservoir Riparian: ↑ Sediment Load, Water Temperature | Suspended Sediment, Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Bank Stabilization / Channel Straightening | Stream or Reservoir Riparian: ↓ Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |
| Bank Instability | Reservoir Riparian: ↑ Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |
| Dredging / Filling (palustrine wetlands) | Stream or Reservoir Riparian: ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, ↓ or ↑ Water Temperature / Gradient | Suspended Sediment, Turbidity, Potential Point Source Contaminants[*5], BOD/COD[*2], Temperature Profile [Palustrine Wetlands] |

| | | |
|---|---|---|
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | ↓ or ↑ Sediment Load, Concentration of Other Dissolved & Suspended Constituents, Water Temperature | Suspended Sediment, Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| △ Sediment Load<br>(due to changes in upland or local land use) | Stream or Reservoir Riparian: ↓ or ↑ Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |
| Non-Point Nutrient & Organic Releases<br>(upland or local land use) | Stream or Reservoir Riparian: ↑ Nutrients, Organic Carbon, Heavy Metals, Palustrine Wetland Eutrophication | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Permitted Wastewater Discharge to Streams | Stream Riparian: ↑ Nutrients, Organic Carbon, Heavy Metals, Aquatic Microorganisms, Palustrine Wetland Eutrophication | Aquatic Microorganisms[*6], Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Point Contaminant Releases<br>(contaminated sites) | Stream or Reservoir Riparian: ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, & Other Toxic Substances (as applicable) | Potential Point Source Contaminants[*5], BOD/COD[*2], Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Atmospheric Deposition | Stream or Reservoir Riparian: ↑ Nitrogen & Sulphur Compounds, Mercury & Other Metals, Pesticides (as applicable) | Nutrients[*1], pH, Mercury & Other Metals, Pesticides<br>(as applicable) Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Tamarisk | Stream or Reservoir Riparian: ↑ Salinity | Salinity [Palustrine Wetlands] |
| Other Exotic / Invasive Riparian Vegetation | Stream or Reservoir Riparian: ↓ or ↑ Bank Erosion, Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |

| | | |
|---|---|---|
| Removal of Upland Riparian Vegetation | Stream or Reservoir Riparian: ↓ Interception of Overland Flow, Cover, ↑ Nutrient Load, Sediment Load, Rate of Organic Carbon Input | Nutrients[*1], BOD/COD[*2], Suspended Sediment, Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Flood | Stream or Reservoir Riparian: ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, ↓ Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Drought | Stream or Reservoir Riparian: ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Climate Change (temperature, precipitation, wind) | Stream or Reservoir Riparian: ↓ or ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Fragmentation (palustrine wetlands) | Loss of Patch Connectivity | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands] |
| Ungulate Grazing / Trampling | Stream or Reservoir Riparian: ↑ Aquatic Microorganisms, Sediment Load, Nutrient Load, Rate of Organic Carbon Input | Aquatic Microorganisms[*6], Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Motorized Boating | ↑ Suspended Sediment, Mobilization of Sorbed Contaminants, Petroleum Hydrocarbons | Suspended Sediment, Turbidity, Petroleum Hydrocarbons [Palustrine Wetlands] |
| Off-Road Vehicle Use | Stream or Reservoir Riparian: ↑ Erosion, Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |
| Sand & Gravel Mining | Stream Riparian: ↑ Sediment Load | Suspended Sediment, Turbidity [Palustrine Wetlands] |
| Altered Fire Regime | Stream or Reservoir Riparian: ↓ or ↑ Nutrient Load, Sediment Load | Nutrients[*1], Suspended Sediment, Turbidity [Palustrine Wetlands] |

*1 Nitrogen and phosphorous.

*2 Biological oxygen demand / chemical oxygen demand.

*3 Dissolved oxygen profile.

*4 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, turbidity.

*5 Synthetic organic compounds, gasoline & diesel-range organic compounds, metals, pesticides, & other toxic substances, as applicable.

*6 Bacteria, viruses, and protozoa.

**Table 16. Stresses and impacts on riparian biota**

| Stresses | Effects | Indicators |
|---|---|---|
| Surface Water Diversions (from streams, reservoirs, or upstream tributaries to reservoirs) | ↑ Concentration of Nutrients, Suspended Sediment, & Other Dissolved and Suspended Constituents, Water Temperature, Phytoplankton, Algae, Light Extinction, ↓ Riparian Water Table, Depth of Submergence (Palustrine Wetlands), △ Areal Extent / Location of Palustrine Wetlands | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Groundwater Pumping | ↑ Concentration of Nutrients, Organic Carbon, Suspended Solids, Water Temperature, Phytoplankton, Algae, Light Extinction, ↓ Riparian Water Table, Depth of Submergence (Palustrine Wetlands), △ Areal Extent / Location of Palustrine Wetlands | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| △ Local Stream Base Level(s) | ↓ or ↑ Stream Stage, Riparian Water Table / Depth of Submergence (Palustrine Wetlands) | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Impoundments | Stream Riparian: ↓ and ↑ Suspended Sediment, Water Temperature, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Shoreline Development (buildings & other structures) | Loss of Bank Habitat (Bank Modification), △ Water Quality, ↓ Amphibians, Waterfowl | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Bank Stabilization / Channel Straightening | Loss of Bank Vegetation / Habitat, ↓ Amphibians, Waterfowl | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |

| | | |
|---|---|---|
| Bank Instability | Loss of Bank Habitat | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Dredging / Filling (palustrine wetlands) | Loss / Alteration of Palustrine Wetland Habitat | Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| △ Infiltration / Runoff Rates (due to changes in upland or local land use – e.g., urbanization or agricultural development) | △ Streamflow / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands, Riparian Habitat, ↓ or ↑ Sediment Load, Concentration of Other Dissolved & Suspended Constituents, Water Temperature | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| △ Sediment Load (due to changes in upland or local land use) | ↓ or ↑ Suspended Sediment, Deposition, △ Areal Extent / Location of Palustrine Wetlands, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Non-Point Nutrient & Organic Releases (upland or local land use) | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Permitted Wastewater Discharge to Streams | ↑ Nutrient Load, Rate of Organic Carbon Input, Heavy Metals, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |

| | | |
|---|---|---|
| Point Contaminant Releases (contaminated sites) | ↑ Synthetic Organic Compounds, Petroleum Hydrocarbons, Heavy Metals, Pesticides, Wastewater Contaminants, & Other Toxic Substances (as applicable) | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Atmospheric Deposition | ↑ Nitrogen & Sulphur Compounds, pH, Mercury & Other Metals, Pesticides (as applicable) | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Tamarisk | ↑ Salinity | Tamarisk Abundance & Distribution; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Other Exotic / Invasive Riparian Vegetation | Competition with Noninvasive Native Palustrine Wetland & Upland Riparian Vegetation, △ Riparian Habitat | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Clearing of Emergent Vegetation & Woody Debris | Loss of Riparian Habitat, ↓ Amphibians, Waterfowl, Fish Growth Rates, △ Water Quality | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Removal of Riparian Vegetation | ↓ Interception of Overland Flow, Cover, ↑ Nutrient Load, Sediment Load, Rate of Organic Carbon Input, Loss of Riparian Habitat | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Exotic / Invasive Vertebrates & Invertebrates | Competition with Noninvasive Native Riparian Vertebrates & Invertebrates | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vertebrates & Invertebrates |
| Flood | △ Suspended Sediment, Water Quality, Water Temperature | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |

| | | |
|---|---|---|
| Drought | ↓ Riparian Water Table / Depth of Water in Palustrine Wetlands,<br>△ Water Quality, Water Temperature | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vertebrates & Invertebrates |
| Climate Change<br>(temperature, precipitation, wind) | ↓ or ↑ Air & Water Temperatures, Stream Stage / Reservoir Level, Riparian Water Table / Depth of Water in Palustrine Wetlands, Nutrient Load, Sediment Load, Concentrations of Other Dissolved & Suspended Constituents | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Fragmentation<br>(palustrine wetlands) | Loss of Patch Connectivity (Palustrine Wetlands & Upland Riparian Habitat) | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Ungulate Grazing / Trampling | ↑ Trampling of Riparian Vegetation & Banks, Nutrient Load, Sediment Load, Rate of Organic Carbon Input, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Off-Road Vehicle Use | ↑ Bank Erosion, Sediment Load, Wetland Deposition, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Sand & Gravel Mining (Stream) | Loss of Riparian Habitat | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Altered Fire Regime | ↓ or ↑ Nutrient Load, Sediment Load, Rate of Organic Carbon Input, Phytoplankton, Algae, Light Extinction | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |

