APPENDIX I: LEGISLATIVE MANDATES GUIDING THE GREATER YELLOWSTONE NETWORK

The legislative mandates and directives guiding the I&M Program, and the GRYN in particular, can be divided into several sections: 1) legislative acts; 2) Executive Orders; 3) NPS management policies and directives; and 4) enabling legislation specific to the network parks.

General legislative acts guiding the I&M Program include the National Park Service Organic Act of 1916 and the National Parks Omnibus Management Act of 1998, which led to the creation of the Natural Resource Challenge in 2000. Many specific legislative acts, such as the Geothermal Steam Act, guide the protection and/or monitoring of certain natural resources within park boundaries.

The directives system, including Executive Orders, (issued by the President of the United States) and Director's Orders (issued by Associate Directors of the National Park Service), is designed to provide NPS management and staff with clear and continuously updated information on NPS policy and required and/or recommended actions.

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

The Government Performance and Results Act (GPRA) is particularly important because of its central role in agency operations and its relationship to the monitoring program. GRPA requires that the NPS set goals for strategic and annual performance plans and report results. In 2001 the National Park Service developed a national strategic plan identifying key goals to be met.

The following legislation, policy and executive guidance all have an important and direct bearing on the development and implementation of natural resource monitoring in the national parks. Relevant federal legal mandates and specific natural resource GPRA goals relevant to GRYN parks are summarized in the following table.

Legislative Acts	Summary content
National Park Service Organic Act (16 U.S.C. § 1-4 [2000])	This Act created the National Park Service within the U.S. Department of the Interior and gave it jurisdiction over parks, monuments, and reservations acquired by the U.S. government for the purpose of wilderness conservation and public enjoyment. *"The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife 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"* (16 U.S.C. § 1 [2000]).
National Park System General Authorities Act of 1970 (16 U.S.C. § 1a-1 – 1a-7 [2000])	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…"* (16 U.S.C. § 1a-1 [2000]).

Legislative Acts	Summary content
National Parks Omnibus Management Act of 1998 (16 U.S.C. § 5931-5937 [2000]) FY2000 Interior Appropriations Bill	The Omnibus Act is the precursor to the Natural Resource Challenge, the prime directive guiding the NPS I&M Program. The goal of the act is to use state-of-the-art methods of scientific research to improve management decisions within the NPS. This act also made the superintendents of each park unit responsible for the care and condition of the resources within the parks. *"The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of the National Park System"* (16 U.S.C. § 5934 [2000]). In addition, the act created the Natural Resources Challenge, which provides the funding for the I&M Program and doubles the natural resources staff within the NPS. *"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data"* (FY2000 Interior Appropriations Bill).
Geothermal Steam Act of 1970 (30 U.S.C. § 1001-1028 [2000]) (Note: Geothermal Steam Act Amendments of 1988 enacted §§ 1026-1027)	This Act is the only one that specifically mandates monitoring within the GRYN. The Act requires the Secretary of the Interior to maintain a list of significant thermal features within the NPS and to undertake a system of monitoring and researching such features. The Act directs the Secretary to maintain a list of significant thermal features within National Park System units, including 16 specified units. The Secretary must maintain a monitoring program for these features and establish a research program on geothermal resources within units with these features. If the Secretary determines that exploration, development or utilization of lands subject to a lease application is reasonably likely to have a significant adverse effect on a significant thermal feature within a National Park System unit, the Secretary is prohibited from issuing the lease. If these activities are reasonably likely to have an adverse effect, the Secretary must include specified stipulations in leases or drilling permits to protect the significant thermal features (30 U.S.C. § 1026 [2000]).
American Indian Religious Freedom Act (42 U.S.C. § 1996 [2000])	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"* (42 U.S.C. § 1996 [2000]).
Archaeological Resources Protection Act of 1979 (16 U.S.C. § 470aa-470mm [2000])	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..."* (16 U.S.C. § 470aa [2000]).
Clean Air Act (42 U.S.C. § 7401-7431 [2000])	This Act promotes the protection of airsheds against sources of pollution through regional air pollution prevention programs. *"The purposes of this title are: (1) to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population; (2) to initiate and accelerate a national research and development program to achieve the prevention and control of air pollution; (3) to provide technical and financial assistance to State and local governments in connection with the development and execution of their air pollution prevention and control programs; and (4) to encourage and assist the development and operation of regional air pollution prevention and control programs. A primary goal of this Act is to encourage or otherwise promote reasonable Federal, State, and local governmental actions, consistent with the provisions of this Act, for pollution prevention"* (42 U.S.C. § 7401 [2000]).

Legislative Acts	Summary content
Federal Water Pollution Control Act (Clean Water Act) of 1972 (33 U.S.C. § 1251-1274 [2000])	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..."* (33 U.S.C. § 1251 [2000]).
Endangered Species Act of 1973 (16 U.S.C. §§ 1531-1544 [2000])	It provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and conserves the ecosystems on which such species depend. The Act defines an endangered species as any species that is in danger of becoming extinct throughout all or a significant portion of its range. A threatened species is one that is likely to become endangered in the foreseeable future. The Act makes it illegal for any individual to kill, collect, remove, harass, import, or export an endangered or threatened species (16 U.S.C. §§ 1531-1533, 1538 [2000]).
Federal Caves Resources Protection Act of 1988 (16 U.S.C. §§ 4301-4310 [2000])	This Act notes the value of protecting caves found on Federal lands from the dangers of increased recreational use and urban sprawl. *"The purposes of this Act are-- (1) to secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and (2) to foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes"* (16 U.S.C. § 4301 [2000]).
Fish and Wildlife Coordination Act (16 U.S.C. §§ 661-667d [2000])	This Act proposes *"to assure that fish and wildlife resources receive equal consideration with other values during the planning of water resources development projects…"* (16 U.S.C. § 661 [2000]). 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.
Government Performance and Results Act (GPRA) of 1993 (31 U.S.C. §§ 1115-1119, 9703 and amendments of §§ 1101, 1105 and sections of Title 5 & 39 [2000]; Pub. L 103-62, 197 Stat. 285)	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 (31 U.S.C. § 1115 [2000]).
Migratory Bird Treaty Act of 1974 (16 U.S.C. §§ 703-712 [2000])	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. *"Unless and except as pemitted by regulations... it shall be unlawful at any time, by any means or in any manner, to persue, hunt, take, capture, kill, attempt to take, capture, or kill, possess, offer for sale, sell, offer to barter, barter, offer to purchase, purchase, deliver for shipment, ship, export, import, cause to be shipped, exported, or imported, deliver for transportation, transport or cause to be tramsported, carry or cause to be carried, or revieve for shipment, transportation, carriage, or export, any migratory bird, any part, nest, or eggs of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof... "* (16 U.S.C. § 703 [2000]).
Mining in the Parks Act (16 U.S.C. §§ 1901-1912 [2000])	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"* (16 U.S.C. § 1901 [2000]).

Legislative Acts	Summary content
National Environmental Policy Act of 1969 (42 U.S.C. §§ 4321-4370 [2000])	This Act creates regulations to prevent damage by humans on natural environments and ensure a healthy environment for generations to come. *"In order to carry out the policy set forth in this Act, it is the continuing responsibility of the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may: 1) fulfill the responsibilities of each generation as trustee of the environment for succeeding generations; 2) assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings; 3) attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences; 4) preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice; 5) achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and 6) enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources"* (42 U.S.C. § 4331 (b) [2000]).
National Historic Preservation Act (16 U.S.C. §§ 470, 470-1, 470a-x [2000])	This Act calls for the preservation of historical sites and structures in order to ensure the spirit of the Nation. *"The preservation of this irreplaceable heritage is in the public interest so that its vital legacy of cultural, educational, aesthetic, inspirational, economic, and energy benefits will be maintained and enriched for future generations of Americans..."* (16 U.S.C. § 470 (b) (4) [2000]).
Taylor Grazing Act (43 U.S.C. §§ 315-315r [2000])	This Act manages grazing on public lands through the use of districts and permitting schedules. The Secretary of the Interior must: provide for the protection, administration, regulation and improvement of 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 (43 U.S.C. § 315a [2000]).

NPS Management Policies – 2001 NPS Directives Systems	Summary content
NPS Directors	Relevant Directors Orders (Website: NPS Office of Policy, Director's Orders and Related Documents, http://data2.itc.nps.gov/npspolicy/DOrders.cfm): DO- 2-1 Resource Stewardship Planning DO- 12 Environmental Impact Assessment DO- 14 Resource Damage Assessment & Restoration DO- 24 Museum Collections Management DO- 41 Wilderness Preservation & Management DO- 47 Sound Preservation & Noise Management DO- 77 Natural Resource Protection
NPS Handbook and Reference Manuals	Website: NPS Office of Policy, Director's Orders and Related Documents, http://data2.itc.nps.gov/npspolicy/DOrders.cfm NPS – 75 Natural Resources Inventory & Monitoring (under Director's Order 77) (http://www.nature.nps.gov/nps75/nps75.pdf) Reference Manual #77 (formerly NPS – 77) - Natural Resources Management Guidelines (under Director's Order 77) (http://www.nature.nps.gov/rm77/) NPS Guide to Federal Advisory Committee Act (under Director's Order 91) (http://www.nps.gov/policy/DOrders/facaguide.html)

Executive Orders	Summary content
E.O. 13112 — Invasive Species (Exec. Or. 13112, 3 C.F.R. 159 [1999])	This Order states that Federal agencies *"whose actions may affect the status of invasive species shall, to the extent practicable and permitted by law, identify such actions; subject to the availability of appropriations, and within Administration budgetary limits, use relevant programs and authorities to: (i) prevent the introduction of invasive species; (ii) detect and respond rapidly to and control populations of such species in a cost-effective and environmentally sound manner; (iii) monitor invasive species populations accurately and reliably; (iv) provide for restoration of native species and habitat conditions in ecosystems that have been invaded; (v) conduct research on invasive species and develop technologies to prevent introduction and provide for environmentally sound control of invasive species; and (vi) promote public education on invasive species and the means to address them…"* (Exec. Or. 13112, 3 C.F.R. § 2 [1999]),
E.O. 11988— Floodplain Management (Exec. Or. 11988, 3 C.F.R. 117 [1977])	This Order mandates the management of floodplains such that their natural flood cycles are maintained, while decreasing the impacts of floods on human safety. *"Each agency shall provide leadership and shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities for (1) acquiring, managing, and disposing of Federal lands, and facilities; (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities"* (Exec. Or. 3 C.F.R. § 1 [1977]).
E.O. 11990— Protection of Wetlands (Exec. Or. 11990, 3 C.F.R. 121 [1977])	This Order provides for the preservation of wetlands in their natural state without modifications by humans. *"Each agency shall provide leadership and shall take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities for (1) acquiring, managing, and disposing of Federal lands and facilities; and (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities"* (Exec. Or. 11990, 3 C.F.R. § 1 [1977]).
E.O. 13186— Protection of Migratory Birds (Exec. Or. 11990, 3 C.F.R. 719 [2001])	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"* (Exec. Or. 13186, 3 C.F.R. § 3(e)(4) [2001]).

Enabling Legislation	Summary content
BICA Enabling Legislation (16 U.S.C. §§ 460t, 460t-1-4 [2000])	Bighorn Canyon National Recreation Area was established on October 15, 1966, following the construction of the Yellowtail Dam along the Bighorn River. The purpose of BICA, as stated in its enabling legislation, is to *"provide for public outdoor recreation use and enjoyment of Yellowtail Reservoir and lands adjacent thereto and for the preservation of the scenic, scientific and historic features contributing to public enjoyment of such lands and waters"* (16 U.S.C. § 460t (a) [2000]).
GRTE Enabling Legislation (16 U.S.C. §§ 406d-1-406d-5, 431a, 451a, 482m, 673b, 673c [2000])	Grand Teton National Park was established on September 14, 1950. Within its enabling legislation, GRTE is specifically mandated to conserve elk within park boundaries: *"...a program to insure the permanent conservation of elk within the Grand Teton National Park established by this Act. Such program shall include the controlled reduction of elk in such park by hunters licensed by the State of Wyoming and deputized as rangers by the Secretary of the Interior, when it is found necessary for the purposes of proper management and protection of the elk"* (16 U.S.C. § 673c (a) [2000]).
YELL Enabling Legislation (16 U.S.C. §§ 21-40 [2000])	Yellowstone National Park was established on March 1, 1872. Within its enabling legislation, YELL is mandated to preserve *"from injury or spoilation...all timber, mineral deposits, natural curiosities, or wonders within said park, and their retention in their natural conditions"* (16 U.S.C. § 22 [2000]).

Government Performance and Results Act		Park Specific Natural Resource GPRA Goals
NPS GPRA GOALS	Bighorn Canyon National Recreation Area	Exotic Vegetation Species: by September 30, 2005, exotic vegetation on 70.25 (2.81%) acres of an estimated 2,500 targeted acres of Bighorn Canyon lands, as of FY 1999, is contained.
		Water Quality: by September 30, 2005, Bighorn Canyon has unimpaired water quality.
		Natural/Cultural Resource Inventories: by September 30, 2005, 4 (66.6%) of 6 Bighorn Canyon primary natural/cultural resource inventories are completed.
		Vital Signs: by September 30, 2005, Bighorn Canyon has identified its vital signs for natural resource monitoring.
	Yellowstone National Park	Natural Resources Fauna: by September 30, 2005, 356 (95%) of the 375 self-sustaining and free-ranging wildlife, native fish and birds identified in Yellowstone National Park as of 1999 are preserved and maintained.
		Geothermal Features: By September 30, 2005, 90 (90%) of the 100 indicator geothermal features identified in Yellowstone National Park as of 1999 are in good condition.
		Native Species of Special Concern: by September 30, 2005, four of Yellowstone National Park's native species of special concern (trumpeter swan, white pelican, pronghorn antelope and Yellowstone sand verbena), as of 1999, have an improved or stable status.
		Exotic Plant Species: by September 30, 2005, invasive exotic vegetation species on 20-22 (2.6%) of 822 targeted acres of Yellowstone National Park lands, as of FY 1999, are eradicated or contained.
		T&E Species Improved: by September 30, 2005, one (the gray wolf) (33%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, has an improved status.
		T&E Species Stable: by September 30, 2005, two (the grizzly bear and bald eagle) (66%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, have a stable status.
		Air Quality: by September 30, 2005, air quality in Yellowstone National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Yellowstone National Park has unimpaired water quality.
		Vital Signs: by September 30, 2005, Yellowstone National Park has identified its vital signs for natural resource monitoring.
	Grand Teton National Park	Exotic Plant Species: by September 30, 2005, spotted knapweed and other alien vegetation species are contained on 20,000 (100%) of 20,000 acres targeted in Grand Teton National Park and the John D. Rockefeller Jr. Memorial Parkway.
		T&E Species: by September 30, 2005, 2 of the 4 federally listed threatened and endangered species NOT having critical habitat in Grand Teton and the Parkway and NOT requiring NPS recovery actions, as of 1997, have an improved status. Monitoring continues on the remaining 2 federally listed species.
		Native Species of Species Concern: by September 30, 2005, 1 of 2 (50%) of Grand Teton National Park and Parkway populations of plant and/or animal species of special concern (e.g. state-listed threatened and endangered species, endemic or indicator species, or native species classified as pests) are at scientifically acceptable levels.
		Air Quality: by September 30, 2005, air quality in Grand Teton National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Grand Teton National Park and Parkway continue to have unimpaired water quality.
		Wildlife Research and Monitoring: by September 30, 2005, 9 of 9 (100%) of Grand Teton National Park and Parkway species of concern will continue to be monitored to provide sufficient information to assist in management decisions.
		Resource Inventories: by September 30, 2005, 50% of the available natural resource data sets for Grand Teton National Park will be collected and evaluated.
		Vital Signs: by September 30, 2005, Grand Teton National Park has identified its vital signs for natural resource monitoring.

APPENDIX II:

CURRENT MONITORING IN THE GREATER YELLOWSTONE NETWORK PARKS AND SURROUNDING LANDSCAPES

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Air and Climate

AIR QUALITY

Atmospheric Deposition Monitoring

Atmospheric deposition monitoring is ongoing in YELL through two major programs: the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) and the Clean Air Status and Trends Network (CASTNET). NADP is a multi-agency (including federal, state and local) approach to monitoring the chemistry of wet deposition throughout the country at over 200 sites (NADP 2004). The NADP/NTN program currently operates one station at Tower Falls in Yellowstone National Park Data collected from this site can be downloaded from: http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=WY08&net=NTN and includes information on daily, weekly, seasonal and annual totals and trends for the site (NADP 2004). NADP also operates a Mercury Deposition Network (NADP/MDN) that collects information on weekly total mercury concentrations in precipitation, as well as seasonal and annual mercury flux. An MDN station was started at Yellowstone Lake in February 2002 and moved to Tower in 2004. All available data can be downloaded from the following website: http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=WY07&net=MDN.

The U.S. Geological Survey, along with the National Park Service-Air Resources Division, U.S. Forest Service and other agencies jointly operate the Rocky Mountain Snowpack Chemistry Network to determine the quality of precipitation and to identify sources of atmospherically deposited pollution. The RMS was created to augment NADP/NTN stations at high elevations (Nanus et al. 2003) and includes sites in Grand Teton and in Yellowstone (Ingersoll et al. 2001). The results of the first 5 years are summarized in a report by Ingersoll et al. (2001) available at http://water.usgs.gov/pubs/of/2001/ofr01-466.

As part of the Clean Air Status and Trends Network program (CASTNET [EPA 2004]), the U.S. Environmental Protection Agency (EPA) has been monitoring atmospheric deposition in YNP since 1996. CASTNET is a joint venture between EPA and the National Park Service-Air Resources Division that operates over 70 dry acidic deposition sites throughout the U.S. These sites provide hourly data on ozone levels and weekly information on the concentration of sulfate, nitrate, ammonium, sulfur dioxide and nitric acid (EPA 2004). This EPA monitoring focuses on dry deposition at one site near Lake Village and data from this site can be downloaded at: http://www.epa.gov/castnet/sites/yel408.html.

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National Atmospheric Deposition Program (NADP). 2004. NADP history and overview. <http://nadp.sws.uiuc.edu/nadpoverview.asp>. Accessed 2004 Jul 15.

Oversnow emissions

Yellowstone National Park funded an air pollutant 'emission' study in 2003 as part of the park's ongoing efforts to monitor air quality and other park resources to assess the impacts of winter use. The study collected over 200 air samples from 21 sites throughout Yellowstone from February 12-16, 2003, using well-recognized methods accepted by the Environmental Protection Agency. Scientists at University of New Hampshire measured approximately 85 different Volatile Organic Compounds (VOCs) including benzene and toluene, as well as carbon monoxide and methane. The study is available at: *www.nps.gov/yell/technical/planning/winteruse/plan/*.

Ozone

Historic Monitoring
Passive ozone monitoring was conducted from1995 through 2004 to determine ozone exposure levels. Data collected from this site can be downloaded from: http://www2.nature.nps.gov/air/studies/passives.htm. Passive ozone monitoring is an inexpensive method that involves exposing the passive sampler to ozone on a weekly basis during the "ozone season" from May to September. After exposure, the sampler is retrieved and mailed to a contract lab for analysis. The passive ozone monitoring program was supervised and funded by the NPS-ARD and was discontinued in 2004.

Visibility Monitoring

Visibility monitoring is ongoing in Yellowstone and Grand Teton National Parks as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. IMPROVE is composed of members from federal, state and regional agencies and has the common goal of providing information to protect visual environments under the Clean Air Act of 1977 (IMPROVE 2004). The program was initiated in 1985 to protect visibility in Class I airsheds in 156 national parks and wilderness areas.

The objectives of the IMPROVE program are: "to establish current visibility and aerosol conditions in mandatory class I areas; to identify chemical species and emission sources responsible for existing man-made visibility impairment; to document long-term trends for assessing progress towards the national visibility goal; and with the enactment of the Regional Haze Rule, to provide regional haze monitoring representing all visibility protected federal Class I areas where practical" (IMPROVE 2004). The website can be accessed at: http://vista.cira.colostate.edu/improve/Overview/Overview.htm and contains downloadable data (including aerosol, light extinction and scatter, and scenes) at: http://vista.cira.colostate.edu/improve/Data/data.htm.