**Table 17. Summary of stresses and indicators of riparian ecosystem function and condition.**

| Stresses | Indicators |
|---|---|
| Surface Water Diversions (△ Streamflow) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Nutrients[*2], BOD/COD[*3], DO Profile[*4], Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Groundwater Pumping (△ Baseflow, Streamflow) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Nutrients[*2], BOD/COD[*3], DO Profile[*4], Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| △ Local Stream Base Level(s) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Impoundments | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Suspended Sediment, Turbidity, Water Temperature [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Shoreline Development (buildings & other structures) | Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Floodplain Morphology) <u>or</u> Reservoir Morphometry[*6]; Suspended Sediment, Basic Water Quality Parameters[*4]; Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Bank Stabilization / Channel Straightening | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*6] & Bank Composition; Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |

| | |
|---|---|
| Bank Instability | Reservoir Morphometry[*6] (Depth Profile/Bank Slope); Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Dredging / Filling<br>(palustrine wetlands) | Stream Geomorphic Parameters[*1] (including Floodplain Morphology) or Reservoir Morphometry[*6]; Suspended Sediment, Turbidity, Potential Point Source Contaminants[*7], BOD/COD[*3], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| △ Infiltration / Runoff Rates<br>(due to changes in upland or local land use – e.g., urbanization or agricultural development) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Suspended Sediment, Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| △ Sediment Load<br>(due to changes in upland or local land use) | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) or Reservoir Morphometry[*6] & Bed Composition; Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Non-Point Nutrient & Organic Releases<br>(upland or local land use) | Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Permitted Wastewater Discharge to Streams | Aquatic Microorganisms[*6], Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Point Contaminant Releases<br>(contaminated sites) | Potential Point Source Contaminants[*7], BOD/COD[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |

| | |
|---|---|
| Atmospheric Deposition | Nutrients[*2], pH, Mercury & Other Metals, Pesticides (as applicable), Basic Water Quality Parameters[*4] [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Tamarisk | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) or Reservoir Morphometry[*6]; Salinity [Palustrine Wetlands]; Tamarisk Abundance & Distribution; Composition, Abundance, & Distribution of Palustrine Wetland Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Other Exotic / Invasive Riparian Vegetation | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) or Reservoir Morphometry[*6];& Bank Composition; Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Clearing of Emergent Vegetation & Woody Debris | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Removal of Upland Riparian Vegetation | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) or Reservoir Morphometry[*6] & Bank Composition; Nutrients[*1], BOD/COD[*2], Suspended Sediment, Basic Water Quality Parameters[*4] [Palustrine Wetlands] |
| Exotic / Invasive Vertebrates & Invertebrates | Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vertebrates & Invertebrates |
| Flood | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Nutrients[*2], BOD/COD[*3], DO Profile[*4], Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Drought | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Nutrients[*2], BOD/COD[*3], DO Profile[*4], Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vertebrates & Invertebrates |

| | |
|---|---|
| Climate Change (temperature, precipitation, wind) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology); Nutrients[*2], BOD/COD[*3], DO Profile[*4], Basic Water Quality Parameters[*5], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Fragmentation (including stream downcutting & floodplain / palustrine wetland abandonment) | Groundwater Level (Riparian Zone), Depth of Water in Palustrine Wetland; Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4], Temperature Profile [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Ungulate Grazing / Trampling | Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) <u>or</u> Reservoir Morphometry[*6] & Bank Composition; Aquatic Microorganisms[*6], Nutrients[*1], BOD/COD[*2], DO Profile[*3], Basic Water Quality Parameters[*4] [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |
| Instream Driving / Vehicle Crossing | Suspended Sediment, Stream Geomorphic Parameters[*1] (including Bank & Floodplain Morphology) |
| Motorized Boating | Suspended Sediment, Turbidity, Petroleum Hydrocarbons [Palustrine Wetlands] |
| Off-Road Vehicle Use | Suspended Sediment, Stream Geomorphic Parameters[*1] <u>or</u> Reservoir Morphometry[*6] & Bank Composition; Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Sand & Gravel Mining | Suspended Sediment, Stream Geomorphic Parameters[*1]; Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates |
| Altered Fire Regime | Suspended Sediment, Bank / Floodplain Composition; Nutrients[*1], Suspended Sediment, Turbidity [Palustrine Wetlands]; Composition, Abundance, & Distribution of Palustrine Wetland / Upland Riparian Vegetation, Macroinvertebrates, Invertebrates, & Vertebrates; Abundance of Phytoplankton & Algae (Palustrine Wetlands) |

*1 Channel cross-section, width/depth, entrenchment, rates of bank erosion and downcutting/aggradation, longitudinal profile, sinuosity, channel pattern, channel location (lateral migration), and pebble count.

*2 Nitrogen and phosphorous.

*3 Biological oxygen demand / chemical oxygen demand.

*4 Dissolved oxygen profile.

*5 Water temperature, pH, dissolved oxygen, major cations and anions, conductivity, turbidity.

*6 Reservoir mean/maximum depth, volume/area, depth profile/bed slope.

*7 Synthetic organic compounds, gasoline & diesel-range organic compounds, metals, pesticides, & other toxic substances, as applicable.

*8 Bacteria, viruses, and protozoa.

## W.5. AQUATIC INVERTEBRATES AS INDICATORS OF ECOSYSTEM CONDITION

Macroinvertebrates are of central importance in aquatic ecosystems because of their variable roles as detritivores, herbivores, predators, competitors, and prey. In addition to their link with the biotic environment, macroinvertebrates are sensitive to the physical and chemical environment. Because macroinvertebrates are affected by water chemistry, they may be used to assess water quality indirectly in place of direct water chemistry analysis. Macroinvertebrates also show greater sensitivity to toxicity than other aquatic organisms (Rosenberg and Resh 1993). Certain taxa of invertebrate are more sensitive than others to specific chemicals. For example, plecopterans and baetids (Ephemeroptera) are very sensitive to insecticides, whereas other taxa are more sensitive to chemicals such as herbicides, fungicides, and industrial chemicals (Rosenberg and Resh 1993).

Because of their utility as an integrated indicator of water quality and the condition of aquatic ecosystems (Allan 1995, Karr and Chu 1999), aquatic macroinvertebrates have been identified as a key monitoring parameter (Miller et al. 2003). Benthic macroinvertebrates offer many advantages for monitoring watershed condition, including: (1) their presence in a variety of aquatic systems and habitats; (2) their occurrence as a large number of species which respond to a spectrum of environmental stressors due to varying habitat and water quality requirements; (3) their sedentary nature which facilitates analyses of the spatial distribution of pollutants and disturbance effects; and (4) their relatively long life-cycles, which elucidate temporal changes in environmental conditions (adapted from Rosenberg and Resh 1993). Invertebrate response to stressors and drivers can be rapid and provide an efficient means of examining temporal and spatial variations in aquatic ecosystem condition. Invertebrate monitoring should be conducted in conjunction with evaluations of aquatic and riparian habitat and water quality.

W.6. LITERATURE CITED


Adair, E.C., and D. Binkley. 2002. Co-limitation of first year Fremont cottonwood seedlings by nitrogen and water. *Wetlands* 22:425-429.

Albertson, F. W., and J. E. Weaver. 1945. Injury and death or recovery of trees in prairie climate. *Ecological Monographs* 15:395-433.

Allan, J.D. 1995. Stream Ecology: *Structure and Functioning of Running Waters*. Chapman and Hall, London. 388 p.

Allred, T.M., and J.C. Schmidt. 1999. Channel narrowing by vertical accretion along the Green River near Green River, Utah. *Geological Society of America Bulletin* 111:1757-1772.

Amaranthus, M., H. Jubas, and D. Arthur. 1989. Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams. Pages 75-91 *in* N.H. Berg (tech coord.), Proceedings of the symposium on fire and watershed management. USDA General Technical Report PSW-109.

Armitage, P.D., and G.E. Petts. 1992. Biotic score and prediction to assess the effects of water abstractions on river macroinvertebrates for conservation purposes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 2:1-17.

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.

Auble, G. T., and M. L. Scott. 1998. Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. *Wetlands* 18:546-556.

Auble, G.T., M.L. Scott, and J. M. Friedman. *In press*. Wetland and riparian vegetation along the Fremont River, Utah, to assess impacts of flow alteration on wetland and riparian area. *Wetlands* 00:00.

Bagstad, K.J., J.C. Stromberg, and S.J. Lite. *In press*. Response of herbaceous riparian plants to flooding of the San Pedro River, Arizona, USA. *Wetlands* 00:00.

Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69:382-392.

Baker, W.L. 1990. Climate and hydrologic effects on the regeneration of Populus angustifolia James along the Animas River, Colorado. *Journal of Biogeography* 17:59-73.

Baltz, D.M., B. Vondracek, L.R. Brown, and P.B. Moyle. 1987. Influence of temperature on microhabitat choice by fishes in a California stream. *Transactions of the American Fisheries Society* 116:12-20.