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WEATHER

Climate

Climate monitoring is currently occurring in all three park units of the GRYN. Gray (2005) prepared a monitoring protocol for the network that defines the climate metrics of interest, the frequency of measurements and reporting units. Climate monitoring stations found within the parks of the GRYN include: the National Climatic Data Center (NCDC) climate stations found in Yellowstone and Grand Teton and north of Bighorn Canyon; the National Weather Service remote automated weather station (RAWS) in all parks; and Natural Resources Conservation Service Snotel and Snowcourse sites in Yellowstone and Grand Teton (Selkowitz 2003) and the Climate Reference Network station in Grand Teton. Much of this climate data is available online through the following Web sites (Gray pers. comm.):

- the Western Regional Climate Center provides detailed climate summaries for stations in the Western U.S. at: http://www.wrcc.dri.edu/climsum.html
- the National Oceanic and Atmospheric Administration NCDC provides access to hourly, daily and monthly climate data, and information on extreme events, at: http://www.ncdc.noaa.gov/oa/climate/climatedata.html
- select National Weather Service and cooperator station hourly climate data can be accessed through: http://www.ncdc.noaa.gov/oa/climate/climatedata.html#HOURLY at the following website for daily observations: http://hurricane.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD and at the following website for monthly observations: http://hurricane.ncdc.noaa.gov/pls/plclimprod/somdmain.somdwrapper?datasetabbv=TD3220
- daily observation from the U.S. Historical Climatology Network can be accessed through: http://www.ncdc.noaa.gov/oa/climate/research/ushcn/daily.html and monthly observations can be accessed through: http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html. The HCN concentrates on providing long-duration, high-quality datasets (therefore, length of records may be shorter than with other services). HCN stations within the GRYN include Mammoth Hot Springs (Yellowstone) and Lake (Yellowstone).
- data from RAWS stations can be accessed through: http://www.met.utah.edu/jhorel/html/mesonet/
- data from the Climate Reference Network: http://www.ncdc.noaa.gov/crn/hourly.

The Climate Reference Network (CRN) station at GRTE, which was established in 2004, is funded by the National Oceanic and Atmospheric Administration (NOAA) and NCDC. The primary goal of the CRN is to provide future long-term, high-quality observations of surface air temperature and precipitation that can be coupled to past long-term observations for the detection

and attribution of present and future climate change. Measures include air temperature, precipitation, solar radiation, wind speed, ground surface temperature and relative humidity.

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Selkowitz D. 2003. Compilation and analysis of climate data in the Greater Yellowstone Ecosystem/Bighorn Canyon Area: completed products, problems encountered and recommendations for the future final report to the Greater Yellowstone/Bighorn Canyon Vital Signs Network. Greater Yellowstone Inventory and Monitoring Network, National Park Service, Bozeman, MT. 5 pp.

Geology and Soils

GEOMORPHOLOGY

Stream Sediment Transport

Historic monitoring

Bed sediment was monitored as part of the USGS National Water-Quality Assessment (NAWQA) program. Bed sediment was sampled throughout the Yellowstone River Basin in 1998, specifically on the Bighorn River at Kane, Soda Butte Creek at park boundary, Yellowstone River at lake outlet and on the Yellowstone River at Corwin Springs (O'Ney and McCloskey 2004). These NAWQA stations are co-located with USGS gaging stations. Information on the NAWQA program and data retrievals can be found on the USGS NAWQA website by visiting http://wy.water.usgs.gov/YELL/htms/data.htm.

Literature Cited

O'Ney SE and McCloskey K, eds. 2004. Water quality monitoring plan, phase II report. National Park Service, Greater Yellowstone Network, Bozeman , MT. 51 pp. plus appendices.

Glaciers

Glacier and snowfield monitoring has focused primarily on synoptic studies at GRTE. In particular, estimates of summer and winter mass balance have been combined with remote sensing data to track the dynamics of key glaciers in the Teton Range (e.g., Elder et al. 1994). Related modeling experiments have also produced forecasts for the response of GRTE glaciers to future climate variability and change (e.g., Plummer and Cecil 2005).

Plummer MA and Cecil LD. 2005. Simulated response of two Wyoming glaciers to projected climate change. Proc. of the 1st Annual MTNCLIM Meeting, March 2005, Pray, Montana.

Elder K, Fullerton S, Tonnessen K. 1994. Winter mass balance measurements on Teton Glacier, Grand Teton National Park. Park Science 14:11-13.

SUBSURFACE GEOLOGIC PROCESSES

Seismic Activity Monitoring

Seismic activity has been monitored in Yellowstone since 1973 (USGS [Pitt 1987]). In 2001, the Yellowstone Volcano Observatory (YVO), a joint venture among the USGS, Yellowstone National Park and the University of Utah, was created as part of the USGS Volcano Hazards Program in an effort to facilitate collaborative monitoring and research of geologic processes associated with the Yellowstone volcano (Olliff 2002). Dr. Jake Lowenstern of the USGS is Scientist-in-Charge of YVO, with coordination from scientists Dr. Bob Smith of the University of Utah and Dr. Hank Heasler of Yellowstone National Park (YVO 2004). Real-time data available on the YVO website include: earthquake data, such as live seismographs, earthquake catalogs (including maps) and a recent history of earthquakes in the area; GPS deformation data, which shows coordinates of spatial variations in the ground due to "magma and hydrothermal transport and fault motions related to earthquakes"; and hydrologic data gathered by the USGS, which includes chloride flux, stream discharge, water temperature and streamflow data (YVO 2004). These data can be accessed at: http://volcanoes.usgs.gov/yvo/monitoring.html. The University of Utah Seismograph Stations (UUSS) Network maintains the following types of monitoring stations in the Yellowstone Seismic Network: 17 short-period, vertical-component, analog telemetry; 2 short-period, three-component, analog telemetry; 2 broadband, three-component, analog telemetry; 1 broadband, three-component, digital telemetry. Funding for the UUSS is mostly provided by the USGS (95%) with some contribution from the National Park Service (5% [UUSS 2004]). Live seismographs from the Yellowstone Seismic Network can be seen at: http://www.seis.utah.edu/helicorder/heli/yellowstone/index.html. Meanwhile, current volcano activity reports can be accessed at the following website: http://volcanoes.usgs.gov/yvo/activity.html.

In order to better understand the geophysical processes at work in GRTE, a number of research and monitoring projects are taking place in the park. Three seismic monitoring stations and one continuously recording GPS receiver are currently in place at GRTE. Real-time data from the seismic monitoring network are available online as indicated for YELL with similar cooperation from the USGS and the University of Utah. Research projects related to geophysical processes include: studying the historic return time of earthquakes on the Teton fault, investigating the intermountain seismic belt as a system, and synthesizing monitoring data in hopes of improving earthquake prediction. As the West-wide Earthscope/Plate Boundary Observatory (PBO) project proceeds, GRTE and YELL may host 1-2 additional GPS units. The Earthscope Web site is found at: http://www.earthscope.org/pbo/index.shtml.

Literature Cited

Olliff T. 2002. Monitoring volcanic and earthquake unrest in Yellowstone. Pages 24-25 in Natural Resources year in Review 2001. J Selleck, ed. National Park Service, Natural Resource Stewardship and Science. WSO-NRID. 70 pp.

Pitt AM. 1987. Catalog of earthquakes in the Yellowstone Park-Hebgen lake Region, Wyoming, Montana, and Idaho, for the years 1973 to 1981. U.S. Department of the Interior, U.S. Geological Survey, Washington, DC.

University of Utah Seismograph Stations (UUSS). 2004. More about UUSS. <http://www.seis.utah.edu/behind/behind.shtml>. Accessed 2004 Jun 14.

Yellowstone Volcano Observatory (YVO). 2004. Volcano monitoring at Yellowstone National Park. <http://volcanoes.usgs.gov/yvo/monitoring.html>. Accessed 2004 Jun 14.

Chloride Flux Monitoring

In addition to monitoring seismic activity and geothermal features directly, Yellowstone also monitors proxies for geothermal activity, including groundwater temperature and chloride flux. High-temperature wells have been drilled throughout Yellowstone for research purposes, starting in 1931, and now consist of fifteen, with the majority drilled in the late 1960s (Heasler et al. 2003). The Yellowstone Spatial Analysis Center updated the inventory of these wells—many of them deteriorating due to hot, acidic geothermal water—in 2002 (Heasler et al. 2003). While they have been used for research purposes—particularly for understanding the impacts of geothermal development outside the park on park resources—there is currently no ongoing, long-term monitoring of groundwater temperature in these wells. Understanding groundwater temperature should give insights into the interaction between groundwater and geothermally influenced waters in the hydrologic system of Yellowstone (Heasler et al. 2003). Chloride flux, in contrast, has been monitored for almost two decades in the Fall, Snake, Madison and Yellowstone Rivers (Heasler et al. 2003). Chloride flux is used as an estimator of heat flow and geothermal activity, and approximately 94% of the chloride in Yellowstone's waters is thought to be from magmatic origin (Norton and Friedman 1985). According to Heasler et al. (2003), "water samples for chloride analysis are collected 28 times a year at river gauging stations: monthly during the winter at low flow, biweekly during the early spring and fall, and weekly during spring runoff." Analyses of these data have shown a 10% decrease in chloride flux over the past 19 years, which may be due to deflation of the caldera (Heasler et al. 2003).

Literature Cited

Heasler H, Jaworowski C, Susong D. 2003. A geothermal monitoring plan for Yellowstone National Park. National Park Service, Yellowstone National Park, Mammoth Hot Springs, Wyoming. 23 pp.

Norton D, Friedman I. 1985. Chloride flux out of Yellowstone National Park: Journal of Volcanology and Geothermal Research, v. 26, p. 231-250.

Geothermal Feature Monitoring

Monitoring of geothermal features in Yellowstone has been performed in the past when personnel and funds were available. Monitoring has been mostly qualitative in nature and can be found in various Yellowstone National Park archives, internal reports and notebooks (Heasler et

al. 2003). An inventory of over 7,000 geothermal features was compiled by the YELL Spatial Analysis Center from 1999-2003; this represents only 60-70% of the total features contained within the park (Heasler et al. 2003). Monitoring of geothermal features generally takes one of two forms, depending on the location of the feature and available funding: features may be monitored in-depth, including collecting data on "temperature, flow, chemistry of water and gases (major anions, cations, metals, trace elements, isotopes, etc.) and spatial extent (using techniques such as photographic surveying methods)," or they may be monitored using remote sensing techniques (Heasler et al. 2003). Yellowstone National Park is currently obtaining funding for in-depth monitoring and remote sensing to be included in the plan for monitoring geothermal resources in the park (Heasler et al. 2003). However, in addition to the informal monitoring of geothermal features, data collection on eruption intervals is ongoing at the Old Faithful Geyser by park interpretive staff, and a volunteer monitors vandalism to features in the Upper, Midway and Lower Basins (Jean et al. 2003). A list of geyser activity—updated in 2002 and including the interval between eruptions and the height of the eruption—can be found at the following website: http://www.nps.gov/yell/nature/geothermal/ycr/activity.html. USGS researchers completed mapping the bottom of Yellowstone Lake in summer 2003 using multibeam sonar imaging and seismic mapping. This mapping revealed an "inflated plain" that rises 100 feet from the lake bottom and is about 2,000 feet long (YVO 2004). While this bulge could possibly lead to a hydrothermal explosion, indications from recent monitoring suggest that this is unlikely in the near future (YVO 2004). The Yellowstone Volcano Observatory is monitoring the temperature of the hydrothermal vents and conducting an assessment of the geologic hazards in Yellowstone National Park (YVO 2004).

Literature Cited

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Jean C, Bischke SD, Schrag AM. 2003. Greater Yellowstone Inventory and Monitoring Network Vital Signs Monitoring Plan: Phase II Report, September 30, 2003. National Park Service, Greater Yellowstone Network, Bozeman, MT. 99 pp. plus appendices.

Yellowstone Volcano Observatory (YVO). 2004. Frequently asked questions about recent findings at Yellowstone Lake. <http://volcanoes.usgs.gov/yvo/new.html>. Accessed 2004 Jul 14.

Water

Water Chemistry

Historic monitoring efforts

Water quality monitoring in the GRYN parks has taken place for several decades. Most monitoring is done as synoptic studies of limited duration (e.g., the EPA EMAP program (2000-2003). The USGS National Water Quality Assessment (NAWQA) program established eight water quality monitoring stations in or near the network parks between 1998 and 2001; these stations are included in the Yellowstone River Basin and upper Snake River Basin study units, both of which were scheduled for the second assessment cycle during this decade (USGS 2001);

however, the focus and sample locations may change, depending on agency goals. At Yellowstone, NAWQA parameters measured included: biological parameters, nutrients, organics, major inorganics, minor and trace elements, physical properties, radio-chemicals and sediment (O'Ney and McCloskey 2004). There were two NAWQA stations in GRTE, Flagg Ranch established in the early 1990's and one at Moose, established in 1996. Parameters measured quarterly included: water temperature, pH, dissolved oxygen, specific conductivity, nutrients and suspended sediment (O'Ney and McCloskey 2004). These parameters were also measured at the NAWQA stations located in or adjacent to Bighorn Canyon NRA. In additional, fecal coliforms were monitored on the Bighorn River at Kane and on the Shoshone River near Lovell (O'Ney and McCloskey 2004) during the NAWQA assessment. Refer to USGS Web site http://water.usgs.gov/nawqa/constituents/ for detailed descriptions of parameters measured by the NAWQA protocols.

Surface water quality data retrievals from six of the EPA's national databases served as the basis for the Baseline Water Quality Data Inventory and Analysis Reports completed for YELL, GRTE and BICA by the Servicewide Inventory and Monitoring Program and the Water Resources Division (National Park Service 1994, 1998b, 2001). These data were later acquired and analyzed for state water quality exceedances by Woods and Corbin (2003a, 2003b, 2003c). Knauf and Williams acquired and analyzed seven data sets for Soda Butte Creek (2005), dating from 1987 to 2001; these data were submitted to EPA for submission to the EPA STORET database. In 2004 the GRYN prepared a phase II Water Quality Monitoring Plan (O'Ney and McCloskey 2004) to address overall water quality goals, background information and conceptual models for water quality monitoring in the GRYN. These reports are located on the GRYN Web page http://www.nature.nps.gov/im/units/gryn/index.shtml.

Current monitoring effort

The following section describes water quality monitoring currently being done by the YELL aquatics section in YELL and by park staff at GRTE. See also sections on geothermal and streamflow monitoring for more information on other water-related monitoring.

Both YELL and GRTE have ongoing water quality monitoring within their boundaries. At the USGS gaging station at Moose (GRTE), there is a real-time, continuous monitor for water temperature, pH, dissolved oxygen and specific conductivity. Also in GRTE, approximately 20 groundwater wells adjacent to sewage ponds and leach fields within park boundaries are presently being monitored once a year for basic water quality parameters, fecals and nutrients to comply with the requirements of Wyoming Department of Environmental Quality. Additionally, Snake River Pit ground water levels are monitored on a biweekly basis from wells installed by the USGS in 1997 (O'Ney and McCloskey 2004). Testing for fecal coliform, including DNA source tracking of *E. coli*, to determine the mammalian source of coliforms, began in 1996 in selected backcountry streams and has continued to date (O'Ney and McCloskey 2004).

A long-term water quality monitoring program was started in YELL in 2002 and includes nineteen fixed sites; twelve of these stations are located on rivers and streams and seven are located on Yellowstone Lake. Field measurements include: pH, dissolved oxygen, specific conductance, temperature and turbidity; samples are collected for total suspended solids (TSS) and volatile suspended solids. Sampling takes place at two-week intervals during the spring,

summer and fall and monthly during the winter (December, January and February). On Yellowstone Lake, monitoring stations were established at four historic sampling stations (Koel et al. 2004), with sampling taking place between May and October (during ice-free periods). Two additional sampling sites on the southern arms of Yellowstone Lake were added in 2003 for a total of seven stations on the lake.

In 2005 the GRYN began monitoring water bodies identified as water quality impaired: Soda Butte Creek and the Bighorn River in Montana and the Shoshone River in Wyoming. The Regulatory Water Quality Monitoring Protocol for the Greater Yellowstone Network (O'Ney 2005) establishes the standing operating procedures for measuring core parameters and discharge plus dissolved and total metals in water and metals in sediment (on Soda Butte Creek), nutrients (on the Bighorn River) and *E.coli* and fecal coliforms (on the Shoshone River). Macroinvertebrates are also monitored at least once a year at each of these three stations.

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Knauf M, Williams MW. 2004. Soda Butte Creek and Reese Creek: Vital Signs Monitoring Program, Final Report. National Park Service, Greater Yellowstone Network, Bozeman, MT. 29 pp. plus appendices.

Koel TM, Arnold JL, Bigelow PD, Doepke PD, Ertel BD and Mahony DL. 2004. Yellowstone Fisheries & Aquatic Sciences: Annual Report, 2003. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, YCR-NR-2004-03.

National Park Service. 1994. Baseline Water Quality Data Inventory and Analysis. Yellowstone National Park. Technical Report NPS/NRWRD/NRTR-94/22.

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National Park Service. 2001. Baseline Water Quality Data Inventory and Analysis. Grand Teton National Park. Technical Report NPS/NRWRD/NRTR-2000/260.

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O'Ney SE. 2005. Regulatory water quality monitoring protocol. Version 1.0. Bozeman (MT): National Park Service, Greater Yellowstone Network. 35 pp. plus appendices.

United State Geological Survey, 2001. The National Water – Quality Assessment Program – Entering a new decade of investigations. USGS Fact Sheet 071-01. July 2001. 6 pp.

Woods SW, Corbin J. 2003a. Vital signs water quality monitoring for the Greater Yellowstone Network: Bighorn Canyon National Recreation Area: Final Technical Report, July 2003. National Park Service. Greater Yellowstone Network, Bozeman, MT.

Woods SW, Corbin J. 2003b. Vital signs water quality monitoring for the Greater Yellowstone Network: Grand Teton National Park: Final Technical Report, August 2003. National Park Service. Greater Yellowstone Network, Bozeman, MT.

Woods SW, Corbin J. 2003c. Vital signs water quality monitoring for the Greater Yellowstone Network: Yellowstone National Park: Final Technical Report, September 2003. National Park Service. Greater Yellowstone Network, Bozeman, MT.

Water temperature

Continuous water temperature is currently being monitored by the USGS at gaging stations on the Gibbon, Firehole and Snake River (at Moose) and on Soda Butte and Tantalus Creeks. In addition, the YELL geothermal monitoring program has an extensive network of temperature loggers scattered throughout the park.

HYDROLOGY

Streamflow

Streamflow (real-time discharge and gage height) is being monitored by the USGS at several gages at flowing rivers throughout the GRYN (see Table 1). Stream gage stations are located on the Madison, Gibbon, Firehole, Gallatin, Yellowstone, Lamar, Gardner, Boiling, Bighorn, Shoshone, Gros Ventre and Snake Rivers; and on Granite, Buffalo Fork, Pacific, Tantalus and Soda Butte Creeks (Table 1). Data can be obtained from http://waterdata.usgs.gov/nwis.

These gages are usually located on the main stem of larger rivers at easily accessible sites. While this network provides invaluable information on regional hydroclimatic variability, the lack of gages in headwaters areas or on smaller tributaries may represent an important data gap for the GRYN. Smaller streams generally respond more rapidly to variations in climate (NAST 2001; Wagner 2003). Small streams also provide key habitats for species of interest within the GYE (e.g., cutthroat trout).

Table 1. Key stream gages for the GRYN parks.

USGS_Station_Name	USGS Station_ID	Data_Collected by USGS	Period_of_USGS_Record
Madison River near West Yellowstone MT	06037500	Real time discharge, gage height	1913-present
Yellowstone River at Yellowstone Lk Outlet YNP	06186500	Real time discharge, gage height; NAWQA	1926-present
Soda Butte Cr nr Lamar Ranger Station YNP	06187950	Real time discharge, gage height, air temperature	1888-89; 1990-present
Lamar River nr Tower Falls Ranger Station YNP	06188000	Real time discharge, gage height	1923-present
Gardner River near Mammoth YNP	06191000	Real time discharge, gage height	1938-present

Boiling River at Mammoth, YNP	06190540	Real time discharge, gage height;	1988-1995; 2002-present
Yellowstone River at Corwin Springs MT	06191500	Real time gage height, discharge, air temperature; NAWQA	1889-1893; 1910-present
Firehole River near West Yellowstone MT	06036905	Real time discharge, gage height, water temperature	1983-1996 (discharge); 2002-present
Gibbon River at Madison Jct, YNP	06037100	Real time gage height, discharge, water temperature	2000-present
Soda Butte Cr at Park Bndry at Silver Gate	06187915	Real time discharge, water temperature, gage height; NAWQA	1999-present
Tantalus Creek at Norris Junction, YNP	06036940	Real time gage height, discharge, precipitation, water temperature	6/25/2004-present
Snake River AT Moose, WY	13013650	Real time discharge, gage height, water temperature, specific conductivity, dissolved oxygen, pH; NAWQA protocols	1995 to present
Snake River AB Jackson Lake at Flagg Ranch WY	13010065	Real time gage height, discharge; NAWQA;	1983 to present; prior to 1988 pub as 13010200
Snake River NR Moran WY	13011000	Real time discharge, gage height;	1903 to present
Pacific Creek at Moran WY	13011500	Real time gage height, discharge;	1906 to 1917; 1944 to 1975; 1978 to current year
Buffalo Fork AAB Lava Creek NR Moran WY	13011900	Real time gage height, discharge;	1965 to present
Gros Ventre River at Zenith WY	13015000	Real time gage height, discharge	July-Sept. 1917 and 1918; October 1987 to present
Granite C AB Granite C Supplemental, NR Moose, WY	13016305	Real time discharge, gage height;	1995 to present
Bighorn River at Kane, WY	06279500	Real time discharge, gage height; NAWQA	1928-present
Bighorn River near St. Xavier, MT	06287000	Real time discharge, gage height;	1934-present
Shoshone River near Lovell, WY	06285100	Real time discharge, gage height;	1966-present

http://waterdata.usgs.gov/nwis

Literature Cited

NAST (National Assessment and Synthesis Team), 2001. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change.* Report for the U.S. Global Change Research Program, Cambridge University Press, Cambridge, UK.

Wagner FH. (ed.), 2003. *Rocky Mountain/Great Basin Regional Climate Change Assessment. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program.* Utah State University, Logan, UT.

Lake and Reservoir elevation

The Bureau of Reclamation also continuously monitors the lake levels of Bighorn and Jackson Lakes. Data for Jackson Lake Reservoir may be found at: http://www.usbr.gov/pn/hydromet/burtea.cfm . Data for Bighorn Lake may be found at: http://www.usbr.gov/gp/htbin/hydromet_teacup?BH.

Biological Integrity

INVASIVE SPECIES

Invasive Plants

Invasive plant monitoring is largely taking place through repeat inventories across the network. At Bighorn Canyon NRA, a subset of high priority invasive plants have been mapped or inventoried (via transects) in all management areas. Major paved roads are treated several times a year for invasive plants followed by informal walk-through surveys to monitor treatment effectiveness. Walkthrough effectiveness surveys are also conducted at other significant weed treatment areas within the NRA (Pickett, pers. comm. 2004).

At Grand Teton NP nearly all invasive plant species have been mapped throughout the Park using a variety of survey methods. A few infestations (orange hawkweed, Dyer's woad, sulphur cinquefoil) that have been treated through mechanical (e.g. hand pulling, mowing) or chemical means are being monitored for treatment effectiveness. Several biological exotic plant control agents have been released in the Park over the last 9 years, and long-term monitoring transects have been installed on all release sites (Haynes and Janssen, pers, comm., 2004).

At Yellowstone annual monitoring of high priority invasive plant species along roads and in developed areas began in the early 1990's (Olliff and others 2001). Informal walk-through surveys are conducted along roadsides to monitor population trends as well as treatment effectiveness. Infestations are classified by density classes (low, medium, high). Opportunistic surveys for exotic plants are also conducted in other areas of YELL by backcountry Rangers (Renkin, pers. comm. 2004). In addition, Dalmatian toadflax was surveyed and monitored in the Mammoth Hot Springs area in the mid-1970's.

<u>References:</u>

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Janssen, Eric. Telephone conversation with: Elizabeth Crowe. 2004, Jul 8.

Olliff T, Renkin R, McClure C, Miller P, Price D, Reinhart D, Whipple J. 2001. Managing a complex exotic vegetation management program in Yellowstone National Park. Western North American Naturalist 61(3):347-358.

Pickett, Bill. Telephone conversation with: Elizabeth Crowe. 2004, Jul 7.

Renkin, Roy. Telephone conversation with: Elizabeth Crowe. 2004, Jul 7.

INFESTATIONS AND DISEASE

Forest Insect and Disease Monitoring

Forest pest insects and diseases in the Greater Yellowstone Ecosystem are monitored by the Forest Health Protection (FHP) program (web address: http://www.fs.fed.us/foresthealth/), which is part of the State and Private Forestry section of the USDA-Forest Service. This program monitors long-term health, insects and pathogens by conducting low-elevation aerial surveys on all federal and state forested lands (Harris pers. comm.). The GYE is completely surveyed approximately every three years. More frequent surveys, however, are conducted in areas of high priority, and YELL has been surveyed in 2002, 2003 and 2004. Outbreaks and expansions of forest insect pests and diseases detected in the aerial surveys are mapped and reported to state and Federal forest management agencies (e.g. NPS, U.S. Forest Service, Wyoming Dept. of Forestry). Some ground surveys are also conducted by FHP entomologists and pathologists to follow up on severe infestations. FHP does not survey BICA currently, but does monitor the nearby Custer and Bighorn National Forests. Reports on forest insect and diseases conditions are released yearly. Regional reports can be found at (http://www.fs.fed.us/foresthealth/current_conditions.shtml) and state reports can be found at (http://www.na.fs.fed.us/spfo/fhm/fhh/fhmusamap.htm).

Transects to survey for the presence of blister rust in whitebark pine throughout YELL were placed in 1957 and have been monitored as recently as 1995 (Kendall and Keane 2001). In 2004 protocols for future whitebark pine monitoring are being piloted in YELL and surrounding national forests (see Whitebark Pine Monitoring Plan and Protocols).

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VERTEBRATE DISEASE

Numerous diseases are known to affect – or have the potential to affect – vertebrates living or migrating through the GRYN parks and, thus, current vertebrate disease monitoring efforts involve several state and federal agencies. USFWS and NPS scientists monitor brucellosis and numerous other pathogens in the Jackson bison and elk herds that range between the National Elk Refuge (NER) and GRTE. Some of this monitoring is in conjunction with Wyoming Game

and Fish, which also surveys for Chronic Wasting Disease. The Jackson elk herd has been included in that surveillance since 2001.

At BICA the USGS recently completed a three-year mortality study of bighorn sheep that included a blood sampling for disease. The work was in response to a 1995 bighorn sheep decline that appeared consistent with disease propagation. The work, which did find evidence of Pasturella pneumonia, is complete with no current plans to extend into a regular monitoring program.

In YELL, disease monitoring is done by the Bison Ecology and Management Program, the Yellowstone Ungulate Program, the Wolf Recovery Program and the Fisheries Management Program and through partnerships and research activities of the Wildlife Conservation Society and the Yellowstone Ecological Research Center. Table 2 summarizes vertebrate disease monitoring underway in YELL.

Table 2. Vertebrate disease monitoring underway in Yellowstone National Park.

Host Species	Disease	Program	Data Source	Non-Park Contact	Park Contact	Reference
Cougar	Feline FIV Feline Parvovirus Feline coronavirus Canine calicivirus Canine distempter Plague Feline herpesvirus	YNP& Wildlife Conservation Society Cougar Research Program, 1987-present	Blood samples collected when animals captured for radio-collaring	Roman Biek Dept. Biology 1510 Clifton Rd Emory University Atlanta, GA 30322 Ph 404.727.9516 FAX 404.727.2880 rbiek@emory.edu	Kerry Murphy YCR POB 168 YNP, WY 82190 307.739.3321 kerry_murphy@nps.gov	Temporal dynamics and risk factors for microparasitic infections in free living cougars. Biek et al., submitted for publication
Coyotes	Canine distemper Canine parvovirus Canine Infectious Hepatitis Tularemia Leptospirosis Plague Fleas, ticks, mites, lice	YNP & Yellowstone Ecological Research Center Coyote Research Program, 1990 – present	Blood samples collected when animals captured for radio-collaring Ear swabs	Bob Crabtree YERC 2048 Analysis Dr. Bozeman, MT 59718 406.556.1414 crabtree@yellowstoneresearch.org	Kerry Murphy YCR POB 168 YNP, WY 82190 307.739.3321 kerry_murphy@nps.gov	Gese, E.M., R.D. Schultz, R. Johnson, E.S. Williams, R.L. Crabtree, and R.L. Ruff. 1997. Serological survey for diseases in free-ranging coyotes (Canis latrans) in Yellowstone National Park, Wyo. J. Wildl. Diseases 33:47-56.
Red Fox	Canine distempter Canine parvovirus Canine Infectious Hepatitis Tularemia Leptospirosis Plague Fleas, ticks, mites, lice	YNP & Yellowstone Ecological Research Center Coyote Research Program, 2002 – present	Blood samples collected when animals captured for radio-collaring Ear swabs	Bob Crabtree YERC 2048 Analysis Dr. Bozeman, MT 59718 406.556.1414 crabtree@yellowstoneresearch.org	Kerry Murphy YCR POB 168 YNP, WY 82190 307.739.3321 kerry_murphy@nps.gov	No references provided
Bats	Rabies	YNP Pest Management Program, periodic as needed	Whole carcass pathology	na	Roy Renkin YCR POB 168 YNP, WY 82190 307.344.2161 roy_renkin@nps.gov	No references provided
Birds	West Nile Virus	Periodic surveillance as needed	Whole carcass pathology	na	Terry McEneaney YCR POB 168 YNP, WY 82190 307.344.2222 terry_mceneaney@nps.gov	NPS IMR West Nile Virus Compendium and Checklist, September 2002
Cutthroat Trout	Whirling disease, Other fish diseases as encountered	YNP Fisheries Management Program	Whole carcass pathology	na	Todd Koel YCR POB 168 YNP, WY 82190 307.344.2281	Koel, T.M., D.L. Mahoney, L. Kinnan, C. Rasmussen, C.J. Hudson, S. Murcia, and B.L. Kerans. In press. Myxobolus cerebalis in native cutthroat trout of the

					todd_koel@nps.gov	Yellowstone Lake ecosystem. Transactions of the American Fisheries Society. Koel, T.M., J.L. Arnold, P.E. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahoney. 2004. Yellowstone Fisheries and Aquatic Sciences: Annual Report, 2003. National Park Service, Yellowstone Center for Resources, YNP, WY, YCR-NR-2004-03.
Gray Wolf	Rabies Canine distemper Canine parvovirus Brucella canis	YNP Wolf Recovery Program, 1995-present	Blood samples collected when animals captured for radio-collaring	na	Doug Smith YCR POB 168 YNP, WY 82190 307.344.2242 doug_smith@nps.gov	YNP Wolf Project 2003 Annual Report. YNP, WY.
Bison	Brucellosis	YNP Bison Ecology and Management Program, 2000-present	Blood samples collected when animals are captured	na	Rick Wallen YCR POB 168 YNP, WY 82190 307.344.2207 rick_wallen@nps.gov	Cheville, N.F., D.R. McCullough, L.R. Paulson. 1998. Brucellosis in the Greater Yellowstone Area. National Academy Press, Washington, DC, 186 pp.
Elk (adult females)	Bovine viral diarrhea virus Parainfluenza-3 virus Respiratory syncytial virus Epizootic hemorrhagic disease Paratuberculosis (Johne's disease) Chlamydia Leptospirosis Lungworm	Yellowstone Ungulate Program, 2001	Blood samples collected when animals are captured	Mark Boyce Department of Biological Sciences University of Alberta Edmonton, Alberta Canada T6G 2E9 Ph 780.492.0081 FAX 780.492.9234 boyce@ualberta.ca	P.J. White YCR, POB 168 YNP, WY 82190 307.344.2442 pj_white@nps.gov	No references provided
Elk calves	Bovine viral diarrhea Infectious bovine rhinotracheitis Respiratory synctial virus Brucellosis Parainfluenza-3 virus	Yellowstone Ungulate Program, 2003-2005	Blood samples collected when animals are captured	L. David Mech U.S. Geological Survey, BRD The Raptor Center, 1920 Fitch Ave University of Minnesota St. Paul, MN 55108 Ph 651.649.5231 FAX 651.649.5233 Mechx002@tc.umn.edu	P.J. White YCR, POB 168 YNP, WY 82190 307.344.2442 pj_white@nps.gov	No references provided
Pronghorn	Chlamydia Parainfluenza-3 virus Brucellosis Bovine viral diarrhea Respiratory synctial virus Bluetongue virus/Epizootic	Yellowstone Ungulate Program, 1999	Blood samples collected when animals are captured		P.J. White YCR, POB 168 YNP, WY 82190 307.344.2442 pj_white@nps.gov	Keating, K. 2002. History of pronghorn population monitoring, research, and management in Yellowstone National Park. Unpublished report dated January 28, 2002, and submitted to the National Park Service by the USGS Northern Rocky Mountain Science Center, Bozeman, Montana. NPS Agreement

	hemorrhagic disease virus Paratuberculosis (Johne's disease) Leptospirosis					#1443-IA-1248-01-006.
Bighorn Sheep	Lungworm	Yellowstone Ungulate Program, 2004	Fecal samples collected during winter on Mt. Everts		P.J. White YCR, POB 168 YNP, WY 82190 307.344.2442 pj_white@nps.gov	No references provided

FOCAL SPECIES OR COMMUNITIES

Aspen

Following the fires of 1988, Roy Renkin and Don Despain established 15 aspen seedling monitoring sites in various habitats in the northern half of the park (Renkin and Despain 1996). Other long-term aspen monitoring transects (112 in total) were established in 1999 and re-read in 2001 to study landscape-level trends in aspen dynamics, especially with regard to the effect of wolves on elk browsing behavior (Ripple et al. 2001). These transects were scheduled to be re-surveyed in 2004 (Renkin pers. comm.). In GRTE and BICA no monitoring of aspen is currently being conducted.

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Renkin R, Despain DG. 1996. Notes on postfire aspen seedling establishment. In: Greenlee JM, editor. Second biennial conference on the Greater Yellowstone Ecosystem; 1993, September; Yellowstone National Park. International Association of Wildland Fire. p 105-106.

Ripple WJ, Larsen EJ, Renkin RA, Smith DW. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation 102: 227-234.

Riparian Monitoring

In Yellowstone National Park, ungulate exclosures constructed from 1957-62 have provided opportunities for long-term vegetation monitoring of vascular plants and riparian communities. Past monitoring has involved repeat photography, rather than site measurements, as a monitoring tool (Kay 1990, Meagher and Houston 1998). Transects installed in willow communities between 1985-1987 have been monitored periodically (Singer 1996, Singer et al. 1994). Another cycle of monitoring these transects started in 2003 and will continue until 2007. A new set of monitoring transects in willow communities are being installed in 2004. The focus of all current willow monitoring is use by ungulates, especially how the reintroduced wolf population has affected ungulate browse behavior. No long-term monitoring of riparian vegetation is currently occurring in BICA or GRTE. A thesis project carried out in 1988 examined changes in riparian vegetation composition along the Bighorn River with BICA from 1938-1986 (Akashi 1988).

Literature Cited

Akashi Y. 1988. Major Vegetation Types Found in the Bighorn River Floodplain Study Area in Bighorn Canyon NRA [MSc thesis]. Laramie: University of Wyoming. 245 p.

Kay CE. 1990. Yellowstone's northern elk herd: a critical evaluation of the "natural regulation" paradigm [dissertation]. Logan: Utah State University. 490 p.

Meagher MM, Houston DB. 1998. Yellowstone and the biology of time: photographs across a century. Norman, OK: University of Oklahoma Press. 287 p.

Singer FJ. 1996. Differences between willow communities browsed by elk and communities protected for 32 years in Yellowstone National Park. In: Singer FJ, editor. Effects of Grazing by Wild Ungulates in Yellowstone National Park. Denver, CO: U.S. Department of Interior, National Park Service. p 279-290.

Singer FJ, Mark LC, Cates RC. 1994. Ungulate herbivory of willows on Yellowstone's northern winter range. Journal of Range Management 47:435-443.

Canada Lynx

In March 2000, the USFWS listed the Canada lynx as a threatened species (USFWS 2000). Canada lynx were listed as threatened due to the inadequacy of forest plans to provide for protection of the ecological needs of lynx. National forest and park resource management plans have been amended, and a strategy is now in place for the conservation of lynx and their habitat. Threats include loss of connectivity between isolated ecosystems supporting lynx, incidental mortality during otherwise lawful trapping, hunting and snaring of other animals, and human encroachment on wildlands (USFWS 2003).

An inventory of Canada lynx in Yellowstone National Park was completed in 2004. Using a variety of survey methods, Canada lynx adults and kittens were detected in the park, with most detections occurring in an area near Yellowstone Lake that supports forests with dense understory vegetation (Murphy et al. 2004). It was concluded that the Canada lynx suffers from reduced population viability in the park, probably because the park represents the limit of its range (Murphy et al. 2004).

GRTE has completed a three-year study in collaboration with the Wildlife Conservation Society to determine (a) the status of lynx in the park, and (b) the activity of their primary prey, snowshoe hares. Results from these efforts will provide information for the determination of coarse-scale habitat requirements and, ultimately, what role Grand Teton plays in the overall conservation of lynx.

Black Bears *(Ursus americanus)*

Black bears occupy much of the same habitat as grizzly bears, although black bears tend to prefer areas that are closer to human occupation and at low- to mid-elevations (IGBST 2004). While previous work on black bears in the GYE has been limited to ground telemetry and home-range estimations, the IGBST has begun to monitor black bear demographics in YELL and GRTE to provide supplemental information to their grizzly bear monitoring efforts. This monitoring should lead to a better understanding of black bear habitat use, competition with grizzly bears and other predators, such as wolves, for limited food resources, and interactions with humans (IGBST 2004). To determine how black bears use the ecosystem, the IGBST collars randomly captured bears and locates them during grizzly bear telemetry flights. In addition, given ample time, the team visits feeding sites on the ground and collects data on vegetation and site characteristics (IGBST 2004).

Yellowstone National Park tracks bear management activities and posts annual updates on the following website: http://www.nps.gov/yell/nature/animals/bear/grizzlyup.html. The site contains information on numbers of sightings and signs reported by visitors and staff, first and last observation dates, bears that were captured, moved or euthanized, mortalities and food availability. Bear sightings reports are also posted every few weeks on the following website: http://www.nps.gov/yell/nature/animals/bear/index.htm.

Cougars (Puma *[Felis] concolor*)

After being nearly eliminated in the GYE in the early 20th century, the number of cougars in northern Yellowstone has fluctuated between 14 and 23 since 1987 (Ruth 2004). Cougar ecology has been monitored in two phases—one before and one after the reintroduction of wolves in Yellowstone—by the Hornocker Wildlife Institute, now part of the Wildlife Conservation Society, and in conjunction with the Yellowstone Wolf Project and the Interagency Grizzly Bear Study Team (Ruth 2004). The goals of this monitoring include understanding the following: cougar movement; habitat use in relation to wolves and bears; cougar demographics; predation rates of cougars, as well as cougar predation on other animals; denning data, including litter sizes and sex ratios; and genetic and disease analyses. Thus far, 65 adults, subadults and kittens have been radio collared and are monitored in an area of northern Yellowstone that corresponds with the ranges of 3-5 wolf packs (Ruth 2004).

Literature Cited

Interagency Grizzly Bear Study Team (IGBST). 2004. Black bear demographics in Yellowstone and Grand Teton National Parks: their interrelationship to other carnivores, habitats and humans. <http://www.nrmsc.usgs.gov/projects/igbst_BB.htm>. Accessed 2004 Jul 13.

Ruth TK. 2004. Ghost of the Rockies: the Yellowstone cougar project. Yellowstone Science 12(1): 13-17.

Ungulates

Under construction!!!

AT-RISK BIOTA

Bald Eagles

Significant increases in population numbers caused the USFWS to downlist the bald eagle from endangered to threatened in 1995 (McEneaney 2004). When the eagle was originally chosen as the national symbol in 1782, some 100,000 nesting pairs of bald eagles resided in the continental United States. By 1963, their numbers were down to 417 pairs (USFWS 1999). A loss of nesting habitat, coupled with the use of DDT and other organochlorines, which caused thinning of egg shells and decreased nesting success, lead to the decline in bald eagle populations (USFWS 1999). Captive breeding programs, reintroduction efforts, nest site protection and law enforcement helped in the recovery effort (USFWS 1999).

Although the eagle has now been downlisted, populations in the Great Lakes region and the desert southwest are still threatened by heavy metal contamination and habitat destruction, respectively (McEneaney 2004). In addition to the protection afforded by the Endangered Species Act, the bald eagle is also protected under the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act (USFWS 1999).