Baltz, D.M., B. Vondracek, L.R. Brown, and P.B. Moyle. 1991. Seasonal changes in microhabitat selection by rainbow trout in a small stream. *Transactions of the American Fisheries Society* 120:166-176.

Barr, J. F. 1986. Population dynamics of Common Loon (Gavia immer) associated with mercury contamination in northwestern Ontario. Canadian Wildlife Service Occasional Paper 56. 23pp.

Beauchamp, V.B. 2004. Effects of flow regulation on a Sonoran riparian ecosystem, Verde River, Arizona. Ph.D. Dissertation, Arizona State University

Benavides-Solorio, J.D.D. 2003. Post-fire runoff and erosion at the plot and hillslope scale, Colorado Front Range. PhD Dissertation, Colorado State University.

Benbow, M.E., and R.W. Merritt. 2004. Road-salt toxicity of select Michigan wetland macroinvertebrates under different testing conditions. *Wetlands* 24:68-76.

Benda, L., N.L. Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004. The network dynamics hypothesis: how channel networks structure riverine habitats. *BioScience* 54:413-427.

Bendix, J. 1994. Scale, direction, and pattern in riparian vegetation-environment relationships. *Annals of the Association of American Geographers* 84:652-665.

Benenati, E.P., J.P. Shannon, and D.W. Blinn. 1998. Desiccation and recolonization of phytobenthos in a regulated desert river: Colorado River at Lees Ferry, Arizona, USA. *Regulated Rivers: Research & Management* 14:519-532.

Benenati, E.P., J.P. Shannon, D.W. Blinn, K.P. Wilson, and S.J. Hueftle. 2000. Reservoir-river linkages: Reservoir Powell and the Colorado River, Arizona. *Journal of the North American Benthological Society* 19:742-755.

Bickerton, M., G. Petts, P. Armitage, and E. Castella. 1993. Assessing the ecological effects of groundwater abstraction on chalk streams: 3 examples from Eastern England. *Regulated Rivers: Research & Management* 8:121-134.

Bennett, E., T. Reed-Anderson, J. Houser, J. Gabriel, and S. Carpenter. 1999. A phosphorus budget for the Lake Mendota watershed. Ecosystems 2:69-75.

Boening, D. 2000. Ecological effects, transport and fate of mercury: a general review. Chemosphere 40:1335-1351.

Blinn, D.W., J.P. Shannon, P.L. Benenati, and K.P. Wilson. 1998. Algal ecology in tailwater stream communities: the Colorado River below Glen Canyon Dam, Arizona. *Journal of Phycology* 34:734-740.

Boggs, K. and T. Weaver. 1994. Changes in vegetation and nutrient pools during riparian succession. *Wetlands* 14: 98-109.

Braatne, J.H., T.M. Hinckley, and R.F. Stettler. 1992. Influence of soil water on the physiological and morphological components of plant water balance in *Populus trichocarpa, Populus deltoides* and their F1 hybrids. *Tree Physiology* 11:325-339.

Bradford, K.J., and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Pages 264-324 *in* O.L. Lang, P.S. Nobel, C.B. Osmond, and H. Ziegler, (eds.), *Encyclopedia of Plant Physiology*. Vol. 12B. Springer-Verlag, Vienna, Austria.

Brady, N.C. 1974. The Nature and Properties of Soils. Eighth edition. MacMillan Publishing Co. Inc., New York, New York. 639 p.

Bramblett, R. G., and K. D. Fausch. 1991a. Fishes, macroinvertebrates and aquatic habitats of the Purgatoire River in Piñon Canyon, Colorado. Southwestern Naturalist. 36:281-294.

Bramblett, R. G., and K. D. Fausch. 1991b. Variable fish communities and the index of biotic integrity in a western Great Plains river. Transactions of the American Fish Society. 120:752-769.

Bravard, J., C. Amoros, G. Pautou, G. Bornette, M. Bournaud, M. Creuzé Des Châtelliers, J. Gibert, J. Peiry, J. Perrin, and H. Tachet. 1997. River incision in south-east France: morphological phenomena and ecological effects. *Regulated Rivers* 13:75-90.

Breshears, D.D., and C.D. Allen. 2002. The importance of rapid, disturbance-induced losses in carbon management and sequestration. *Global Ecology & Biogeography* 11:1-5.

Breshears, D.D., J.J. Whicker, M.P. Johansen, and J.E. Pinder, III. 2003. Wind and water erosion and transport in semi-arid shrubland, grassland and forest ecosystems: Quantifying dominance of horizontal wind-driven transport. *Earth Surface Processes and Landforms* 28: 1189-1209.

Briers, R.A., J.H.R.Gee, and R. Geoghegan. 2004. Effects of the North Atlantic Oscillation on growth and phenology of stream insects. *Ecography* 27:811-817.

Brinson, M.M., B.L. Swift, R.C. Plantico, and J.S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish and Wildlife Service Biological Report 81. 155 p.

Brown, L. R. 2000. Fish communities and their associations with environmental variables, lower San Joaquin River drainage, CA. *Environmental Biology of Fishes* 57:251-269.

Brown, L.R., and T. Ford. 2002. Effects of flow on the fish communities of a regulated California river: implications for managing native fishes. *River Research and Application* 18:331-342.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30:492-507.

Burkham, D.E. 1972. Channel changes of the Gila River in Safford Valley, Arizona 1846-1970. U.S. Geological Survey Professional Paper 655-G.

Busch, D.E., N.L. Ingraham, and S.D. Smith. 1992. Water uptake in woody riparian phreatophytes of the southeastern United States: a stable isotope study. *Ecological Applications* 2:450-459.

Busch, D.E., and S.D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. *Ecological Monographs* 65:347-370.

Cairns, J. Jr., and J.R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. Pages 10-27 *in* D.M. Rosenberg and V.H. Resh (eds.), *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman & Hall, New York, New York.

Canton, S.P., L.D. Cline, R.A. Short, and J.V. Ward. 1984. The macroinvertebrates and fish of a Colorado stream during a period of fluctuating discharge. *Freshwater Biology* 14:311-316.

Carothers, S.W. and S.W. Aitchinson. 1976. An ecological survey of the riparian zone of the Colorado River between Lee's Ferry and the Grand Wash Cliffs, Arizona. Colorado River Research Series Technical Report No. 10, Grand Canyon National Park, Arizona.

Carsten von der Ohe, P., and M. Liess. 2004. Relative sensitivity distribution of aquatic invertebrates to organic and metal compounds. *Environmental Toxicology and Chemistry* 23:150-156.

Castella, E., M. Bickerton, P.D. Armitage, and G.E. Petts. 1995. The effects of water abstractions on invertebrate communities in U.K. streams. *Hydrobiologia* 308:167-182.

Carpenter S. and D. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. Aquatic Botany 26:341-370.

Carpenter, S., D. Bolgrien, R. Lathrop, C. Stow, T. Reed, and M. Wilson. 1998. Ecological and economic analysis of lake eutrophication by nonpoint pollution. Australian Journal of Ecology. 1:68-79.

Cayan, D.R., K.T. Redmond, and L.G. Riddle. 1999. ENSO and hydrologic extremes in the western United States. *Journal of Climate* 12:2881-2893.

Chapin, F.S., III. 1993. Funtional role of growth forms in ecosystem and global processes. Pages 287-312 *in* J.R. Ehleringer and C.B. Field (eds.), *Scaling physiological processes: leaf to globe*. Academic Press, San Diego, California.

Chapin, D.M., R.L. Beschta, and H.W. Shen. 2002. Relationships between flood frequencies and riparian plant communities in the Upper Klamath Basin, Oregon. *Journal of the American Waters Resources Association* 38:603-617.

Chapin, F.S., III, M.S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148:1016-1037.

Cipra, J.E., E.F. Kelly, L. McDonald and J. Norman. 2002. Soil properties, erosion, and implications for rehabilitation and aquatic systems. Pages 204-219 *in* R. Graham (ed.), Hayman Fire Case Study. USDA Forest Service General Technical Report, RM-141.

Cleverly, J.R., S.D. Smith, A. Sala, and D.A. Devitt. 1997. Invasive capacity of *Tamarix ramosissima* in a Mojave Desert floodplain: the role of drought *Oecologia* 111:12-18.

Cole, G. 1994. A Textbook of Limnology, Fourth Edition. Waveland Press. 412 pp.

Comstock, J.P., and J.R. Ehleringer. 1992. Plant adaptation in the Great Basin and Colorado Plateau. *The Great Basin Naturalist* 52:195-215.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs: high diversity of trees and corals is maintained only in a non-equilibrium state. *Science* 199:1302-1310.