Yellowstone National Park publishes an annual report documenting the population status, territorial occupancy and nest productivity of the bald eagle. Bald eagle monitoring has been ongoing in Grand Teton National Park since the 1970s, including ground surveys for nests and monitoring reproductive status at historical nests (Wolff 2003). Bald eagle nests south of Bighorn Canyon National Recreation Area are currently monitored by Wyoming Game and Fish and the Bureau of Land Management (D. Saville pers. comm.). This monitoring is mostly within the boundaries of the Yellowtail Wildlife Habitat Area, but also extends approximately 0.5 miles into BICA boundaries (B. Pickett pers. comm.). Please see Appendix III for links to reports and information on monitoring by the Greater Yellowstone Coordinating Committee outside the parks.

The Yellowstone National Park Bird Report began as a quarterly document and became an annual report in 1996. The reports can be accessed at the following website: http://www.nps.gov/yell/nature/animals/birds/birdreports.htm. In the 2003 Yellowstone Annual Bird Report, 32 active nests produced 24 fledged eaglets—the highest number in recorded history (McEneaney 2004). While the 1988 fires have not yet proved to be a detriment to bald eagle populations, falling trees may lead to nest failure and territory changes in the future (McEneaney 2004).

Much of the monitoring information on bald eagle status in GRTE, including nesting status, number of nestlings, and fledgling success, has not been recorded in approximately 30% of known nests due to staffing constraints in the past few years. In 2001, Science and Resource Management at GRTE identified eight historical nests and one new nest during a helicopter survey funded by the GRYN. GPS coordinates for nest sites were taken and will be used for monitoring in the future (Wolff 2003).

The Greater Yellowstone Bald Eagle Working Group, a subcommittee of the Greater Yellowstone Coordinating Committee, is comprised of participants from the following organizations: Yellowstone and Grand Teton National Parks, Caribou-Targhee National Forest, Bridger-Teton National Forest, Gallatin National Forest, USFS Regional T&E staff, Red Rock Lakes National Wildlife Refuge, Montana Fish, Wildlife and Parks, Idaho Fish and Game, Wyoming Game and Fish, USFWS consultation biologists, University of Wyoming, Montana State University, BLM, private industry and Bureau of Reclamation. The Bald Eagle Working Group began in 1981 and met twice annually from 1982 to 1995 with the goal to create management goals and objectives and facilitate research and cooperation with respect to bald eagles in the Greater Yellowstone Area (GYCC 2003). The subcommittee produced a management plan for bald eagles in the GYA in 1983, which was subsequently updated in 1995, when the bald eagle was downlisted to threatened. This management plan is likely to be used as a “Conservation and Monitoring Plan” for the bald eagle if it is removed from the threatened

species list (GYCC 2003). As of 2004, Bob Oakleaf of the Wyoming Game and Fish Department in Cheyenne was the chair of the subcommittee (GYCC 2003).

Literature Cited

Greater Yellowstone Coordinating Committee. 2003. Summary of subcommittees/working groups.

McEneaney T. 2004. Yellowstone bird report 2003. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, YCR–NR–2003–01.

U.S. Fish and Wildlife Service (USFWS). 1999. The bald eagle is back! President Clinton announces proposal to remove our national symbol from endangered species list. <http://news.fws.gov/NewsReleases/R9/A11C3CEE-AC20-11D4-A179009027B6B5D3.html>. Accessed 2004 Jun 7.

Wolff S. 2003. Bald eagle and sage grouse inventory update 2001-2003. National Park Service, Grand Teton National Park, Moose, Wyoming. 4 pp.

Grizzly Bears

Grizzly bears were listed as threatened under the Endangered Species Act on July 28, 1975 (USFWS 1993). At the time of listing, they occupied only 2% of their original range in the continental United States and numbered 800 to 1,000 individuals in five or six populations (USFWS 1993). After listing, work began on the recovery plan for the species, which was approved on January 29, 1982, with revisions made in 1993 (USFWS 1993). The primary threats to grizzly bear populations are loss of habitat due to fragmentation, and adverse bear-human interactions, which leads to the destruction of "nuisance" bears (USFWS 1993). Human encroachment into grizzly habitat is a major threat because of the bears' very large home ranges that cover 309-537 square miles for females and 813-2,075 square miles for males (YELL 2004a).

In an effort to provide information to assist with long-term management of grizzly bears in the GYE, the Interagency Grizzly Bear Study Team (IGBST) was formed in 1973. This team has representatives from the following agencies: U.S. Geological Survey, National Park Service, U.S. Forest Service, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game, Montana Fish, Wildlife and Parks, and the Wyoming Game and Fish Department. The IGBST is responsible for: "conduct[ing] both short- and long-term research projects addressing information needs for bear management; monitor[ing] the bear population, including status and trend, numbers, reproduction, and mortality; monitor[ing] grizzly bear habitats, foods and impacts of humans; and provid[ing] technical support to agencies and other groups responsible for the immediate and long-term management of grizzly bears in the GYE" (Schwartz and Moody 2004). For further information on recovery goals, the IGBST and bear management activities in YELL, please consult Appendix III.

This recovery plan delineated a recovery area in the Greater Yellowstone Ecosystem that includes all or most of the following federal land units: Yellowstone National Park, Grand Teton

National Park, John D. Rockefeller, Jr. Memorial Parkway, Bridger-Teton National Forest, Shoshone National Forest, Gallatin National Forest, Caribou-Targhee National Forest, Custer National Forest, Beaverhead-Deer Lodge National Forest, and state, private and Bureau of Land Management lands in Idaho, Montana and Wyoming (YELL 2004).

Main recovery goals for the grizzly bear include: "1) average 15 adult females with cubs of the year inside the recovery zone and within a 10-mile area surrounding the recovery zone; 2) females with young occupy 16 of 18 recovery zones and no two adjacent areas shall be unoccupied; 3) known human-caused mortality is below 4% of the population estimate based on the most recent three-year sum of females with cubs minus known adult female deaths. In addition, no more than 30% of the known human-caused mortality shall be females. These mortality limits cannot be exceeded during any two consecutive years" (YELL 2004).

The IGBST website is at: http://www.nrmsc.usgs.gov/research/igbst-home.htm. An annual report is published (and available on the website) that summarizes findings from monitoring and research throughout the year. IGBST captures and collars a number of bears each year that they radio monitor throughout the year in order to track denning activity, mortality, occupancy and reproduction. Also important to understanding the ecology of grizzly bears is research on food sources, including ungulates, cutthroat trout, whitebark pine seeds, army cutworm moths and other insects, as well as their interactions with humans and the correlation between these interactions and the availability of natural food sources (IGBST 2004). In 2003, the Interagency Conservation Strategy Team—made up of representatives from NPS, USFS, USFWS, IGBST, Idaho Department of Fish and Game, Montana Fish, Wildlife and Parks and the Wyoming Department of Game and Fish—published the final Conservation Strategy for the grizzly bear in the Greater Yellowstone Ecosystem, which would go into effect if the bear is delisted in the future (USFS 2003).

Yellowstone National Park tracks bear management activities and posts annual updates on the following website: http://www.nps.gov/yell/nature/animals/bear/grizzlyup.html. The site contains information on numbers of sightings and signs reported by visitors and staff, first and last observation dates, bears that were captured, moved or euthanized, mortalities and food availability. Bear sightings reports are also posted every few weeks on the following website: http://www.nps.gov/yell/nature/animals/bear/index.htm.

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Interagency Grizzly Bear Study Team (IGBST). 2004. Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team, 2003. CC Schwartz and MA Haroldson, eds. U.S. Geological Survey, Bozeman, MT. 64 pp. plus appendices.

U.S. Fish and Wildlife Service (USFWS). 2003. U.S. Fish and Wildlife Service finds that Canada lynx should remain listed as threatened in lower 48. <http://news.fws.gov/NewsReleases/R6/560B1008-2E34-4321-B5E1508B05545815.html>. Accessed 2003 Aug 27.

Yellowstone National Park (YELL). 2004. Yellowstone resources and issues 2004. National Park Service, Yellowstone National Park, Division of Interpretation, Mammoth Hot Springs, WY. 191 pp.

Gray Wolves

Although listed as a non-essential, experimental species under the final U.S. Fish and Wildlife Service (USFWS 1994) ruling, national parks are directed to manage wolves as a threatened species under Section 10(j) of the Endangered Species Act.

In Yellowstone, wolves have been monitored since their reintroduction in 1995 and 1996; this monitoring includes information on population dispersal, distribution, reproduction, mortality and predation of ungulates (Smith et al. 2003).

After their 70-year absence from Jackson Hole, gray wolves returned to Grand Teton National Park in the fall of 1998, when two groups from the Yellowstone reintroduction appeared. Most of the monitoring ongoing outside of Yellowstone National Park is lead by USFWS and USFS staff and consists of censusing, monitoring of reproduction and mortalities, and movement and dispersal patterns (USFWS et al. 2004). Science and Resource Management personnel at Grand Teton locate radio-collared wolves using aerial surveys and conduct ground-based observations of packs in the region from May through September (GRTE 2004). Please see Appendix III for links to reports and further information on monitoring outside the parks.

The Yellowstone Wolf Project team publishes an annual report documenting population status, pack summaries, wolf management, and research and public education efforts related to wolves in the GYE (Smith et al. 2003). This report is available through the Yellowstone National Park website at http://www.nps.gov/yell/nature/animals/wolf/wolfup.html.

The U.S. Fish and Wildlife Service, Nez Perce Tribe, National Park Service and USDA Wildlife Service collaborate on a Rocky Mountain Wolf Recovery Annual Report, available at http://westerngraywolf.fws.gov/annualreports.htm (USFWS et al. 2004). This report covers wolf populations found in three recovery areas: the northwest Montana recovery area, the Greater Yellowstone recovery area and the central Idaho recovery area, and includes information on current ongoing research and monitoring efforts in the recovery areas (USFWS et al. 2004). Wolves in the northwest Montana recovery area are classified as threatened as of 2004, with wolves in the other two recovery areas classified as non-essential experimental populations (USFWS 2004). Additionally, the USFWS publishes a weekly wolf update that can be accessed at http://westerngraywolf.fws.gov/index.htm. This report gives detailed information about specific wolf monitoring, ongoing research and management information.

Information on packs located within Grand Teton National Park can be found in both the Yellowstone Wolf Project Annual Report and the Rocky Mountain Wolf Recovery Annual Report.

Literature Cited

Smith DW, Stahler DR, Guernsey DS. 2003. Yellowstone Wolf Project: Annual Report, 2002. National Park Service, Yellowstone Center for Resources, Yellowstone National Park, Wyoming, YCR-NR-2003-04.

U.S. Fish and Wildlife Service (USFWS), Nez Perce Tribe, National Park Service and USDA Wildlife Services. 2004. Rocky Mountain Wolf Recovery 2003 Annual Report. T. Meier, ed. USFWS, Ecological Services, 100 N Park, Suite 320, Helena MT. 65 pp.

Ecosystem Pattern and Processes

FIRE

Fire

The National Park Service Fire Effects Program provides scientific information to help evaluate prescribed fire management. Fire effects monitoring takes place at all three network parks with GRTE crews helping in BICA. At GRTE, a fire effects crew maintains a network of permanent vegetation monitoring plots in the park and surrounding Bridger-Teton National Forest. The plots follow protocols outlined in the NPS Fire Monitoring Handbook (NPS 2001)

Literature Cited

National Park Service. 2001. Fire Monitoring Handbook. Boise (ID) National Interagency Fire Center. 274 pp.

LAND USE AND COVER

Land Cover

Derived from the early to mid-1990s Landsat Thematic Mapper satellite data, the National Land Cover Data (NLCD) is a 21-class land cover classification scheme applied consistently over the United States. The spatial resolution of the data is 30 meters and mapped in the Albers Conic Equal Area projection, NAD 83. The NLCD are provided on a state-by-state basis. The state data sets were cut out from larger "regional" data sets that are mosaics of Landsat TM scenes. More detailed information on this dataset and the Land Cover Characterization Program can be found at http://landcover.usgs.gov/. The base data set for this project was leaves-off Landsat TM data, nominal-1992 acquisitions. Development of the 1992 NLCD was started in 1995, and the goal to develop a global 1km land cover characteristics database, was met in 1997.

The next-generation product, the 2001 NLCD database, is being compiled across all 50 states and Puerto Rico as a cooperative mapping effort of the MRLC 2001 Consortium. This land-cover database is created using mapping zones and contains standardized land cover components useful for a variety of applications. Zones 21, 22, and 29 that include the parks of the Greater Yellowstone Network are less than 10% complete for the 2001 NLCD (as of July 2004). All of the available data for this and the 1992 NLCD project can be viewed online at http://gisdata.usgs.net/website/MRLC/.

The Thematic Mapper multi-band mosaics were processed using an unsupervised clustering algorithm. Both leaves-off and leaves-on data sets were analyzed. The resulting clusters were then labeled using aerial photography and ground observations. Clusters that represented more than one land-cover category were also identified and, using various ancillary data sets, models developed to split the confused clusters into the correct land-cover categories.

Literature Cited:
USGS. 2004 National Land Cover Dataset, Product Description. USGS website. (http://landcover.usgs.gov/prodescription.asp.) Accessed 7/2/2004.

LAND USE

Under construction!!

SOUNDSCAPES

Soundscape Monitoring

Winter Soundscapes are being monitored in Yellowstone and Grand Teton National Parks to determine of management thresholds selected in the final Record of Decision for the Winter Use Plan are being met. A secondary objective is to collect baseline acoustic data for park-wide Soundscape management. The primary concern is human noise created by motorized recreational vehicles. Winter recreational use zones have been delineated and assigned threshold standards for maximum decibel levels and maximum audibility (percent of time sound is audible) for human-created sounds. Monitoring of sound in the different recreation management zones began during the 2003-2004 winter use season (December-March) (Burson 2003; Burson pers. comm.).

In GRTE an additional concern is noise emanating from the international airport located within the park boundary. Year-round monitoring began in 2003 with the installation of instrumentation to measure sound at four locations surrounding the airport. Information will be gathered about the audibility and decibel levels of aircraft and other sound sources. In addition, one year-round sound monitor is installed on Signal Mountain in GRTE (Burson 2003).

Literature Cited
Burson S. 2003. Soundscape Research in Grand Teton National Park 2003-2004. November 18, 2003. National Park Service, Grand Teton National Park, Moose, WY. 9 pp.

APPENDIX III: CONCEPTUAL MODELS

Conceptual models developed during Phase I and Phase II are presented in the following appendix.

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Ecosystem Conceptual Models for Bighorn Canyon National Recreation Area, Grand Teton National Park, and Yellowstone National Park

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INTRODUCTION

Adaptive management within the national parks requires an understanding of the complexity of the natural and human systems that interact in these areas. Adaptive management includes several important processes that produce information and understanding of the system enabling decision makers to proceed in an informed fashion. Although adaptive management is basically a way of "learning while doing", it is necessary to describe the interactive nature of the system being managed and monitored which leads to further management steps.

Important procedures needed within an adaptive management framework include (a) development of conceptual models of the system as well as issues and processes within the system, (b) identification of important issues and uncertainties, (c) development of research and programs to understand the uncertainties and to address issues, and (d) development of long-term monitoring programs that will assist assessment of management decisions and understanding of research outcomes.

The National Park Service has undertaken a program to identify "vital signs" or indicators of important changing conditions within the parks. Information from monitoring these indicators will be used to develop management decisions within an adaptive management framework. In a sense, vital signs or indicators are selected to be "the canary in the mine", forewarning managers of changes in important ecosystem parameters prior to these parameters, or related processes, reaching some critical threshold stage.

The conceptual models developed in this part of the vital signs program will be used to better understand the ecosystems of concern and to help guide those who will be selecting appropriate vital signs. These models have been developed based on the authors' understanding of the literature and the systems, and in consultation with scientists at the different parks. Consequently, this report does not include a literature review on which the models are based.

Rather than develop a single conceptual model to represent all of the important processes within the parks, we have chosen to develop a nest of models including (a) a general and simple overview model of the whole system, (b) a complex interactive system model for the whole system, (c) a set of sub-models relating to particular components or issues within each park, many potentially overlapping in stressors and/or indicators, and (d) temporal/spatial models of stressors, processes and outcomes to be used to help identify the importance of time and space in selection of vital signs or indicators for monitoring the system.

The temporal/spatial (time/space) models have been developed for only a few ecosystem sub-models. Three time/space models are presented in this report representing different aspects of the ecosystems. One is associated with the Bighorn Canyon uplands, one with the Grand Teton National Park water-related system, and one with the Yellowstone National Park aspen communities. The shaded area within the time/space models (100 years and 100-500 km^2) represents a temporal and spatial monitoring scope to be used to identify parameters that may likely be useful for monitoring. The line for each parameter is at the greatest time period in which that parameter functions; however, this means that the parameter may also be functioning in time frames much shorter than where the line falls and possibly as short as a year or less. The discussion about the time/space models is limited to a few comments on how the models might be used to select indicators.

In the ecosystem sub-models, drivers are represented in rectangles, stressors in ovals, processes in diamonds, outcomes in hexagons and indicators (possible vital signs) in parallelograms. The process polygon (diamond) may represent a set of interactions or a small internal sub-models. These internal process sub-models are not presented in this report, but rather, the statement "dynamics" within many diamond polygons often implies more than a simple process.

This project has developed conceptual models for Bighorn Canyon National Recreation Area, Grand Teton National Park, and Yellowstone National Park. The latter two parks are adjacent and thus share many similar attributes and issues, while Bighorn Canyon is in an arid region and quite separate from the other parks. Although the conceptual model development process was similar, the models are quite different with the exception of the general systems model for Yellowstone and Grand Teton. In some cases, models addressing similar issues between parks are quite different because the importance of drivers or stressors of the ecosystem or attribute of concern are different.

BIGHORN CANYON NATIONAL RECREATION AREA

Bighorn Canyon National Recreation Area (BICA) was established in response to recreational potentials related to Bighorn Canyon reservoir. Uplands associated with the reservoir were also included. These arid uplands encompassed part of a wild horse range, and supported a population of bighorn sheep. Conceptual model development for BICA had to consider both the water related components

of the system as well as the uplands.

An important aspect of understanding the BICA systems is an understanding of the external influences on the park. Unlike Yellowstone National Park and Grand Teton National Park, BICA is greatly influenced by activities in the surrounding and upstream watersheds, especially those factors that influence quality and quantity of inputs to the reservoir.

The simple overview model of BICA (BICA Figure 1) shows the linkages among the major attributes of the system. Internally within BICA geology and climate drive biological and hydrological aspects. Various biotic components respond to these attributes, for example, herbivore response to vegetation and aquatic biota response to streams and reservoirs. Of significance, as pointed out above, are the external influences on streams and the reservoir.

Bighorn Canyon NRA General Conceptual Model

The general conceptual model of the whole BICA system (BICA Figure 2) expands on the simple model showing details of the factors that control the system and the interactions among the internal and external attributes. External inputs relate directly to hydrological controls upstream of BICA and use of the external watersheds, for example, grazing and agriculture. The internal interactions show upland processes tied to vegetation and influencing factors, and reservoir processes and inputs. Although this model shows a complexity of interactions, the sub-models that follow show greater detail.

BIGHORN CANYON NRA SUB-MODELS

Two sub-models were developed for BICA. One presents the upland system, and the other the water-related system.

UPLAND VEGETATION SUB-MODEL

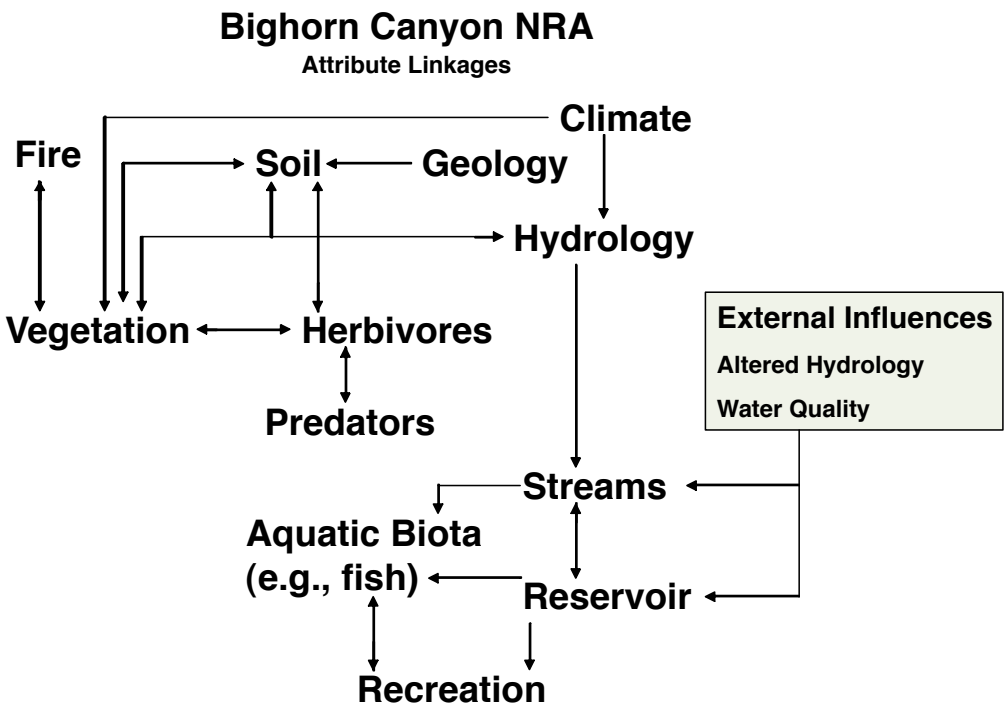
The upland system model (BICA Figure 3) shows the factors that drive vegetation and how the vegetation change. The indicators or potential vital signs of vegetation change include parameters of the different vegetation community types (e.g., grasses/forbs, shrubs/cacti, forest). Invasion of exotic plants and the increase of juniper stands in the upland may be of concern. Also, animals associated with the vegetation types may also be possible indicators of unacceptable change in the upland of BICA. This sub-model presents possible metrics that might be measure for each indicator.