Cook, R.U., and R.W. Reeves. 1976. *Arroyos and environmental change in the American southwest.* Clarendon Press, Oxford, England. 213 p.

Cooper, D.J., D.M. Merritt, D.C. Anderson, and R.A. Chimner. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the upper Green River, USA. *Regulated Rivers: Research and Management* 15:419-440.

Cooper, D.J., D.R. D'Amico, and M.L. Scott. 2003. Physiological and morphological response patterns of Populus deltoides to alluvial groundwater declines. *Environmental Management* 31:215-226.

Covich, A.P., M.A. Palmer, and T.A. Crowl. 1999. The role of benthic invertebrate species in freshwater ecosystems. *BioScience* 49:119-127.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31. Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm (Version 04DEC98).

Cross, F. B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. Report to Kansas Department of Wildlife and Parks, Contract No. 46, Pratt, KS.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pp. 155-165 in W. J. Matthews and D. C Heins, eds. Communitiy and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Cuffney, T.F., M.R. Meador, S.D. Porter, and M.E. Gurtz. 1997. Distribution of fish, benthic invertebrate, and algal communities in relation to physical and chemical conditions, Yakima River Basin, Washington, 1990. U.S. Geological Survey Water Resources Investigations Report 96-4280. 94 p.

Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp.

Dahm, C.N., M.A. Baker, D.I. Moore, and J.R. Thibault. 2003. Coupled biogeochemical and hydrological responses of streams and rivers to drought. *Freshwater Biology* 48:1219-1231.

Dale, V.H., S. Brown, R.A. Haeuber, N.T. Hobbs, N. Huntly, R.J. Naiman, W.E. Riebsame, M.G. Turner, and T.J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10:639-670.

Davies-Colley, R.J., J.W. Nagels, R.A. Smith, R.G. Young, and C.J. Phillips. 2004. Water quality impact of a dairy cow herd crossing a stream. *New Zealand Journal of Marine and Freshwater Research* 38:569-576.

Davis, M. B. 1981. Quaternary history and the stability of forest communities. In D.C. West, H. Shigart and D. Botkin, editors, Forest Succession. Springer Verlag.

DeAngelis, D., J. Kitchell, and W. Post. 1985. The influence of naticid predation on evolutionary strategy of bivalve prey: conclusions from a model. American Naturalist 126:817-842.

Dennis, N. 1989. The effects of fire on watersheds: a summary. Pages 92-95 *in* N.H. Berg (tech coord.), Proceedings of the symposium on fire and watershed management. USDA General Technical Report PSW-109.

Diamond, J.M., and V.B. Serveiss. 2001. Identifying sources of stress to native aquatic fauna using a watershed ecological risk assessment framework. *Environmental Science and Technology* 35:4711-4718.

Díaz, S., and M. Cabido. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution* 16:646-655.

Dillon, P. and L. Molot 1997. Effect of landscape form on export of DOC, iron and phosphorus from forested stream catchments. Water Resources Res. 33:25912600.

Dobkin, D. S., A. C. Rich, and W. H. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. *Conservation Biology* 12:209-221.

Dugan, J. T., T. McGrath, and R. B. Zelt. 1994. Water-level changes in the High Plains aquifer predevelopment to 1992. U.S. Geological Survey Water-Resources Investigations Report 94-4027. 34 pp.

Earl, S.R., and D.W. Blinn. 2003. Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. streams. *Freshwater Biology* 48:1015-1030.

Ehleringer, J.R., S. Schwinning, and R. Gebauer. 2000. Water use in arid land ecosystems. Pages 347-365 *in* M.C. Press, J.D. Scholes, and M.G. Barker (eds.), Physiological Plant Ecology. Proceedings of the 39th Symposium of the British Ecological Society, 7-9 September 1998, University of York. Blackwell Science, Boston, Massachusettes.

Ellison, L., and E.J. Woolfolk. 1937. Effects of drought on vegetation near Miles City, Montana. *Ecology* 18:329-336.

Engel, S. 1990. Ecosystem responses to growth and control of submersed macrophytes: a literature review. Tech. Bull. 170. Department of Natural Resources, Madison, WI, USA.

Erman, N.A., and D.C. Erman. 1995. Spring permanence, Trichoptera species richness, and the role of drought. *Journal of the Kansas Entomological Society* 68:50-64.

Eschner, T. R., R. F. Hadley, and K. D. Crowley. 1983. Hydrologic and morphologic changes in channels of the Platte River basin in Colorado, Wyoming, and Nebraska: a historical perspective. Geological Survey Professional Paper 1277-A, Washington DC.

Everitt, B.L. 1968. Use of the cottonwood in an investigation of the recent history of a floodplain. *American Journal of Science* 266:417-439.

Everitt, B.L. 1980. Ecology of saltcedar: a plea for research. *Environmental Geology* 3:77-84.

Fausch, K. D. and K. R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. Knopf, F. L. and Samson, F. B., Editors. Ecology and conservation of Great Plains vertebrates. New York: Springer; 1997; pp. 131-166.

Fausch, K. D. and R. G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. Copeia. 1991:659-674.

Feminella, J.W., and C.P. Hawkins. 1995. Interactions between stream herbivores and periphyton: a quantitative analysis of past experiments. *Journal of the North American Benthological Society* 14:465-509.

Fisher, S. G. 1983. Succession in streams. Pages 7-27 *in* J.R. Barnes and G.W. Minshall (eds.), *Stream Ecology: application and testing of a general ecological theory*. Plenum Press, New York.

Flug, M. 1998. Ecosystem Resource Considerations in Reservoir Management: Water Resources Update: Universities Council on Water Resources. 43-56.

Freckman, D.W., T.H. Blackburn, L. Brussaard, P. Hutchings, M.A. Palmer, and P.V.R. Snelgrove. 1997. Linking biodiversity and ecosystem functioning of soils and sediments. *Ambio* 26:556-562.

Friedman, J.M., G.T. Auble, P.B. Shafroth, M.L. Scott, M.F. Merligiano, M.D. Freehling, and E.R. Griffin. *In press.* Dominance of non-native riparian trees in western USA. *Biological Invasions* 00:00.

Friedman, J.M., and V.J. Lee. 2002. Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecology* 72:409-425.

Friedman, J.M., W.R. Osterkamp, and W.M. Lewis, Jr. 1996. Channel narrowing and vegetation development following a Great Plains flood. *Ecology* 77:2167-2181.

Frissell, C.A., W.J. Liss, C.E. Warren and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* 10:199-214.

Frost, T., D. Angelis, S. Bartell, D. Hall, and S. Hurlbert. 1988. Scale in the design and interpretation of aquatic communities research. In S. R. Carpenter, Complex interactions in lake communities. Springer Verlag.

Garrison, P. and R. Wakeman. 2000. Use of paleolimnolgy to document lake shoreland development effect on water quality. Journal of Paleolimnology 4:369-393.

Glass, G. 2001. Methylmercury bioaccumulation dependence on northern pike age and size in 20 Minnesota lakes. In R. Lipinsky, J. Hermens, K. Jones, and D. Muir, editors, Persistent, bioaccumulation and toxic chemicals. I. Fate and exposure. Washington, DC, USA. ACS Symposium Series 772:150-163.

Gordon, N.D., T.A. McHahon, B.L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley and Sons Inc., New York, New York.

Graf, W.L. 1978. Fluvial adjustments to the spread of tamarisk in the Colorado Plateau Region. *Geological Society of America Bulletin* 89:1491-1501.

Graf, W. L. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research* 35(4):1305-1311.

Grams, P.E. and J.C. Schmidt. 2002. Geomorphology of the Green River in the Eastern Uinta Mountains, Dinosaur National Monument, Colorado and Utah. Pages 81-111 *in* A.J. Miler and A. Gupta (eds.), *Varieties of Fluvial Form*, John Wiley & Sons, Oxford, England.

Gray, L. J. and W. K. Dodd. 1998. Structure and dynamics of aquatic communities. Knapp, A. K.; Briggs, J. M.; Hartnett, D. C., and Collins, S. L., editors. Grassland dynamics: long-term ecological research in tallgrass prairie. New York, NY: Oxford University Press. pp. 177-189.

Gray, L. J.; G. L. Macpherson, J. K. Koeliker, and W. K. Dodds. 1998. Hydrology and aquatic chemistry. Knapp, A. K.; Briggs, J. M.; Hartnett, D. C., and Collins, S. L., editors. Grassland dynamics: long-term ecological research in tallgrass prairie. New York, NY: Oxford University Press. pp. 159-176.

Gregory, H.E. 1916. The Navajo country. U.S. Geological Survey Water-Supply Paper 380. Washington Government Printing Office. Washington, D.C.

Gregory, S.V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. *BioScience* 41:540-550.