Upland Vegetation Time/Space Model

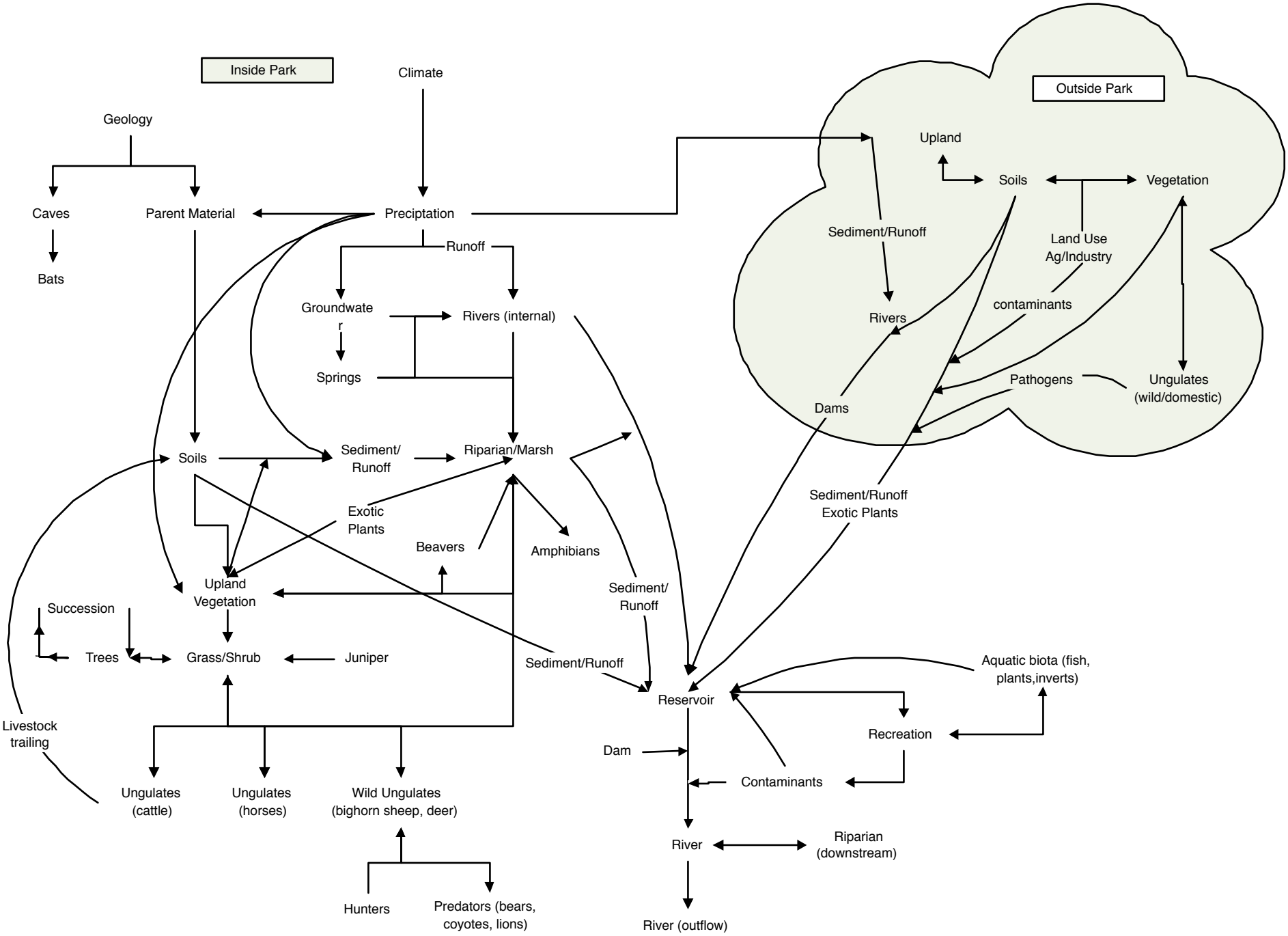
The time/space model for upland vegetation in Bighorn Canyon NRA (BICA Figure 3a) has three stressors, two within the monitoring scope time limits but extending beyond the spatial limits while the third (topographic aspect) relates to geological time and space. Except for climatic changes, the stressors relate directly to the presence of wild horses, a stressor that should probably continue to be monitored. Most of the outcomes also are with a monitoring time frame that would make indicators associated with these outcomes logical ones to consider. Change in herbaceous vegetation is short-term and may lead to a logical single indicator.

WATER-RELATED SUB-MODEL

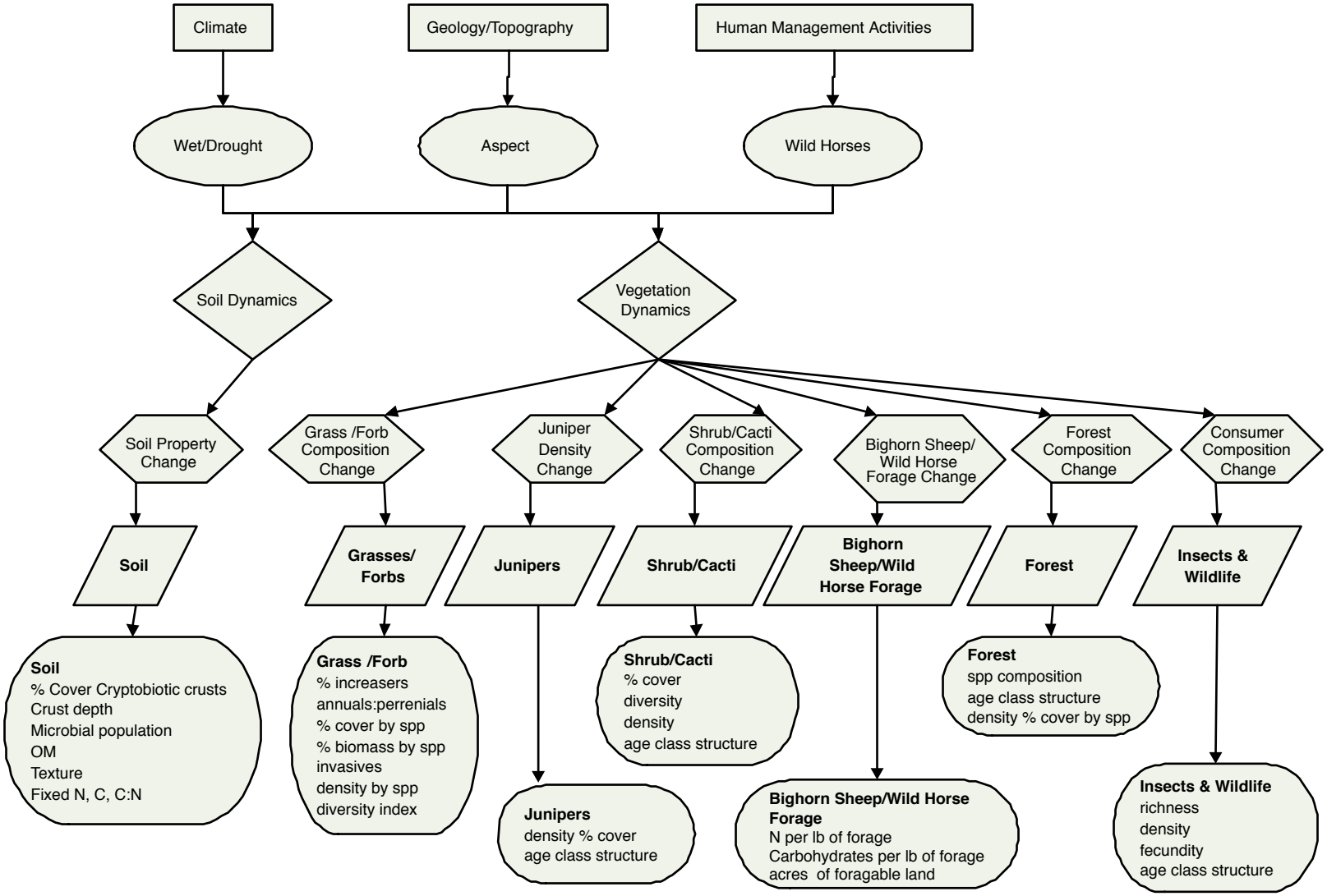
The water-related sub-model for BICA (BICA Figure 4) shows both water-related issues relative to streams and the reservoir, and riparian and spring related parameters. Similar stressors influence these different groups which include human activities in the upland and on the reservoir as well as upland land uses and changes. Changing climate and altered hydrology from within and outside the park also play a role in influencing the water-related attributes of BICA. Consequently, the model shows that possible indicators of water-related issues include parameters tied to streams, reservoir, springs, riparian areas and recreation. Selecting among these many potential water-related parameters will require a close evaluation of their interactions.



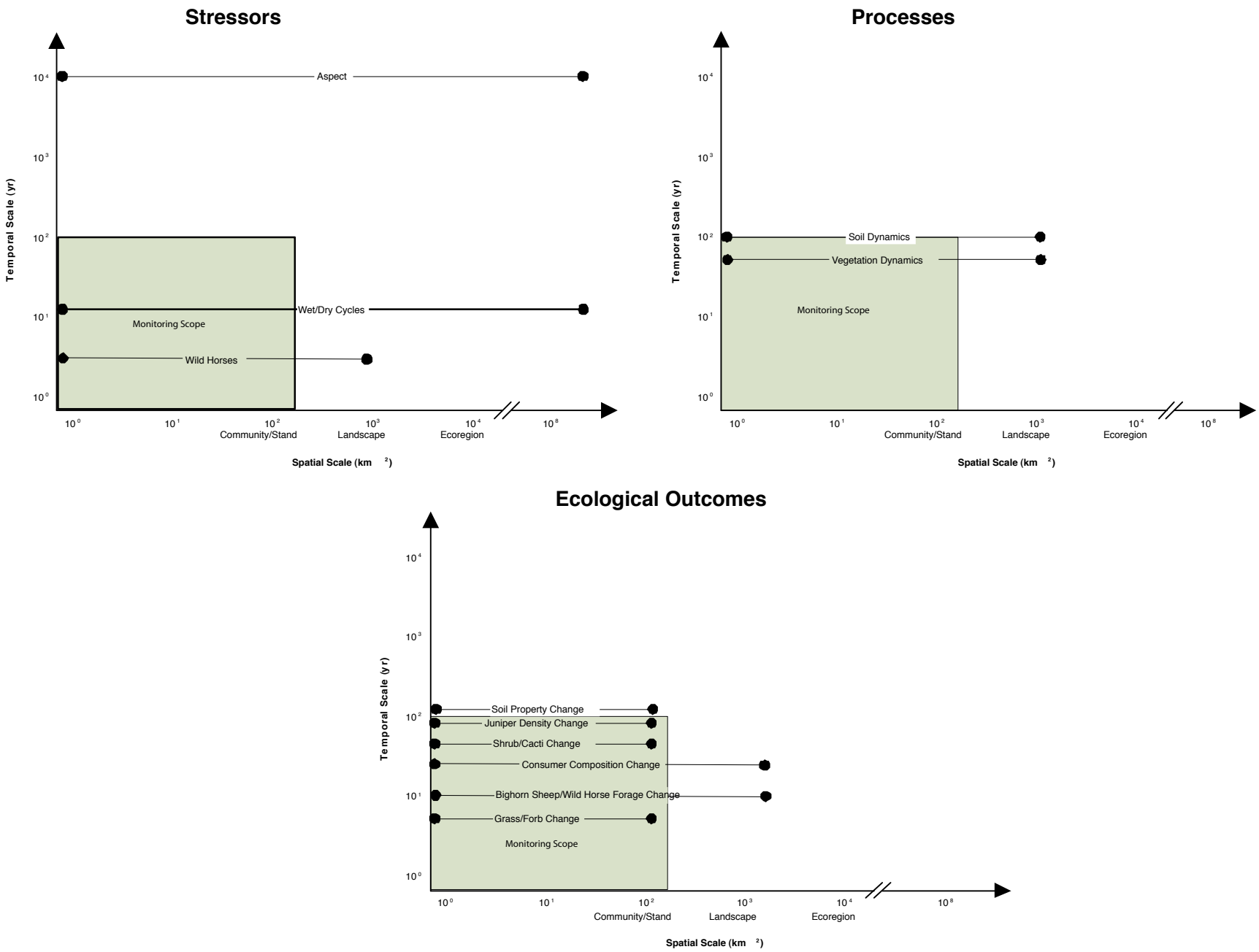
BICA FIGURE 1 Bighorn Canyon NRA overview model.



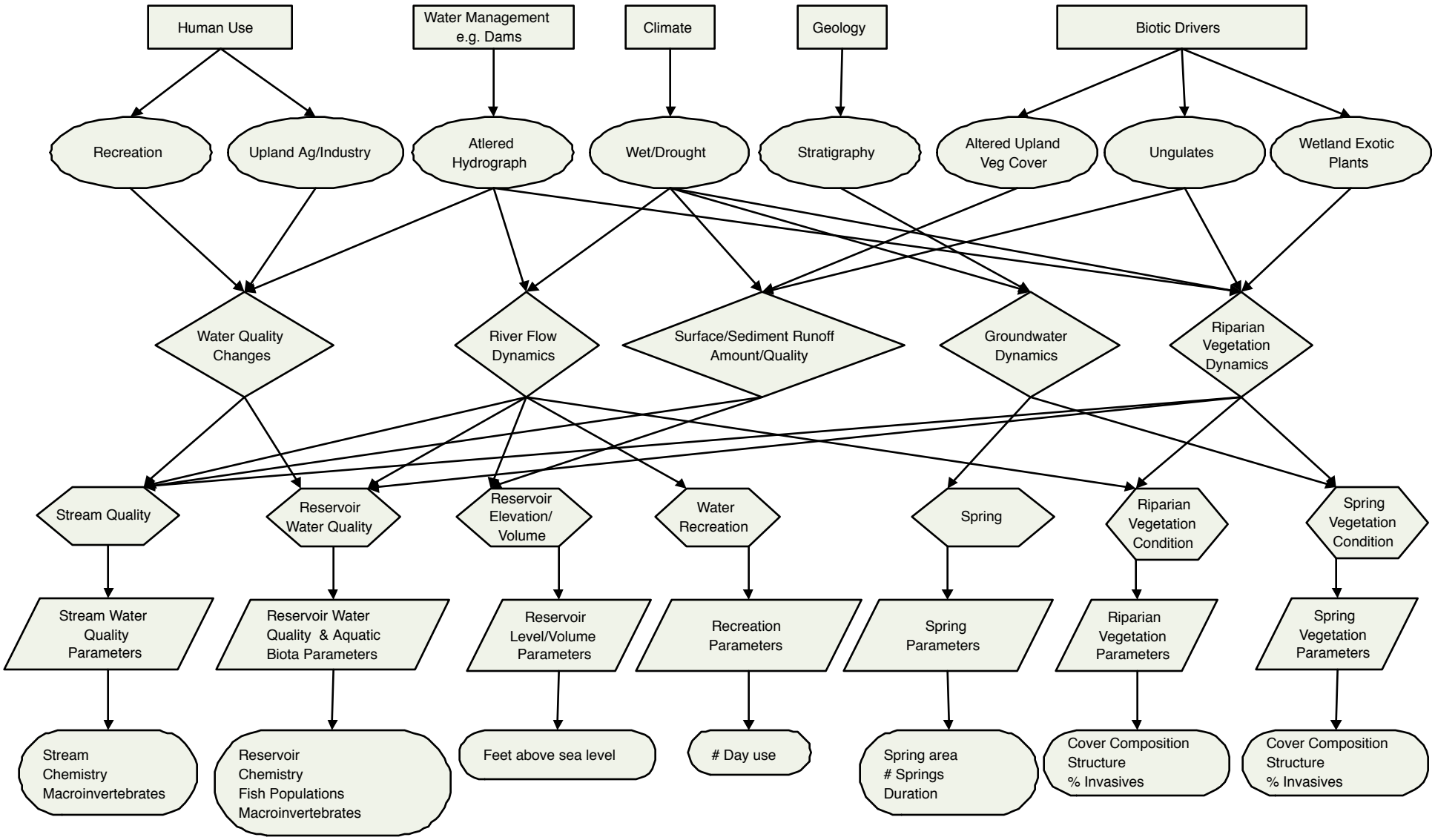
BICA FIGURE 2 General conceptual model.



BICA FIGURE 3 Upland vegetation system model.



BICA FIGURE 3A Upland vegetation time/space model.



BICA FIGURE 4 Water related resources model.

GRAND TETON NATIONAL PARK

Conceptual models for Grand Teton National Park (GTNP) include a simple and complex system model and sub-models related to uplands and components of uplands, and water related attributes and components of these. The simple system model (GTNP Figure 1) shows the relationships and linkages among the many primary components of the park. Climate, geology and human activities are the primary drivers. Human activities are used in this simple model but not in the one for Yellowstone National Park, not because humans don't influence many aspects of Yellowstone, but because when GTNP was enlarged in the 1950s many human activities were "grandfathered" into activities and management of the park, for example, a dam and reservoir, domestic grazing, and hunting. These activities have not existed or no longer occur in Yellowstone. GTNP Figure 1 also shows the interactions between many factors demonstrating that ecosystem processes are not unidirectional.

Grand Teton National Park Complex System Model

The complex systems model for GTNP (GTNP Figure 2) attempts to show all of the major attributes of the park and relationships among them. There are many attributes not included in this model, such as insects and small birds, but some of these attributes are covered in sub-models of the system. Of importance in this systems model are primary drivers of climate and geology and the interactions among vegetation, herbivores and predators. Also, the model shows how the controlled hydrology of the Jackson Lake reservoir relates to the whole system, as well as the role of fire and forest succession. This model, like a similar one for Yellowstone, uses different arrow types to show whether a process is an energy flow, physical or chemical, or successional process. The role of humans in recreation and influence on animal behavior and migration also are shown. Details of various interactive processes within the GTNP system are shown in sub-models and associated time/space models.

GRAND TETON NATIONAL PARK SUB-MODELS

Sub-models for GTNP relate to both uplands and water-related issues. In addition to the Upland Ungulates Sub-model (GTNP Figure 3), two additional sub-models were developed that relate to upland ecosystems. One is a sub-model showing ecosystem processes that influence medium sized predators and herbivores (GTNP Figure 4) and the other relates to birds (GTNP Figure 5). This was done because the model on upland ungulates covered large herbivores and predators and ignored smaller species.

UPLAND UNGULATES SUB-MODEL

The primary upland model (GTNP Figure 3) deals with upland ungulates (e.g., elk and deer). This model shows an array of stressors that influence the ungulate population and the vegetation on which ungulates depend. Humans play an important role in ungulate behavior just by their presence as well as through hunting, an activity that is relatively unique to GTNP. Unlike the Bighorn models, this upland ungulate sub-model only presents indicators and does not suggest possible metrics for these indicators. Other GTNP sub-models may suggest metrics. In this upland ungulate model, although the stressors are many, the indicators are few, that is, ungulate parameters and vegetation parameters.

MEDIUM SIZED UNGULATES AND PREDATORS SUB-MODEL

Medium sized ungulates and predators (GTNP Figure 4) are greatly influenced by humans, large predators and climatic variables. The latter, in turn, influences productivity of the herbivore food source. Possible indicators and metrics for this model primarily include demographic parameters of each group of species.

BIRD SUB-MODEL

The second upland related sub-model (GTNP Figure 5) covers birds, a group of species that were not fully covered in the complex systems model. In this model, humans, climate and factors that influence avian habitat and food sources (e.g., plants, seeds and insects) are the primary drivers and stressors. The indicators cover most functional groups of bird species as well as associated insects.

WATER RELATED SUB-MODELS

The next three conceptual model sets relate to water or water-oriented attributes of GTNP. The first (GTNP Figure 6) is a relatively general model that covers water-oriented recreation, water quality, altered hydrology and factors influencing riparian vegetation. The emphasis of this model is the role of modification of the river through establishment of a dam and reservoir along with limited bank stabilization as well as other hydrological modifications such as irrigation take-outs and return flows. Consequently, the set of indicators are quite broad and cover an array of factors including water quality, recreation use and riparian condition.

Water-Related Time/Space Model

The time/space model for water related processes within Grand Teton National Park shows most stressor, process and outcome parameters falling within the monitoring scope area with some, such

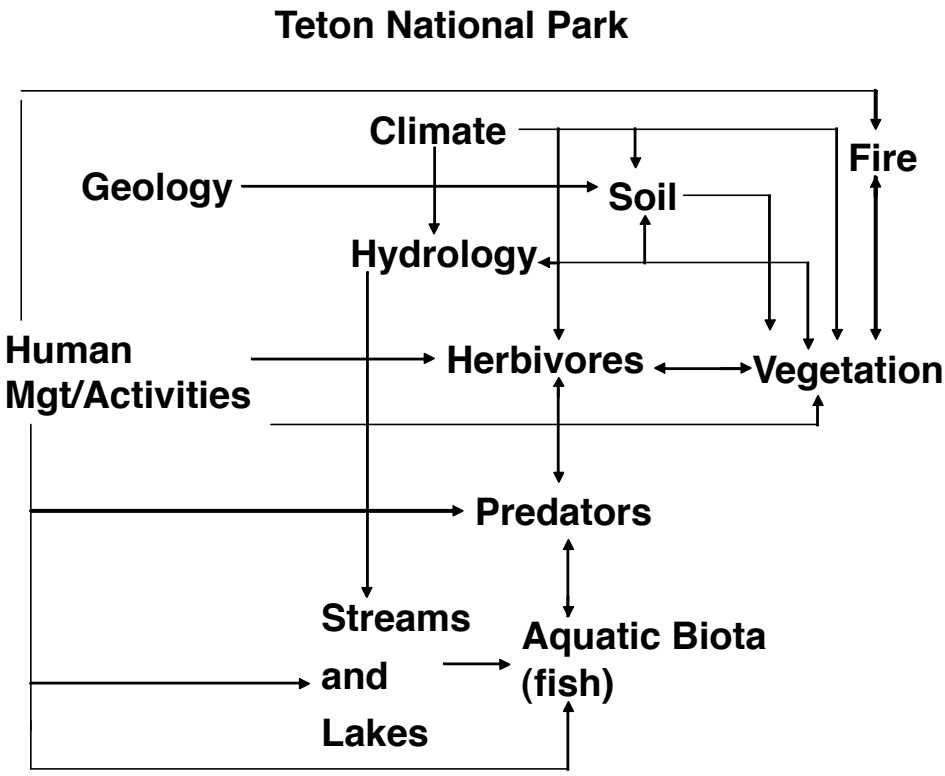
as climatic factors, falling outside the area spatially. This does not mean these should not be considered for measurement, but rather their importance relates to the whole park but still may be important parameters to consider for measuring or monitoring. Several outcome parameters are short-term and relate to hydrological conditions, conditions that may have logical indicators for long-term monitoring, but that which require regular short-term measurements.

RIVERINE SUB-MODEL

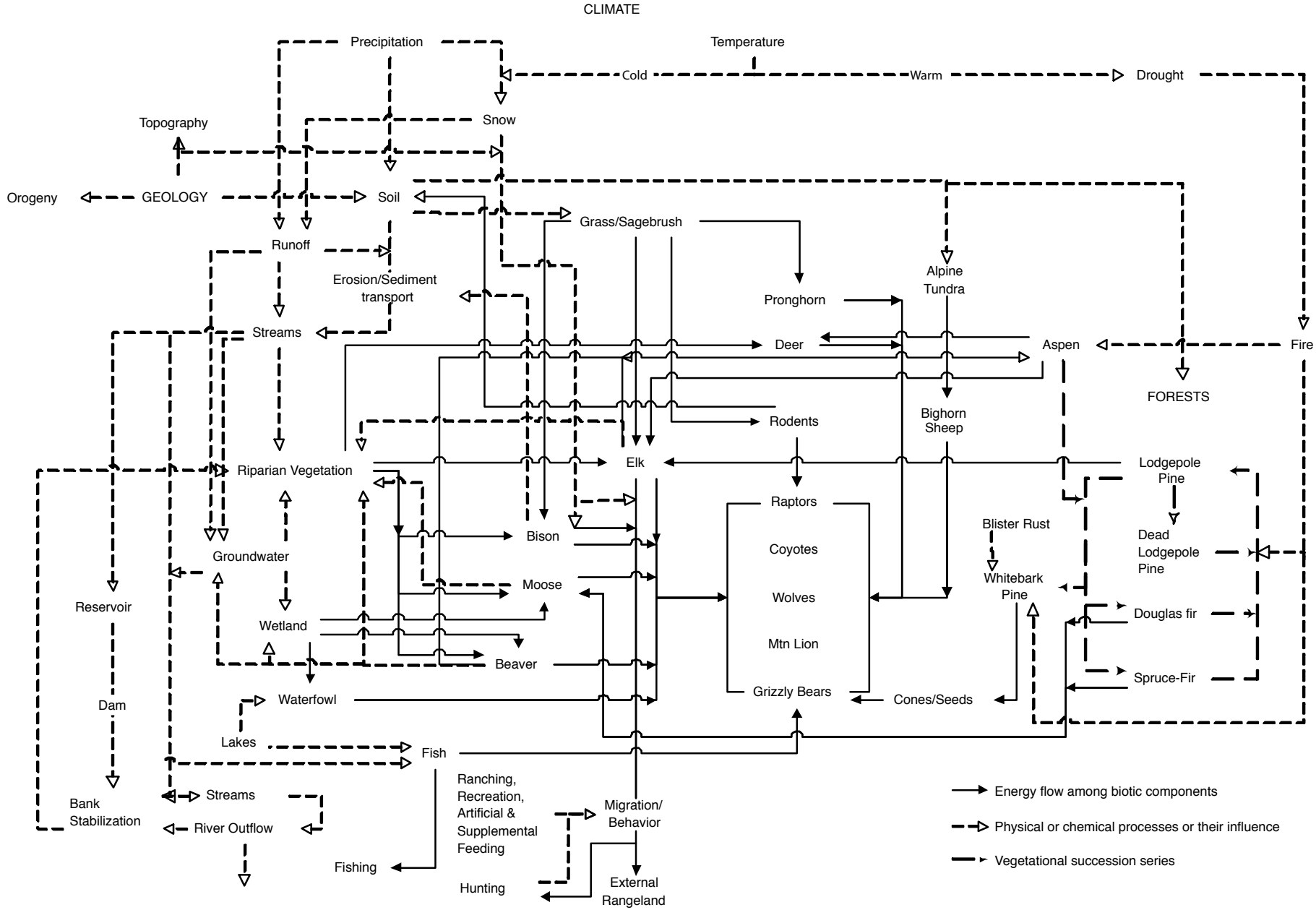
The second water-related model (GTNP Figure 7) relates to the riverine system of GTNP and emphasizes hydrological, fluvial and riparian processes. There are some similar drivers, stressors and indicators as the prior model (GTNP Figure 6), but the indicators of this model relate to the river and not the reservoir. Many of the processes lead to riparian vegetation and thus one might assume that riparian vegetation in these water-related models may be an important indicator. Other indicators such as exotic plants and river geomorphology may also rise to the surface as important, across-the-board indicators.

WETLANDS SUB-MODEL

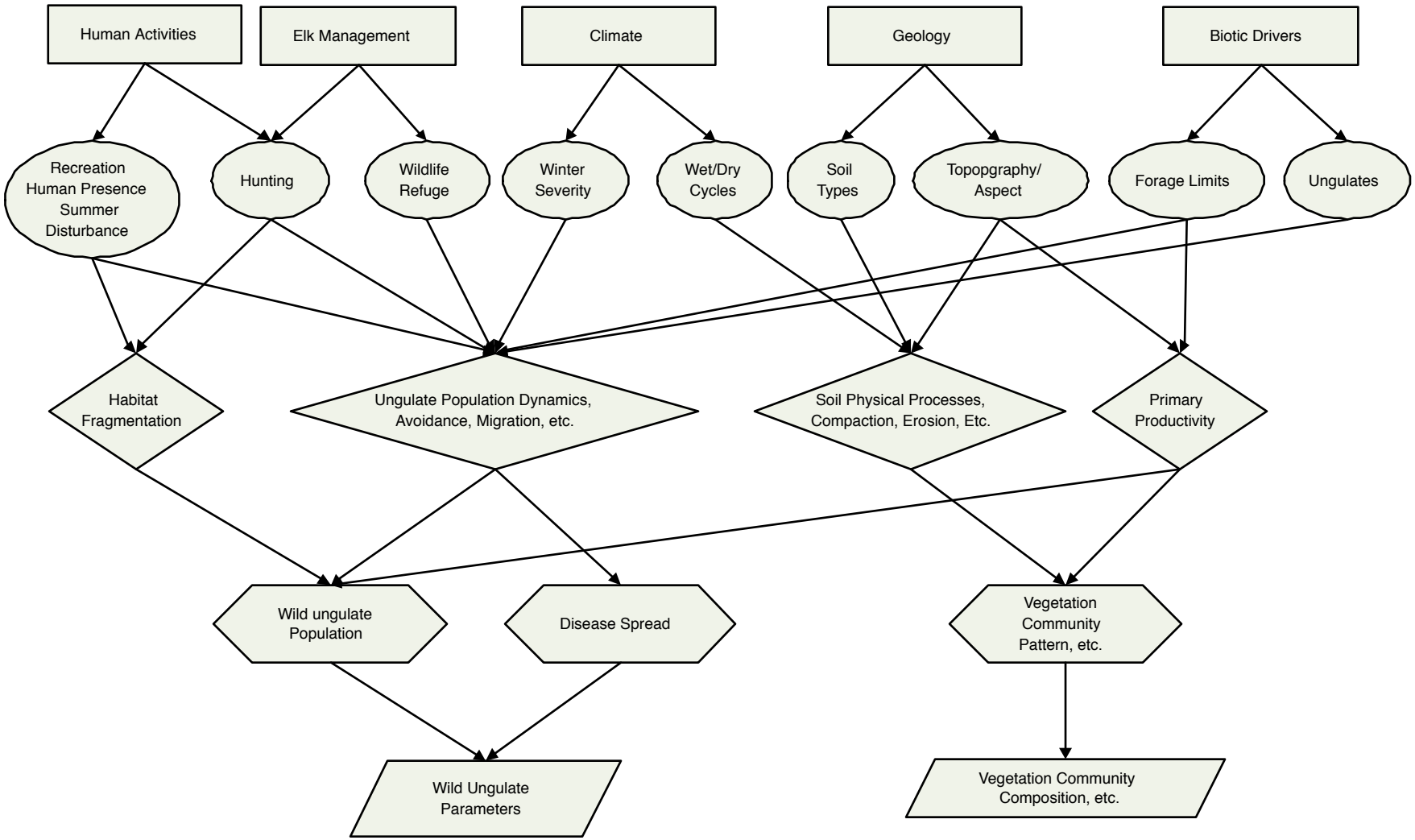
Wetlands are often considered sites of high biodiversity. Consequently, the third of the water-related conceptual models deals with wetlands within GTNP (GTNP Figure 8). Many factors influence processes that create or maintain wetlands such as climate, humans, predators on beavers, and wetland plant herbivores. These all, in some way, eventually influence the condition of the several different wetland types in GTNP (i.e., potholes, willow communities, beaver dam wetlands, and herbaceous wetlands). Indicators of wetlands are not exclusively habitat oriented, such as vegetation parameters, but also include important species that use the habitat. For this reason, important indicators of wetlands may include amphibians and birds that may exclusively depend on these habitats.



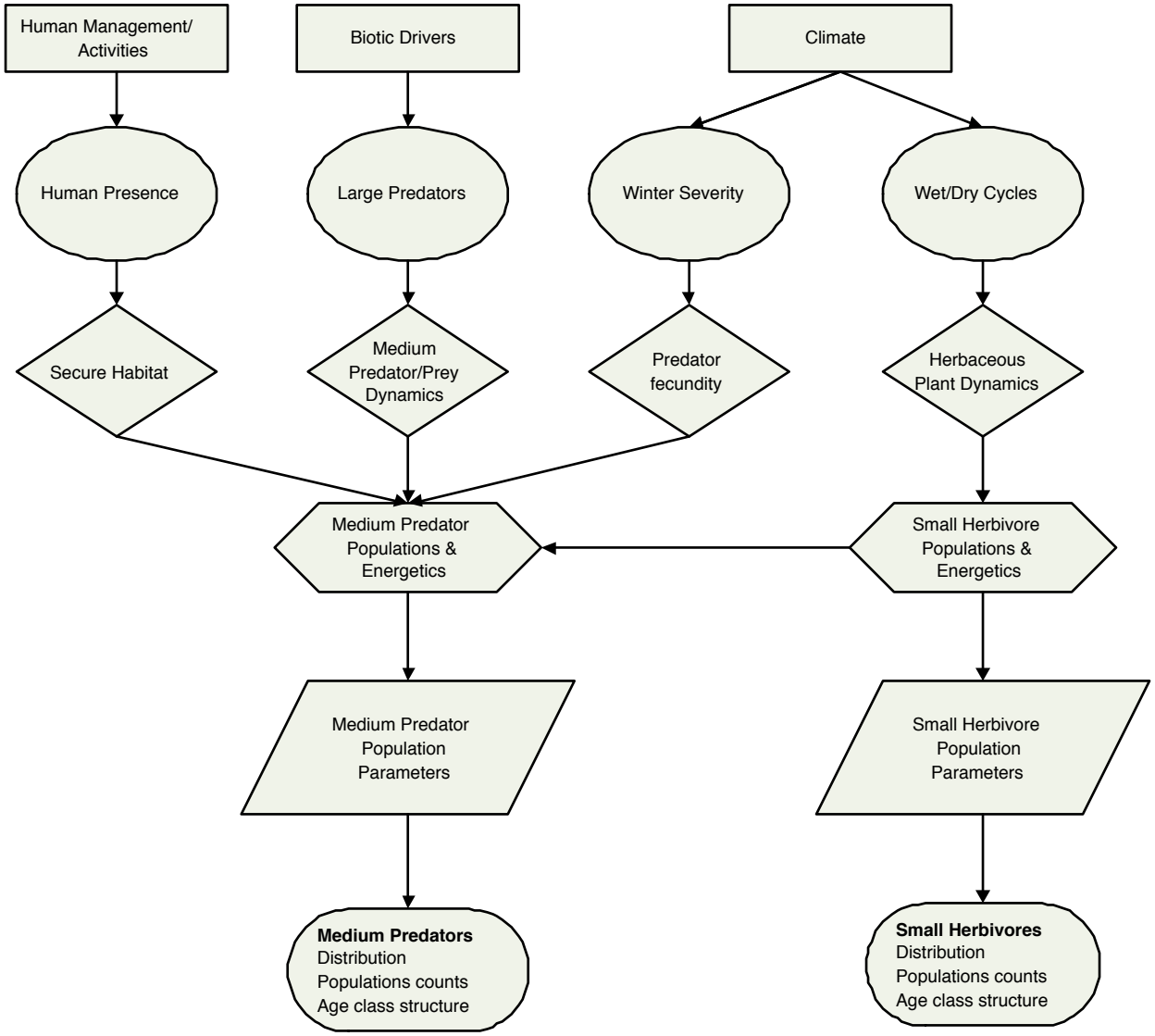
GTNP FIGURE 1 Grand Teton system overview model.



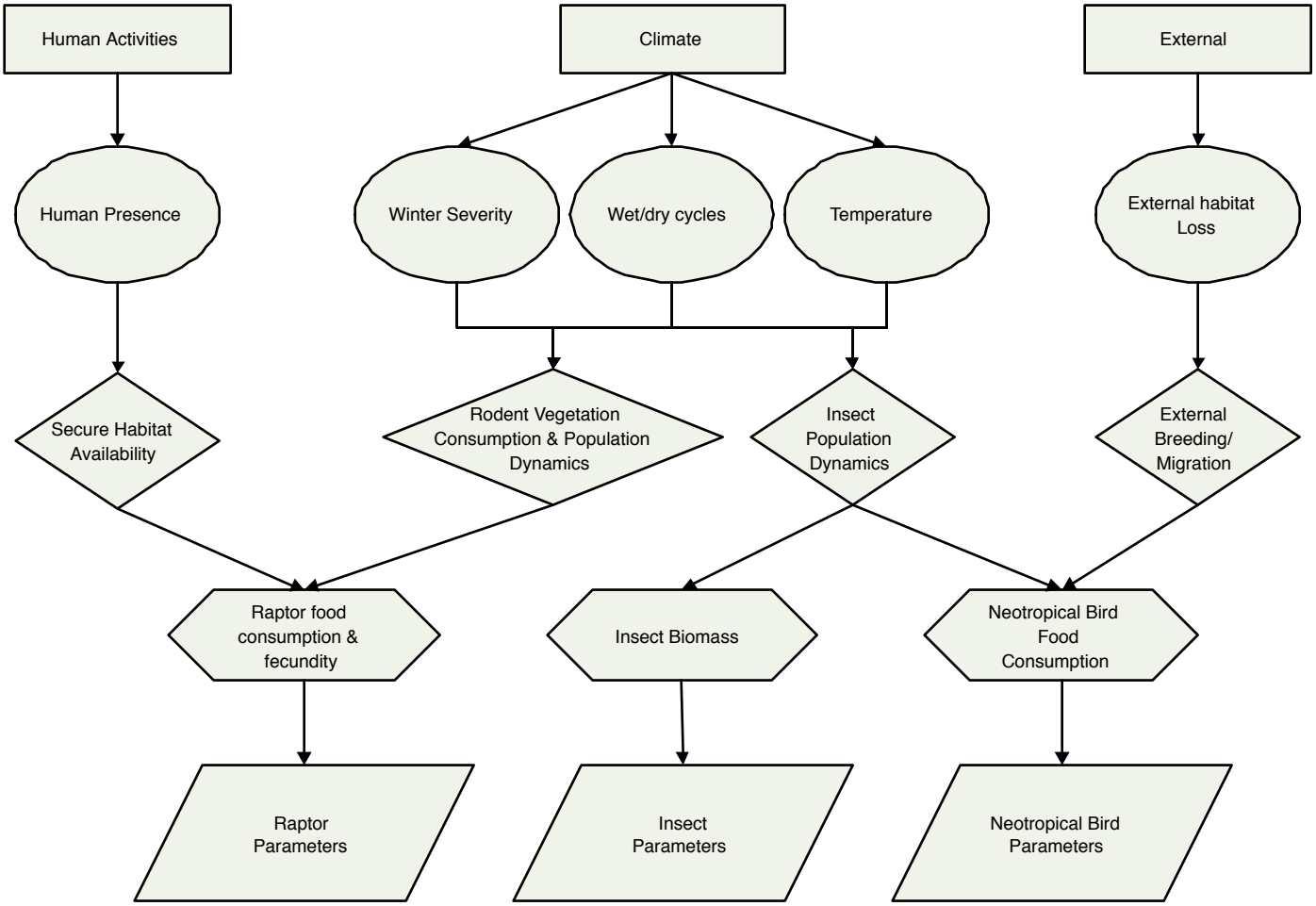
GTNP FIGURE 2 Complex system model.