Groeneveld, D.P., and T.E. Griepentrog. 1985. Interdependence of groundwater, riparian vegetation, and streambank stability: a case study. USDA Forest Service General Technical Report RM 120:44-48.

Haefner, J.W., and A.M. Lindahl. 1988. The ecology of small pools in Capitol Reef National Park, Utah. Final Report for Phase I of: USDI/NPS Contract No. PX-1350-7-0259. 25 p.

Haefner, J.W., and A.M. Lindahl. 1991. The ecology of small pools in Capitol Reef National Park, UT: Phase II. Final Report for Phase II of USDI/NPS Contract No. PX-1350-8-0187. 172 p.

Hereford, R. 1984. Climate and ephemeral-stream processes: twentieth-century geomorphology and alluvial stratigraphy of the Little Colorado River, Arizona. *Geological Society of America Bulletin* 95:654-668.

Hereford, R. 1986. Modern alluvial history of the Paria River drainage basin, southern Utah. *Quaternary Research* 25:293-311.

Hereford, R. 1987. Late Holocene sediment storage in canyons of the Colorado Plateau. Geological Society of America Bulletin 99:261-271.

Hereford, R., and R.H. Webb. 1992. Historic variation of warm-season rainfall, southern Colorado Plateau, Southwestern USA. *Climatic Change* 22:239-256.

Hereford, R., R. H. Webb, and S. Graham. 2002. Precipitation history of the Colorado Plateau Region, 1900-2000. USGS Fact Sheet 119-02. U.S. Department of Interior, U.S. Geological Survey. 4 p.

Horton, J.L., T.E. Kolb, and S.C. Hart. 2001a. Physiological response to groundwater depth varies among species and with river flow regulation. *Ecological Applications* 11:1046-1059.

Horton, J.L., T.E. Kolb, and S.C. Hart. 2001b. Responses of riparian trees to interannual variation in ground water depth in a semi-arid river basin. *Plant, Cell and Environment* 24:293-304.

Huntzinger, T. L. 1996. Surface water: a critical Great Plains resource. In S. Johnson and A. Bouzaher, editors. Conservation of Great Plains ecosystems: current science, future options. Kluwer Academic Press, Dordrecht, The Netherlands.

Huston, M. 1979. A general hypothesis of species diversity. *American Naturalist* 113:81-101.

Hutchinson, G.E. 1961. The paradox of the plankton. *American Naturalist* 95:137-145.

Hutchinson, G.E. 1969. Eutrophication, past and present. In Eutrophication: Causes, consequences and corrections. National Academy of Sciences, Washington, DC, USA.

Hynes, H.B.N. 1975. The stream and its valley. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 19:1-15.

Innis, S.A., R.J. Naiman, and S.R. Elliott. 2000. Indicators and assessment methods for measuring the ecological integrity of semi-aquatic terrestrial environments. *Hydrobiologica* 422/423: 111-131.

Jenny, H. 1941. *Factors of soil formation: a system of quantitative pedology*. McGraw-Hill, New York, New York. 281 p.

Jenny, H. 1980. Th*e soil resource: origin and behavior.* Springer-Verlag, New York, New York. 377 p.

Johnson, L. 2001. Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. Ecological Applications 11:1789-1792.

Johnson, R.K., T. Wiederholm, and D.M. Rosenberg. 1993. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates.

Pages 40-158 *in* D.M. Rosenberg and V.H. Resh (eds.), *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman & Hall, New York, New York, USA.
Jordan, D. S. 1891. Report on explorations in Colorado and Utah during the summer 1889, with an account of fishes found in each of the river basins examined. U. S. Fisheries Commission Bulletin 9:1-40.
Kallemeyn, L. 1987. Correlation of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management 7:513-521.
Kaller, M.D., and K.J. Hartman. 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. *Hydrobiologia* 518:95-104.
Karasov, W. and M. Meyer. 2000. Testing the role of contaminants in depressing avian numbers. Revista Chilena de Hisstoria Natural. 73:461-471.
Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications* 1:66-84.
Karr, J.R., and E.W. Chu. 1999. *Restoring life in running waters*. Island Press, Washington, D.C. 206 p.
Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: a review. *Journal of Range Management* 37:430-438.
Kaylor, J.F., C.C. Starring, and C.P. Ditman. 1935. A survey of past plantings. Pages 39-47 *in* Possibilities of shelterbelt planting in the Plains region. U.S. Forest Service, Washington, D.C.
Kemp, W., M. Brooks, and R. Hood. 2001. Nutrient enrichment, habitat variability and trophic transfer efficiency in simple models of pelagic ecosystems. Marine Ecological Progress Series 223:73-87.
Klump, V., D. Edgington. P. Sager, and D. Robertson. 1996. Sediment phosphorus cycling and a phosphorus mass balance for the Green Bay (Lake Michigan) ecosystem. Can. J. Fish. Aquat. Sci. 54:10-27.
Knopf, F. L., and M. L. Scott. 1990. Altered flows and created landscapes in the Platte River headwaters, 1840-1990. Pages 47-70 in J. M. Sweeney, editor. Management of dynamic ecosystems. North Central Section of the Wildlife Society, West Lafayette, Ind.
Kondolf, G.M. 1994. Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning* 28:225-243.
Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. *Environmental Management* 21:533-551.
Kondolf, G.M., and R.R. Curry. 1986. Channel erosion along the Carmel River, Monterey County, California. *Earth Surface Processes and Landforms* 11:307-319.
Koplin, D. W., M. R. Burkart, and E. M. Thurman. 1994. Herbicides and nitrate in near-surface aquifers in the midcontinental United States, 1991. U.S. Geological Survey Water-Supply Paper 2413. 34 pp.
Kraft, C., P. Sullivan, A. Karatayev, L. Burlakova, J. Nekola, L Johnson and D. Padilla. 2002. Landscape patterns of an aquatic invader: assessing dispersal from spatial distributions. Ecological Applications 12:749-759.
Kromm, D.E., and S.E. White. 1992. Groundwater Exploitation in the High Plains. University Press of Kansas, Lawrence, Kansas, USA.
Landres, P., S. Meyer, and S. Mathews. 2001. The wilderness act and fish stocking: an overview of legislation, judicial interpretation and agency implementation. Ecosystems 4:287-295.
Lane, P.N., and G.J. Sheridan. 2002. Impact of an unsealed forest road stream crossing: water quality and sediment sources. *Hydrological Processes* 16:2599-2612.
Lavelle, P. 1997. Faunal activities and soil processes: adaptive strategies that determine ecosystem function. *Advances in Ecological Research* 27:93-132.
Leland, H.V., and S.V. Fend. 1998. Benthic invertebrate distributions in the San Joaquin River, California, in relation to physical and chemical factors. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1051-1067.
Leopold, L.B. 1994. *A View of the River*. Harvard Univeristy Press, Cambridge, Massachusetts.

Lenat, D.R. 1984. Agriculture and stream water quality: a biological evaluation of erosion control practices. *Environmental Management* 8:333-344.
Lodge, D. and J. Lorman. 1987. Reduction in submersed macrophyte biomass and species richness by the crayfish, Orconectes rusticus. Can J. Fish. Aquat. Sci. 44:591-597.
Lohr, S. C., and K. D. Fausch. 1997. Multiscale analysis of natural variability in stream fish assemblages of a western Great Plains watershed. *Copeia* 4:706-724.
Longo, P. J., and D. W. Yoskowitz. 2002. Water on the Great Plains: issues and policies. Texas Tech U., Lubbock. 200pp.
Ludwig, J.A., and D.J. Tongway. 1997. A landscape approach to rangeland ecology. Pages 1-12 *in* J. Ludwig, D. Tongway, D. Freudenberger, J. Noble, and K. Hodgkinson (eds.), *Landscape ecology, function and management: principles from Australia's rangelands*. CSIRO Publishing, Collingwood, VIC, Australia.
Lyons, J. 1996. Patterns in the species composition of fish assemblages among Wisconsin streams. *Environmental Biology of Fishes* 45:329-341.
Mackay, D. and L. Toose. 2003. Quantifying the fate of mercury in the Greal Lakes basin: Towards an ecosystem approach. Unpubl. Report. Canadian Env. Modelling Centre, Trent University, Peterborough, ON, CN.
Mahoney, J.B., and S.B. Rood. 1992. Response of hybrid poplar to water table decline in different substrates. *Forest Ecology and Management* 54:141-156.
Mahoney, J.M., and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. *Wetlands* 18:634-645.
Mantua, N.J., and S.R. Hare. 2002. The Pacific decadal oscillation. *Journal of Oceanography* 58: 35-42.
Maret, T.R. 1995. Water-quality assessment of the Upper Snake River Basin, Idaho and Western Wyoming-summary of aquatic biological data for surface water through 1992. U.S. Geological Survey Water-Resources Investigations Report 95-4006. 59 p.
Maret, T. R., C. T. Robinson, and G. W. Minshall. 1997. Fish assemblages and environmental correlates in least-disturbed streams of the Upper Snake River basin. *Transactions of the American Fisheries Society* 126:200-216.
Matta, M.B., C. Cairncross, and R.M. Kocan. 1998. Possible effects of polychlorinated biphenyls on sex determination in rainbow trout. *Environmental Toxicology and Chemistry* 17:26-29.
Matthews, W. J. and E. G. Zimmermann. 1990. Potential effects of global warming on native fishes of the southern Great Plains and the southwest. Fisheries. 15(6):26-32.
McBride, J.B., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. *American Midland Naturalist* 112:235-245.
McCafferty, W.P. 1998. *Aquatic entomology: the fishermen's and ecologists' illustrated guide to insects and their relatives.* Jones and Bartlett Publishers, Sudbury, Massachusetts, USA. 448 p.
McDowall, R.M. 2003. Impacts of introduced salmonids on native galaxiids in New Zealand upland streams: a new look at an old problem. *Transactions of the American Fisheries Society* 132:229-238.
McMahon, R. 2002. Evolutionary and physiological adaptation of aquatic invasive animals: r-selection vs resistance. Can. J. Fish. Aquat. Sci. 59:1235-1244.
Meador, M.R., L.R. Brown, and T. Short. 2003. Relations between introduced fish and environmental conditions at large geographic scales. *Ecological Indicators* 3:81-92.
Mead, J. R. 1896. A dying river. Transactions of the Kansas Academy of Sciences. 14:111-112.
Meadows, D.W. 2001. Effects of bison trampling on stream macroinvertebrate community structure on Antelope Island, Utah. *Journal of Freshwater Ecology* 16:83-92.
Meffe, G.K. 1984. Effects of abiotic disturbance on coexistence of predator and prey fish species. *Ecology* 65:1525-1534.
Meinzer, O.E. 1927. Plants as indicators of ground water. U.S. Geological Survey Water-Supply paper 577. 95 p.

Minckley, W.L., and J.E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species." *Science* 159:1424-1432.
Millard, S. and P. Sager. 1994. Comparison of phosphorus, light climate and photosynthesis between two culturally eutrophic bays: Green Bay, Lake Michigan and Bay of Quinte, Lake Ontario. Can. J. Fish, Aquat. Sci. 51:2579-2590.
Miller, M. E., D. Sharrow, and L. Cudlip. 2003. Northern Colorado Plateau Vital Signs Network and Prototype Cluster plan for natural resources monitoring: Phase II report. National Park Service, Northern Colorado Plateau Network, Moab, UT. 111 p + appendices.
Mitsch, W.J., and J.G. Gosselink. 1993. *Wetlands*. Second edition. Van Nostrand Reinhold, New York, New York.
Mitsch, W.J., and J.G. Gosselink. 2000. *Wetlands*. Third edition. John Wiley & Sons, New York, New York.
Montogomery, D.R. 1999. Process domains and the river continuum. *Journal of the American Water Resources Association* 35:397-410.
Montgomery, D.R. and J.M. Buffington. 1997. Channel reach morphology in mountain drainage basins. *Geological Society of America Bulletin*. 109: 596-611.
Montgomery, D.R. and L.H. MacDonald. 2002. Diagnostic approach to stream channel assessment and monitoring. *Journal of the American Water Resources Association* 38: 1-16.
Moody, J.A. and D.A. Martin. 2001. Hydrologic and sedimentologic response of two burned watershed in Colorado. US Geological Survey Water-Resources Investigation Report. WRIR 01-4122.
Munn, M.D., R.W. Black, and S.J. Gruber. 2002. Response of benthic algae to environmental gradients in an agriculturally dominated landscape. *Journal of the North American Benthological Society* 21:221-237.
Nadler, C. T., and S. A. Schumm. 1981. Metamorphosis of South Platte and Arkansas Rivers, eastern Colorado. Physiological Geography. 2:95-115.
Naiman, R.J., H. Decamps, J. Pastor, and C.A. Johnston. 1988. The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* 7:289-306.
Naiman, R.J., D.G. Lonzarich, T.J. Beechie, and S.C. Ralph. 1992. General principles of classification and the assessment of conservation potential in rivers. Pages 93-123 *in* P.J. Boon, P. Calow, and G.E. Petts (eds.), *River Conservation and Management*. John Wiley and Sons, New York, New York.
Nilsson, C., A. Ekblad, M. Gardfjell, and B. Carlberg. 1991. Long-term effects of river regulation on river margin vegetation. *Journal of Applied Ecology* 28:963-987.
Noon, B.R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 *in* D.E. Busch and J.C. Trexler (eds.). *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives.* Island Press, Washington, D.C.
Norman, J. and P. Sager 1978. Modeling phosphorus transfer rates in lake water. J. Theoretical Biology 71:381-385.
Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics* 4:25-51.
Olden, J.D. and N.L. Poff. 2003. Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. *River Research and Applications* 19: 101-121.
Ohmart, R.D., and B.W. Anderson. 1982. North American desert riparian ecosystems. Pages 433-479 *in* G.L. Bender (ed.), *Reference Handbook on the Deserts of North America*, Greenwood Press, Westport, CN.
Pallardy, S.G., J.S. Pereia, and W.C. Parker. 1991. Measuring the state of water in tree systems. Pages 28-75 *in* J.P. Lassie, and T.M. Hinckley (eds.), *Techniques and Approaches in Forest Tree Ecophysiology.* CRC Press Inc., Boca Raton, Florida.
Petts, G.E. 1987. Time-scales for ecological change in regulated rivers. Pages 257-266, *in* J.F. Crain and J.B. Kemper (eds.), *Regulated Streams*, Plenum Press, New York, New York, USA.

Platts, W.S. 1991. Livestock grazing. Pages 389-423 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland management on Salmonid Fishes and Their Habitats,* American Fisheries Society Special Publication 19, Bethesda, MD, USA.

Poff, N.L., J.D. Allen, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. *BioScience* 47:769-784.

Poff, N.L. and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patters. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1805-1817.

Power, M. 1990. Effects of fish in river food webs. *Science* 250:811-814.

Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner, and I.R. Wais De Badgen. 1988. Biotic and abiotic controls in river and stream communities. *Journal of the North American Benthological Society* 7:456-479.

Rahel, F. 2002. Homogenization of freshwater faunas. Rev. Ecol. And Systematics 33:291-315.

Reed–Andersen, T., E. Bennett, B. Jorgenson, G. Lauster, D. Lewis, D. Nowacek, J. Rieva, B. Sanderson, and R. Stedman. 2000a. Distribution of recreational boating across lakes: Do landscape variables affect recreational use? Freshwater Biology.

Reed-Andersen, T., S. Carpenter, D. Padilla, and R. Lathrop. 2000b. Predicted impact of zebra mussel (Dreissena polymorpha) invasion on water clarity in Lake Mendota. Can. J. Fish. Aquat. Sci. 57:1617-1626.

Reice, S.R. 1985. Experimental disturbance and the maintenance of species diversity in a stream community. *Oecologia* 67:90-97.

Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R.C. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7:433-455.

Reynolds, H.L., A. Packer, J.D. Bever, and K. Clay. 2003. Grassroots ecology: Plant-microbe-soil interactions as drivers of plant community structure and dynamics. *Ecology* 84:2281-2291.

Richter, B.D., J.V. Baumgartner, J. Powell and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10: 1163-1174.

Richman S. and S. Dodson. 1983. The effect of food quality on feeding and respiration by Daphnia and Diaptomous. Limnol. and Oceanog. 28:948-956.

Robinson, T.W. 1958. Phreatophytes. Geological Survey Water-Supply Paper 1423. 84 p.

Rood, S. B. and J. M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. *Environmental Management.* 14:451-464.

Rood, S.B., J.B. Mahoney, D.E. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. *Canadian Journal of Botany* 73:1250-1260.

Rood, S.B., S. Patino, K. Coombs, and M.T. Tyree. 2000. Branch sacrifice: cavitation-associated drought adaptation of riparian cottonwoods. *Trees* 14:248-257.

Rosgen, D.L. 1996. *Applied river morphology.* Wildland Hydrology, Pagosa Springs, Colorado.

Rosenberg, D.M., and Resh, V.H. 1993. Introduction to freshwater biomonitoring and benthic macroinvertebrates. Pages 1-9 *in* D.M. Rosenberg and V.H. Resh (eds.), *Freshwater Biomonitoring and Benthic Macroinvertebrates*, Chapman and Hall, New York, New York.