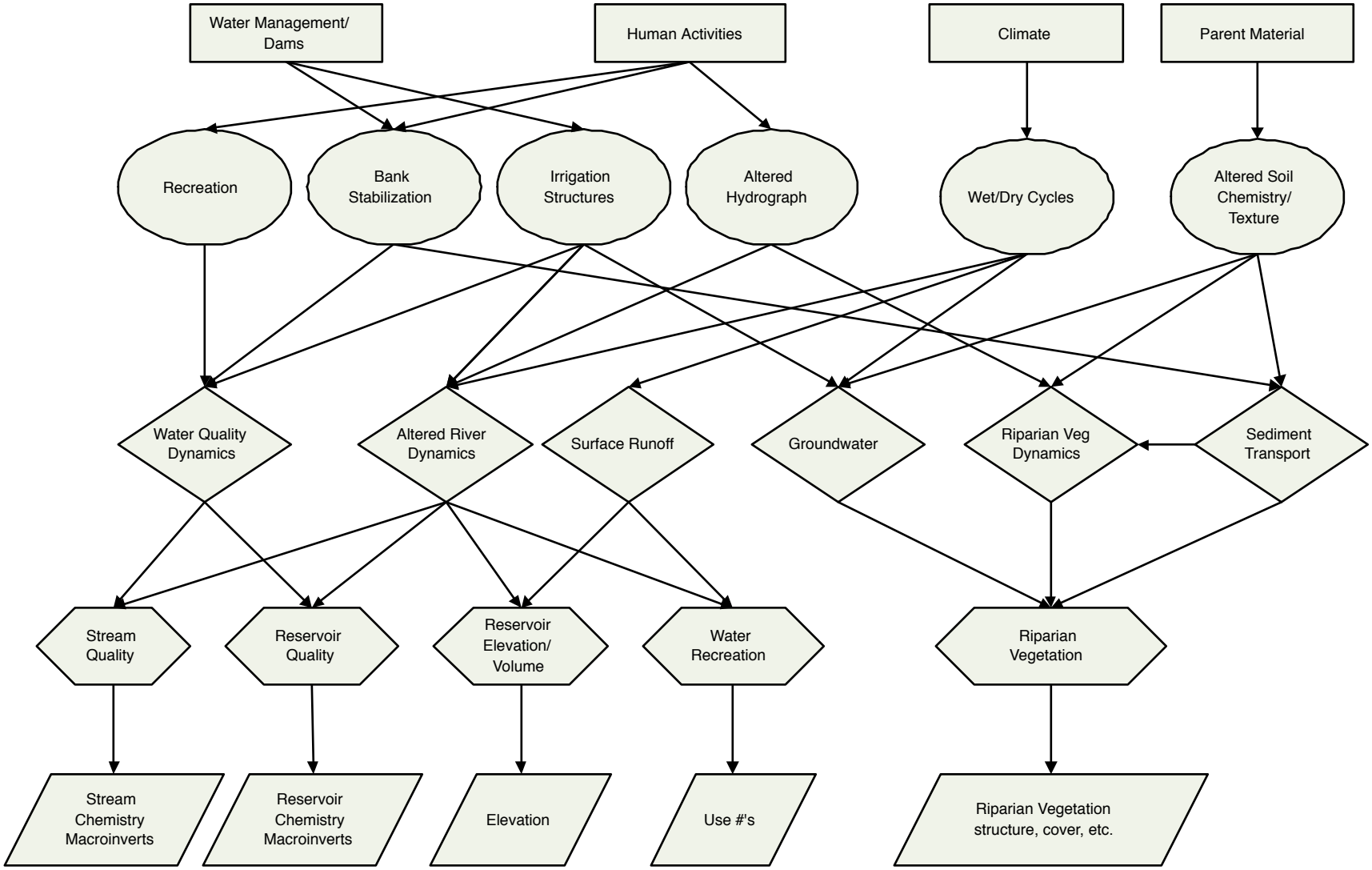
GTNP FIGURE 3 Upland ungulate model.



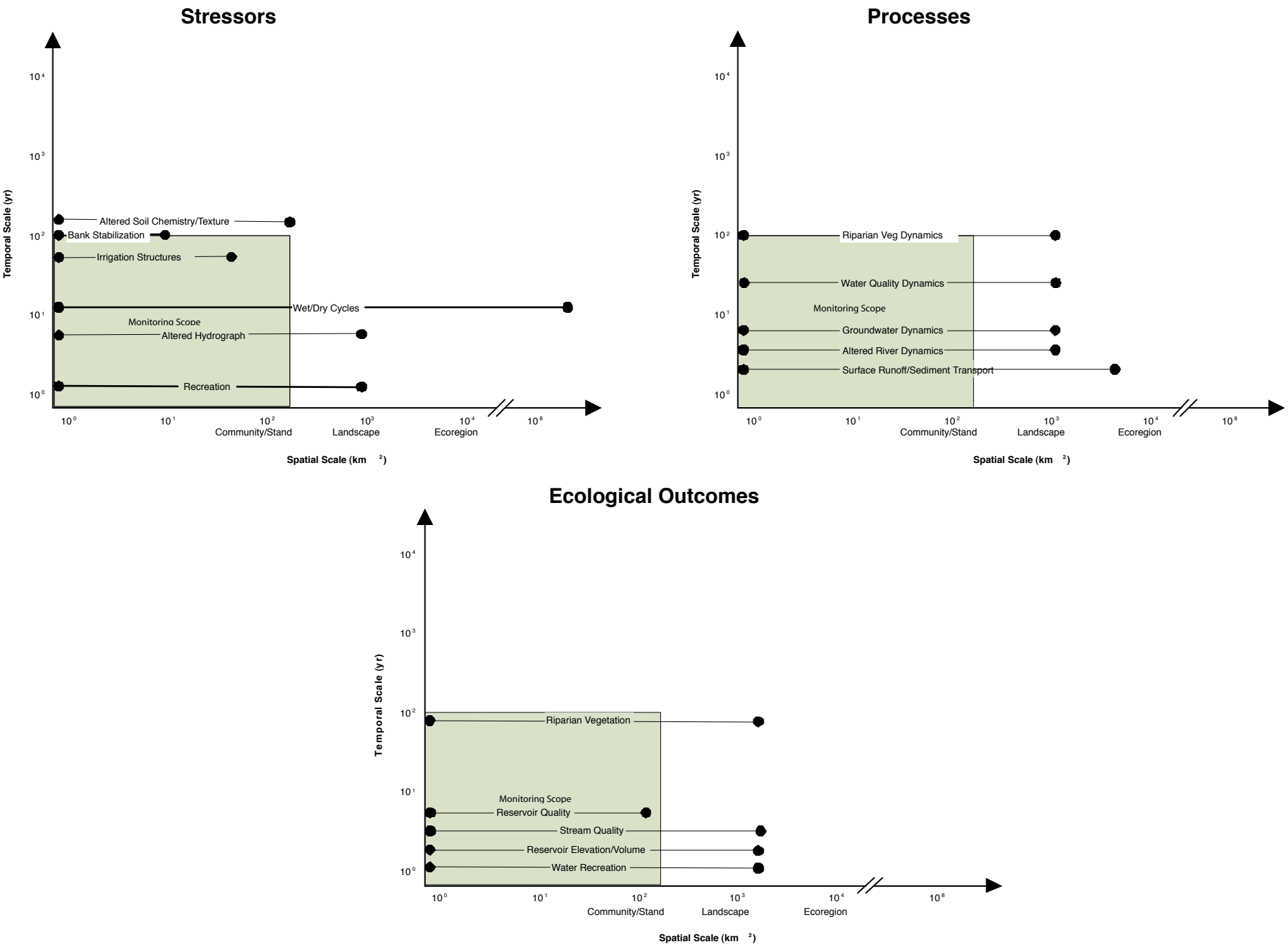
GTNP FIGURE 4 Medium predators & herbivores sub-model.



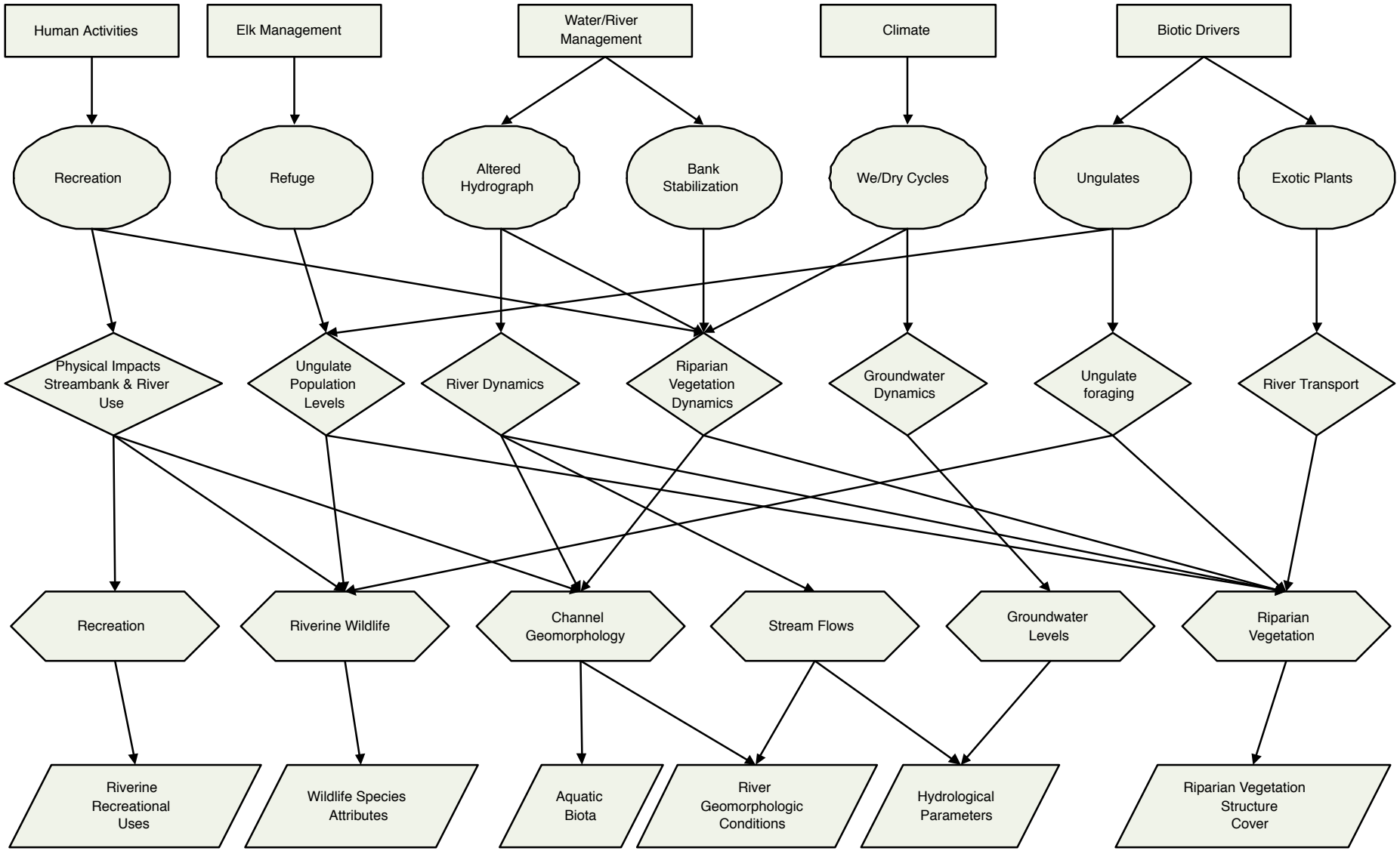
GTNP FIGURE 5 Bird sub-model.



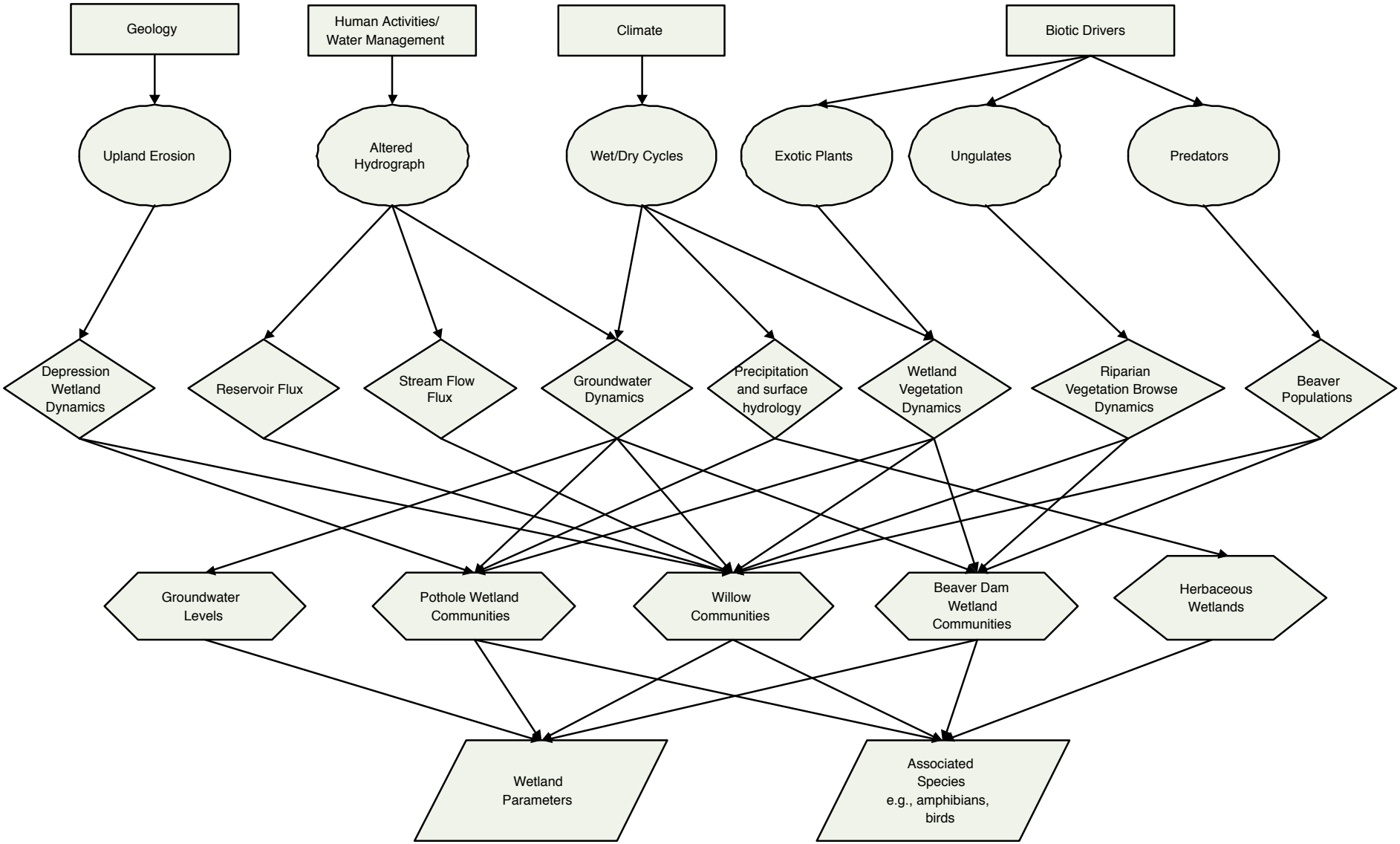
GTNP FIGURE 6 Water related model.



GTNP FIGURE 6A Water resource time/space model.



GTNP FIGURE 7 Riverine model.



GTNP FIGURE 8 Wetlands model.

YELLOWSTONE NATIONAL PARK

Conceptual models developed for Yellowstone National Park (YNP) are similar to those developed for GTNP in that they include a simple overview model, a complex system model and a set of sub-models that represent various ecosystems or components of the overall YNP system. The simple model of the YNP system (YNP Figure 1) illustrates the primary linkages among the general components of YNP. Unlike the GTNP simple model, this one does not include the role of humans, because YNP internally is not open to significant human actions that may modify components of the system as hunting and dam operations do within GTNP. However, human presence and management decisions do play an important role in the condition of ecosystems, communities and species populations within YNP.

Complex System Model

The complex system model for YNP (YNP Figure 2) includes most of the primary ecosystem components, and like the Teton model shows whether the interactions between components are energy flow, physical or chemical, or successional processes. The primary drivers of the model are climate and geology with the former (climate) producing conditions that influence major ecosystem altering conditions, such as fire, and conditions that influence wildlife such as snow, while the latter (geology) drives important attributes such as topography and soils, but may be more obvious as a driver of the geothermal features of YNP. The role of humans is documented in the model as influencing ungulate migration and behavior, some of this being done from outside the park as hunting and development pressures. The model attempts to show linkages among hydrology, vegetation and wildlife, interactions and processes that have become important management issues.

YELLOWSTONE NATIONAL PARK SUB-MODELS

Several sub-models of important processes or attributes within the YNP system have been developed to allow a better understanding of the interrelationships among stressors, processes, outcomes and indicators than can be discerned from the whole system conceptual model. The sub-models presented here include ones dealing with elk, aspen, riparian/wetlands, and sediment/erosion processes. There are many other potential models such as those dealing with other ungulates and predators, or fires, but the ones included here have many of the drivers, stressors and processes that would be in those models as well.

Elk Sub-Model

The elk sub-model (YNP Figure 3) emphasizes both the climatic and predatory (hunting and predators) nature of the stressors on elk populations. Disease also plays a role as do those factors influencing food sources for elk. The indicators for this sub-model list some potential metrics for monitoring.

ASPEN SUB-MODEL

The condition of aspen in YNP has become a management issue as well as an ecological problem. Aspen stands appear to be declining and no new mature aspen have established since the 1920s. The aspen sub-model shows the role of several animals as stressors. These include herbivory and girdling by ungulates, and the effects of beavers altering soil and ground water, and directly affecting aspen stands through cutting and girdling. Aspen sometimes functions as a riparian species when elevated groundwater levels create moist soil conditions. Fire is also considered a major stressor influencing destruction and recovery of aspen stands. Indicators for aspen communities include attributes other than just plant features. Most important non-vegetation parameters are the associated species that use aspen stands, such as songbirds.

Aspen Time/Space Model

The time/space model for aspen in Yellowstone National Park (YNP Figure 4a) shows that most of the stressors, processes and outcomes fall within the monitoring scope although some may extend across the landscape or region. When considering parameters to monitor relative to aspen communities, using outcomes that fall not only in the monitoring scope area but are short-term such as soil moisture and aspen recruitment as guidance may lead to potentially viable indicators more so than using outcomes that are long-term. Monitoring tied to community structure may also be possible if long-term results are needed. To understand the aspen system there is also a need to measure stressors. Those that are very long-term such as parent material need only be measured once or every decade or so, while short-term stressors that could change every year, such as herbivory or beaver dams and activity may need to be measured regularly (e.g., every year or two).