Rothrock, J.A., P.K. Barten, and G.L. Ingman. 1998. Land use and aquatic biointegrity in the Blackfoot River watershed, Montana. *Journal of the American Water Resources Association* 34:565-581.

Sager, P. 2004. Inland reservoirs ecosystem conceptual model: *Conceptual ecosystem models for Long-Term Ecological Monitoring in the Great Reservoirs Network*. Great Reservoirs Network Technical Report GLKN/2004/04: 53-71.

Sager, P. and S. Richman. 1991. Functional interaction of phytoplankton and zooplankton along the trophic gradient in Green Bay, Lake Michigan. Can. J. Fish. Aquat. Sci. 48:116-122.

Sager, P., H. Harris, and P. Robinson. 1996. Remedial measures to restore submersed aquatic vegetation in lower Green Bay. Final Report to Wisconsin Department of Natural Resources.

Sala, O.E., and W.K. Lauenroth. 1982. Small rainfall events: An ecological role in semiarid regions. *Oecologia* 53:301-304.
Sample, L.J., J. Steichen, and J.R. Kelley, Jr. 1998. Water quality impacts from low water fords on military training lands. *Journal of the American Water Resources Association* 34:939-949.
Sappington, J.M. 1998. Recreational disturbance of a desert stream fish community: detecting ecological effects of environmental impact. Master's thesis, Department of Biological Sciences, University of Nevada, Las Vegas.
Schade, J.D., E. Marti, J.R. Welter, S.G. Fisher, and N.B. Grimm. 2002. Sources of nitrogen to the riparian zone of a desert stream: implications for riparian vegetation and nitrogen retention. *Ecosystems* 5:68-79.
Scheuhammer, A. and D. Bond. 1991. Factors affecting the determination of total mercury in biological samples by continuous flow cold vapor atomic absorption spectrophotometry. Biol. Trace Element Research 31:157-169.
Schindler, D. 1999. From acid rain to toxic snow. Ambio 28:350-355.
Schindler, D.E., S. Geib, and M. Williams. 2000. Patterns of fish growth along a residential development gradient in north temperate lakes. Ecosystems 3:229-237.
Schultz, T. T., and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. *Journal of Range Management* 43:295-299.
Schulz, R., and M. Liess. 2001a. Acute and chronic effects of particle-associated fenvalerate on stream macroinvertebrates: a runoff simulation study using outdoor microcosms. *Archives of Environmental Contamination and Toxicology* 40:481-488.
Schulz, R., and M. Liess. 2001b. Toxicity of aqueous-phase and suspended particle-associated fenvalerate: chronic effects following pulse-dosed exposure of Limnephilus lunatus (Trichoptera). *Environmental Toxicology and Chemistry* 20:185-191.
Schumm, S.A. 1981. Evolution and response of the fluvial system, sedimentological implications. *The Society of Economic Palentologists and Mineralogists* 31:19-29.
Schumm, S.A. and H.A. Kahn. 1972. Experimental study of channel patterns. *Geological Society of America Bulletin* 83:1755-1770.
Schumm, S.A., and R.W. Lichty. 1963. Channel widening and floodplain construction along Cimarron River in southwestern Kansas. U.S. Geological Survey Professional Paper 352-D.
Schumm, S.A., and R.W. Lichty. 1965. Time, space, and causality in geomorphology. *American Journal of Science* 263:110-119.
Scott, M.L. and J.H. Haskins. 1987. The effects of grazing by Chrysomelid beetles on two wetland herbaceous species. *Bulletin of the Torrey Botanical Club*. **114**: 13-17.
Scott, M.L., G.T. Auble, and J.M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. *Ecological Applications* 7:677-690.
Scott M. L., J. M. Friedman and G. T. Auble. 1996. Fluvial Process and the Establishment of Bottomland Trees. Geomorphology 14:327-339.
Scott, M.L., P.B. Shafroth and G.T. Auble. 1999. Response of riparian cottonwoods to alluvial water table declines. *Environmental Management* 23:347-358.
Scott, M.L., G.C. Lines, and G.T. Auble. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. *Journal of Arid Environments* 44:399-414.
Scott, M.L., S.K. Skagen, and M.F. Merligiano. 2003. Relating breeding bird diversity to geomorphic change and grazing in riparian forests. *Conservation Biology* **17**:284-296.
Scott, M.C., E. Reynolds, A. Brasher, A. Caires, and M.E. Miller. June, 2005. The Structure and functioning of riparian and aquatic ecosystems of the Colorado Plateau – Conceptual models to inform monitoring. U.S. Geological Survey – U.S. National Park Service Interagency Report (Draft), 91 p.
Scrimgeour, G.J., and S. Kendall. 2003. Effects of livestock grazing on benthic invertebrates from a native grassland ecosystem. *Freshwater Biology* 48:347-362.
Scrimgeour, G., W. Tonn, C. Paszkowski, and C. Cameron. 2001. Benthic macroinvertebrate biomass and wildfires: Evidence for enrichment of boreal subarctic lakes. Freshwater Biology 46:367-378.

Seastedt, T.R. 2001. Soils. Pages 157-173 *in* W.D. Bowman and T.R. Seastedt (eds.), *Structure and function of an alpine ecosystem: Niwot Ridge, Colorado.* Oxford University Press, New York, New York.
Segelquist, C.A., M.L. Scott, and G.T. Auble. 1993. Establishment of Populus deltoides under simulated alluvial groundwater declines. *American Midland Naturalist* 130:274-285.
Shafroth, P.B., G.T. Auble, and M.L. Scott. 1995. Germination and first-year establishment of a native riparian tree and an invasive exotic. *Conservation Biology.* 9:1169-1175.
Shafroth, P.B., J.C. Stromberg and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. *Western North American Naturalist* 60:66-76.
Shannon, J.P., D.W. Blinn, P.L. Benenati, and K.P. Wilson. 1996. Organic drift in a regulated desert river. *Canadian Journal of Fisheries and Aquatic Sciences* 53:1360-1369.
Shannon, J.P., D.W. Blinn, and L.E. Stevens. 1994. Trophic interactions and benthic animal community structure in the Colorado River, Arizona, U.S.A. *Freshwater Biology* 31:213-220.
Sibley, P.K., K.N. Kaushik, and D.P. Kreutzweiser. 1991. Impact of a pulse application of permethrin on the macroinvertebrate community of a headwater stream. *Environmental Pollution* 70:35-55.
Skjelkvale, B., J. Stoddard, and T. Anderson. 2001. Trends in surface water acidification in Europe and North America (1989-1998). Water, Air and Soil Pollution 130:787-792.
Skujins, J. 1984. Microbial ecology of desert soils. *Advances in Microbial Ecology* 7:49-91.
Smith, M., P. Keevin, P. Mettler-McClure, and R. Barkau. 1998. Effect of the flood of 1993 on Boltonia ducurrens, a rare floodplain plant. *Regulated Rivers-Research and Management.*
Smith, S.D., B.A. Wellington, J.L. Nachlinger, and C.A. Fox. 1991. Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. *Ecological Applications* 1:89-97.
Smith, S.E., and D.J. Read. 1997. Mycorrhizal symbiosis. Second edition. Academic Press, San Diego, California. 604 p.
Smith, T., H. H. Shugart, and F.I. Woodward (eds.). 1997. *Plant functional types*. Cambridge University Press, Cambridge. 369 p.
Snyder, K.A., and D.G. Williams. 2000. Water sources used by riparian trees varies among stream types on the San Pedro River, Arizona. *Agricultural and Forest Meteorology* 105:227-240.
Stanford, J.A., Ward J.V., Liss W.J., Frissell C.A., Williams R.N., Lichatowich J.A., and Coutant, C.C. 1996. A general protocol for restoration of regulated rivers. *Regulated Rivers: Research and Management* 12:391-413.
Steinman, A.D. 1996. Effects of grazers on freshwater benthic algae. Pages 341-373 *in* R.J. Stevenson, M.L. Bothwell, and R.L. Lowe (eds.), *Algal ecology: freshwater benthic ecosystems*. Academic Press, San Diego, California.
Stevens, L.E., B.T. Brown, J.M. Simpson, and R.R. Johnson. 1977. The importance of riparian habitat to migrating birds. Pages 156-164 *in* R.R. Johnson and D.A. Jones (tech. coord.), Importance, preservation, and management of riparian habitat: a symposium. U.S. Forest Service General Technical Report RM-43.
Stevens, L.E., J.P. Shannon, and D.W. Blinn. 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: Dam, tributary and geomorphological influences. *Regulated Rivers: Research & Management* 13:129-149.
Stoddard, J., C. Driscoll, J. Kahl, and J. Kellogg. 1998. A regional analysis of lake acidification trends for the northeastern U.S., 1982-1994. Env. Monitoring and Assessment. 51:399-413.
Stromberg, J.C. 1993. Riparian mesquite forests: a review of their ecology, threats, and recovery potential. *Journal of the Arizona-Nevada Academy of Sciences* 27:111-124.
Stromberg, J.C., J. Fry, and D.T. Patten. 1997. Marsh development after large floods in an alluvial, arid-land river. *Wetlands* 17:292-300.
Stromberg, J.C., and D.T. Patten. 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California. *Rivers* 2:1-11.
Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. *Ecological Applications* 6:113-131.

Szaro, R. C., and C. P. Pase. 1983. Short-term changes in a cottonwood-ash-willow association on a grazed and an ungrazed portion of Little Ash Creek in central Arizona. *Journal of Range Management* 36:382-384.
Taylor, D. M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. *Journal of Range Management* 39:254-258.
Thiere, G., and R. Schulz. 2004. Runoff-related agricultural impact in relation to macroinvertebrate communities of the Lourens River, South Africa. *Water Research* 38:3092-3102.
Tiedemann, A.R., C.E. Conrad, J.H. Dieterich, J.W. Hornbeck, W.F. Megahan, L.A. Viereck, and D.D. Wade. 1979. Effects of fire on water: a state-of-knowledge review. USDA General Technical Report WO-10.
Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. *Science* 277:1300-1302.
Townsend, C.R., C.J. Arbuckle, T.A. Crowl, and M.R. Scarsbrook. 1997. The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierarchically scaled approach. *Freshwater Biology* 37:177-191.
Trappe, J.M. 1981. Mycorrhizae and productivity of arid and semiarid rangelands. Pages 581-589 *in* J.T. Manassah and E.J. Briskey (eds.), *Advances in food-producing systems for arid and semiarid lands.* Academic Press, New York, New York.
Trimble, S.W., and A.C. Mendel. 1995. The cow as a geomorphic agent- A critical review. *Geomorphology* 13:233-253.
Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.
Tyree, M.T., K.J. Kolb, S.B. Rood, and S. Patiño. 1994. Vulnerability to drought-induced cavitation of riparian cottonwoods in Alberta: a possible factor in the decline of the ecosystem? *Tree Physiology* 14:455-466.
Vahter, M., M. Berglund, and A. Akesson. 2002. Metals and women's health. Env, Research 88:145-155.
Vannote, R.I., G.W. Minshall, K.W. Cummings, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:120-137.
Vanoni, V.A. (ed.). 1975. Sedimentation Engineering. American Society of Civil Engineers, New York. 620-625
Veenhuis, J.E. 2002. Effects of wildfire on the hydrology of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico. U.S. Geological Survey Water-Resources Investigations Report 02-4152. 39 p.
Vinson, M.R. 2001. Long-term dynamics of an invertebrate assemblage downstream from a large dam. *Ecological Applications* 11:711-730.
Vitousek, P.M. 1994. Factors controlling ecosystem structure and function. Pages 87-97 *in* R.G. Amundson, J.W. Harden, and M.J. Singer (eds.), *Factors of soil formation: a fiftieth anniversary retrospective.* SSSA special publication no. 33. Soil Science Society of America, Madison, Wisconsin.
Waite, I.R., and K.D. Carpenter. 2000. Associations among fish assemblage structure and environmental variables in Willamette Basin Streams, Oregon. *Transactions of the American Fisheries Society* 129:754-770.
Walker, B.H. 1997. Functional types in non-equilibrium systems. Pages 91-103 *in* T.M. Smith, H.H. Shugart, and F.I. Woodward (eds.), *Plant functional types: their relevance to ecosystem properties and global change.* Cambridge University Press, Cambridge.
Walker, B., A. Kinzig, and J. Langridge. 1999. Plant attribute diversity, reslience, and ecosystem function: The nature and significance of dominant and minor species. *Ecosystems* 2:95-113.
Walker, L.R., and F.S. Chapin, III. 1987. Interactions among processes controlling successional change. *Oikos* 50:131-135.

Ward, J.V., and J.A. Stanford. 1983. The serial discontinuity concept of running waters. Pages 29-42 *in* T.D. Fontaine and S.M. Bartell (eds.), *Dynamics of lotic ecosystems,* Ann Arbor Science, Ann Arbor, Michigan.

Wardle, D.A. 2002. *Communities and ecosystems: Linking the aboveground and belowground components.* Princeton University Press, Princeton, New Jersey. 392 p.

WASAL. 2003. Waters of Wisconsin. The Future of Our Aquatic Ecosystems and Resources. Madison, WI. Wisconsin Academy of Science, Arts and Letters.

Watras, C., K. Morrison, R. Hudson, T. Frost, and T. Kratz. 2000. Decreasing mercury in northern Wisconsin: temporal patterns in bulk precipitation and precipitation-dominated lakes. Env. Sci and Tech. 34:4051-4057.

Wedel, W. R. 1986. Central Plains prehistory: Holocene environments and culture change in the Republican River basin. University of Nebraska Press, Lincoln.

Weigel, B.M., J. Lyons, L.K. Paine, S.I. Dodson, and D.J. Undersander. 2000. Using stream macroinvertebrates to compare riparian land use practices on cattle farms in Southwestern Wisconsin. *Journal of Freshwater Ecology* 15:93-106.

Weisberg, S.B., A.J. Janicki, J. Gerritesen, and H.T. Wilson. 1990. Enhancement of benthic macroinvertebrates by minimum flow from a hydroelectric dam. *Regulated Rivers: Research & Management* 5:265-277.

Wetzel, R. G. 1983. Limnology, Second Edition. Saunders, Philadelphia. 767 pp.

Wetzel, R.G. 1979. The role of the littoral zone and detritus on lake metabolism. Arch. Hydrobiol. Beih. 13:145-161.

Whisenant, S.G. 1999. *Repairing damaged wildlands: A process-oriented, landscape-scale approach.* Cambridge University Press, Cambridge. 312 p.

Whitford, W.G. 1996. The importance of the biodiversity of soil biota in arid ecosystems. *Biodiversity and Conservation* 5:185-195.

Whitford, W.G. 2002. *Ecology of desert systems.* Academic Press, San Diego, California. 343 p.

Winter, T.C. 1999. Relations of streams, reservoirs, and wetlands to groundwater flow systems. *Hydrogeology Journal* 7:28-45.

Woessner, W.W. 2000. Stream and fluvial plain ground water interactions: rescaling hydrogeological thought. *Ground Water* 38:423-429.

Wood, P.J., and G.E. Petts. 1994. Low flows and recovery of macroinvertebrates in a small regulated chalk stream. *Regulated Rivers: Research & Management* 9:303-316.

Woodford, J. and M. Meyer. 2003. Impacts of lakeshore development on green frog abundance. Biological Conservation 110:73-78.

Woodward, D.F., W.G. Brumbaugh, A.J. DeLonay, E.E. Little, and C.E. Smith. 1994. Effects on rainbow trout fry of a metals-contaminated diet of benthic invertebrates from the Clark Fork River, Montana. *Transactions of the American Fisheries Society* 123:51-62.

Wynn, K.H., N.J. Bauch, and N.E. Driver. 2001. Gore Creek Watershed, Colorado-Assessment of historical and current water quantity, water quality, and aquatic ecology, 1968-98. U.S. Geological Survey Water-Resources Investigations Report 99-4270.

Zimmer, R.R., and T.E. Lisle. 1998. Hydrology. Pages 43-68, *in* R.J. Naiman and R.E. Bilby (eds.), River Ecology and Management, Springer-Verlag, New York, New York, USA.

Zimmerman, R.C. 1969. Plant ecology of an arid basin, Tres Alamos-Reding area, southeastern Arizona. United States Geological Survey Professional Paper 485-D.

CITED IN TEXT BUT NO REFERECNCE YET

Anderson and Cooper 2000
Archer and Smeins 1991
Auble et al. 1997
Backer et al. 1986
Bardsett and Wardle 2003
Behmer and Hawkins 1986
Bethlenfalvay and Dakessian 1984

Bradley and Smith 1986
Briske 1991
Briske and Richards 1995
Brode and Bury 1984
Busch et al. 1995
Cooke and Reeves 1972
Davis et al. 2000
Dunne 1978
Falck et al. 2003
Fleishman et al. 1999
Haden et al. 2003
Harig and Bain 1998
Knutson et al 1996
Lugo et al. 1990
Magnuson et al 2000
Magnuson in press
Matthews 1988
Naiman et al. 1993
Naiman and Rogers 1997
Pollock et al. 1998
Richter and Richter 2000
Stromberg et al. 1991
Thorp and Covich 1991
Thurow 1991
Vieira 2004
Vieira et al. 2004
Wallace and O'Hop 1985
Welcomme 1985