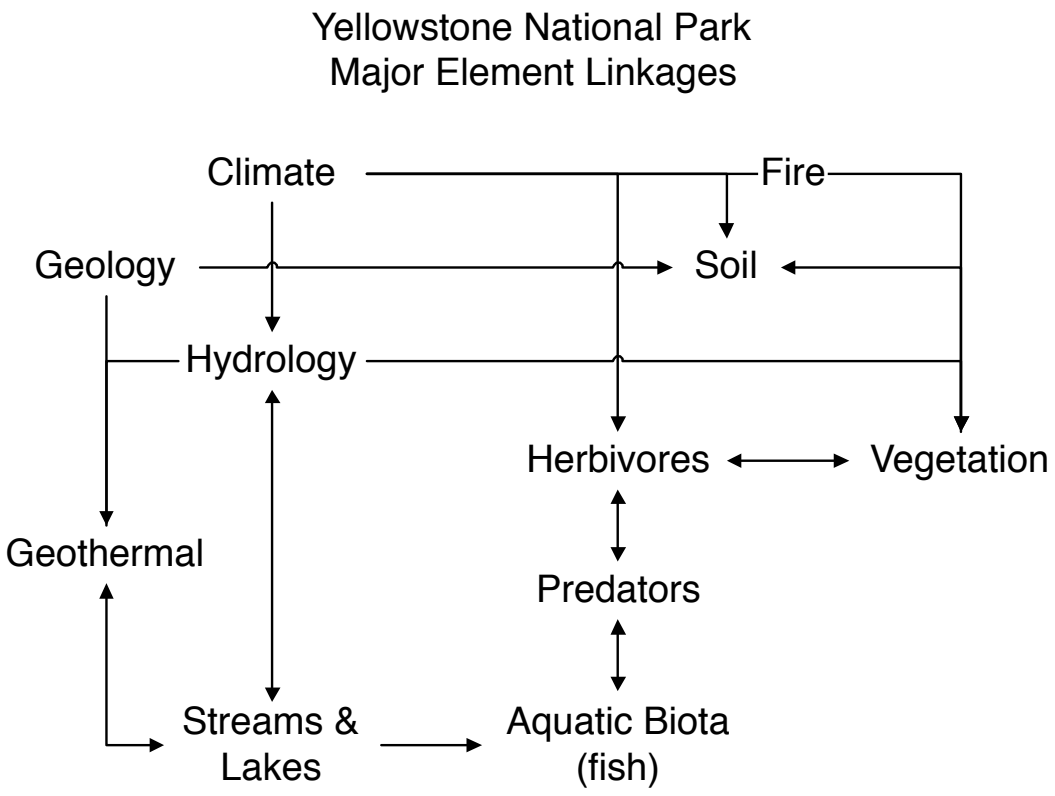
RIPARIAN AND WETLAND SUB-MODEL

Riparian and wetland ecosystems within YNP are known to maintain high levels of biodiversity. They also are systems that may be threatened by ungulate populations and potential climate change. The riparian/wetland conceptual model (YNP Figure 5) shows the multi-

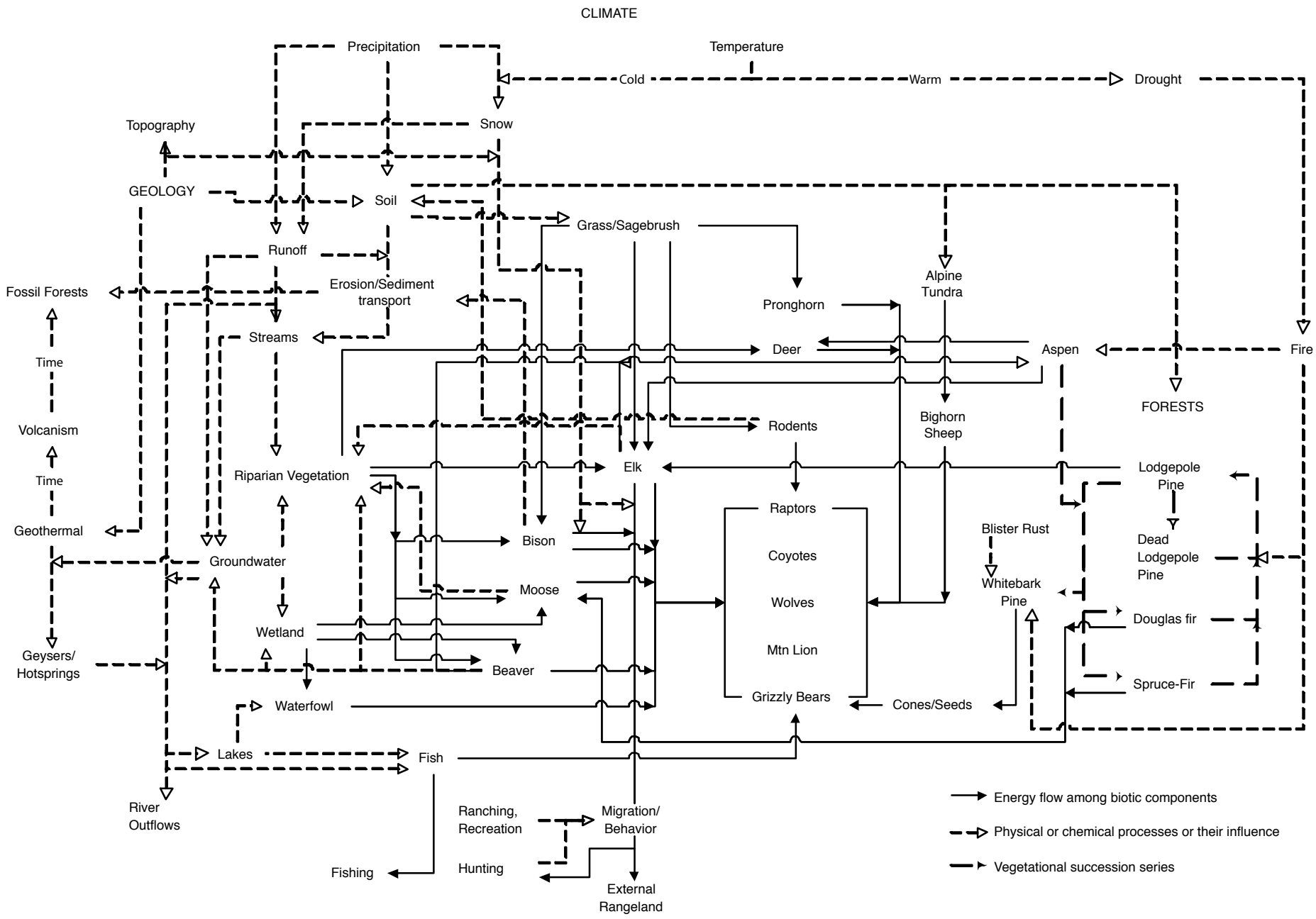
tude of drivers and stressors that influence these systems. The many processes that result from these stressors demonstrate the complex interactive nature of systems that interface between aquatic and terrestrial environments. Indicators of the condition of riparian/wetland ecosystems should include, not only vegetation conditions, but those species that use these ecosystems as habitat. In several cases, these associated species, for example amphibians, have been found to be very sensitive to environmental change.

EROSION AND SEDIMENT TRANSPORT SUB-MODEL

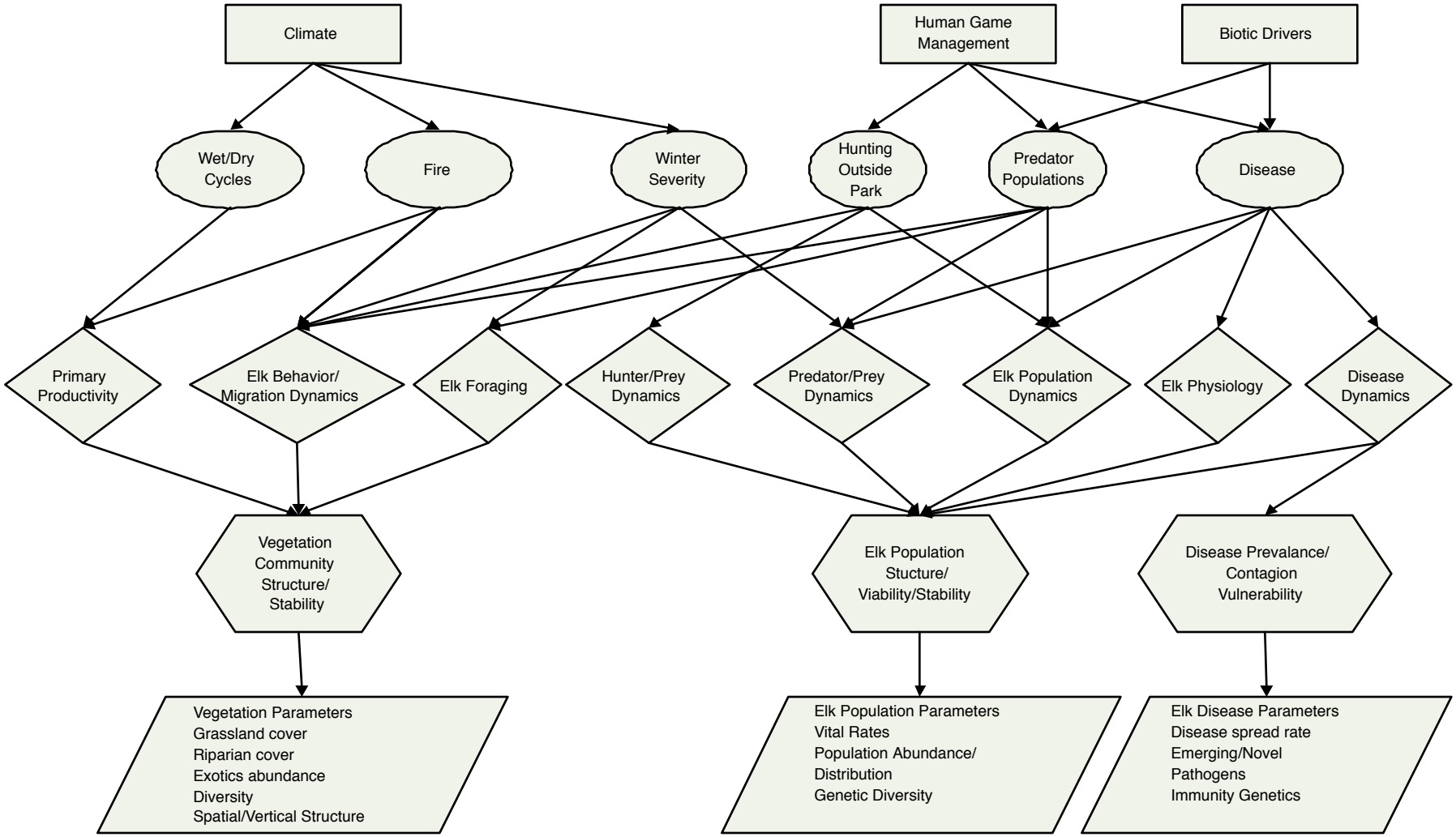
The final sub-model for the YNP ecosystem illustrates the complex processes of erosion and sediment transport (YNP Figure 6). The important drivers and stressors in this model include more physical processes than biological processes. The role of some biological components of the ecosystem, such as physical alteration of soil surfaces and vegetation structure by large herbivores, also may greatly influence the physical processes. Sediment loss from the land is a natural process but can be accelerated by many ecosystem components that are acting outside their historic range of variability. Consequently, the influence of sediment transport and deposition not only affects streams and depression areas but species that may depend on these systems. For this reason, the model includes spawning habitat in rivers. It doesn't include other animals that may be associated with wetland depressions because these are included in the riparian/wetland model. This is just one example of the overlap among the sub-models.



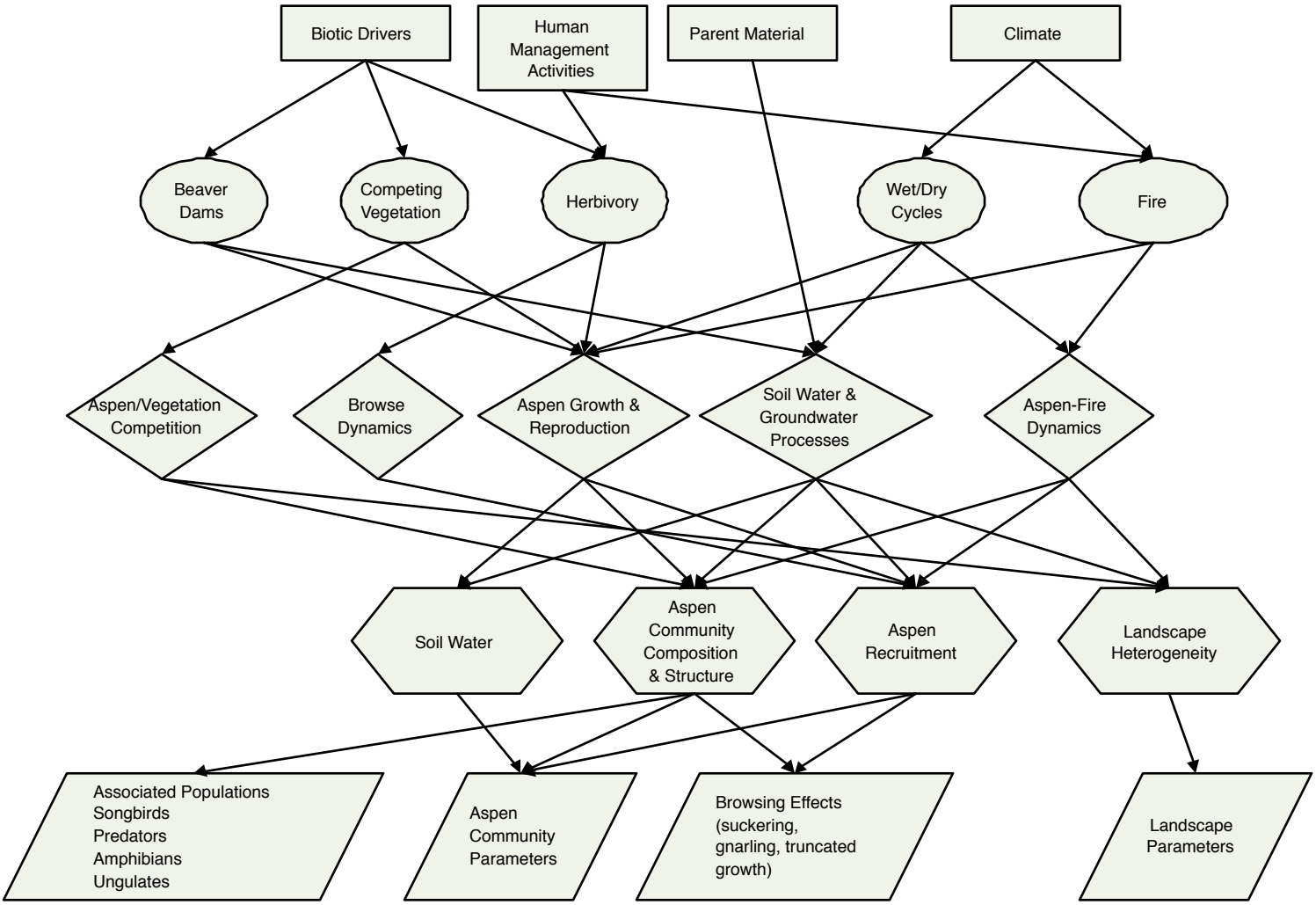
YNP FIGURE 1 Park overview model.



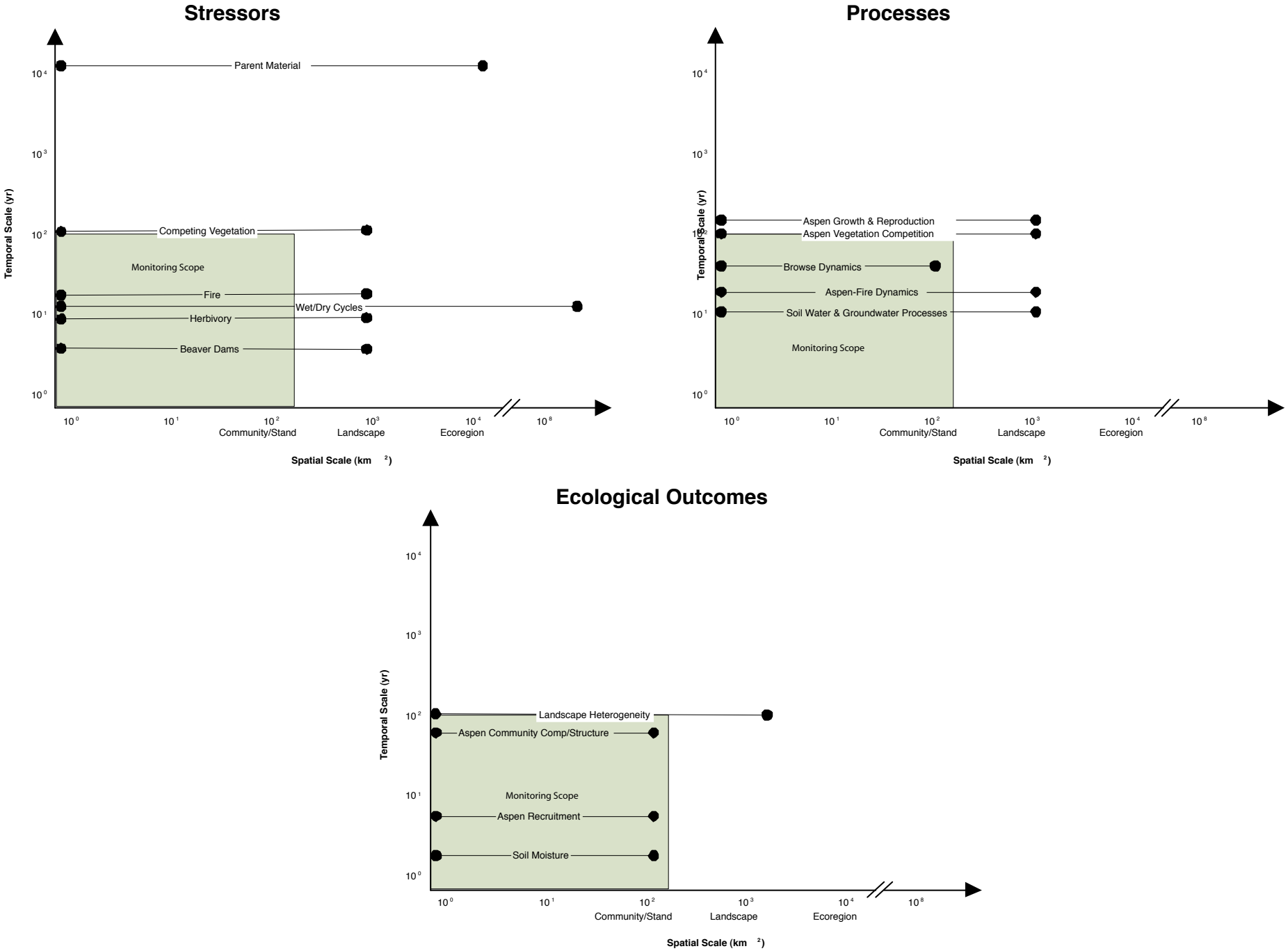
YNP FIGURE 2 Complex system model.



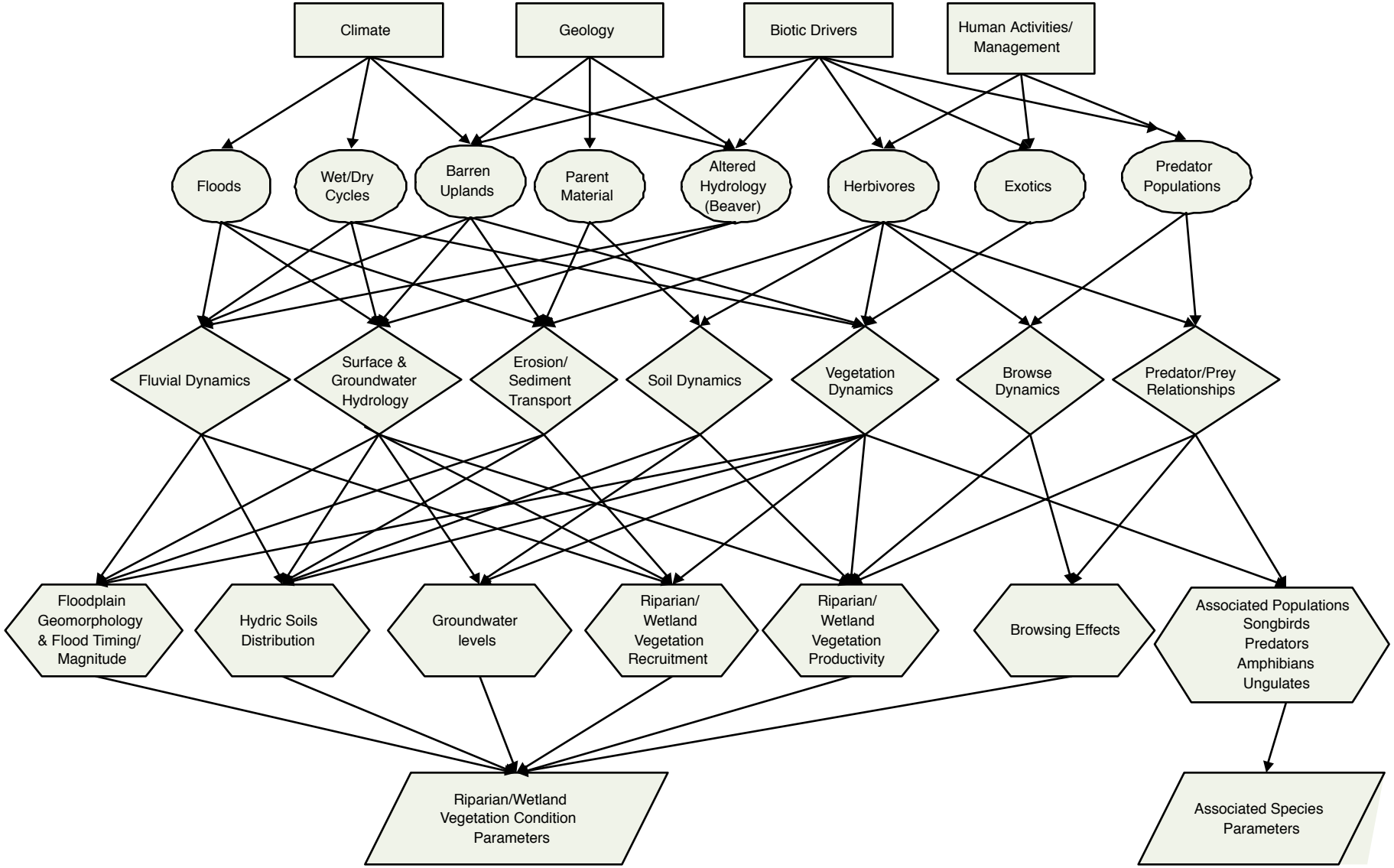
YNP FIGURE 3 Elk sub-model.



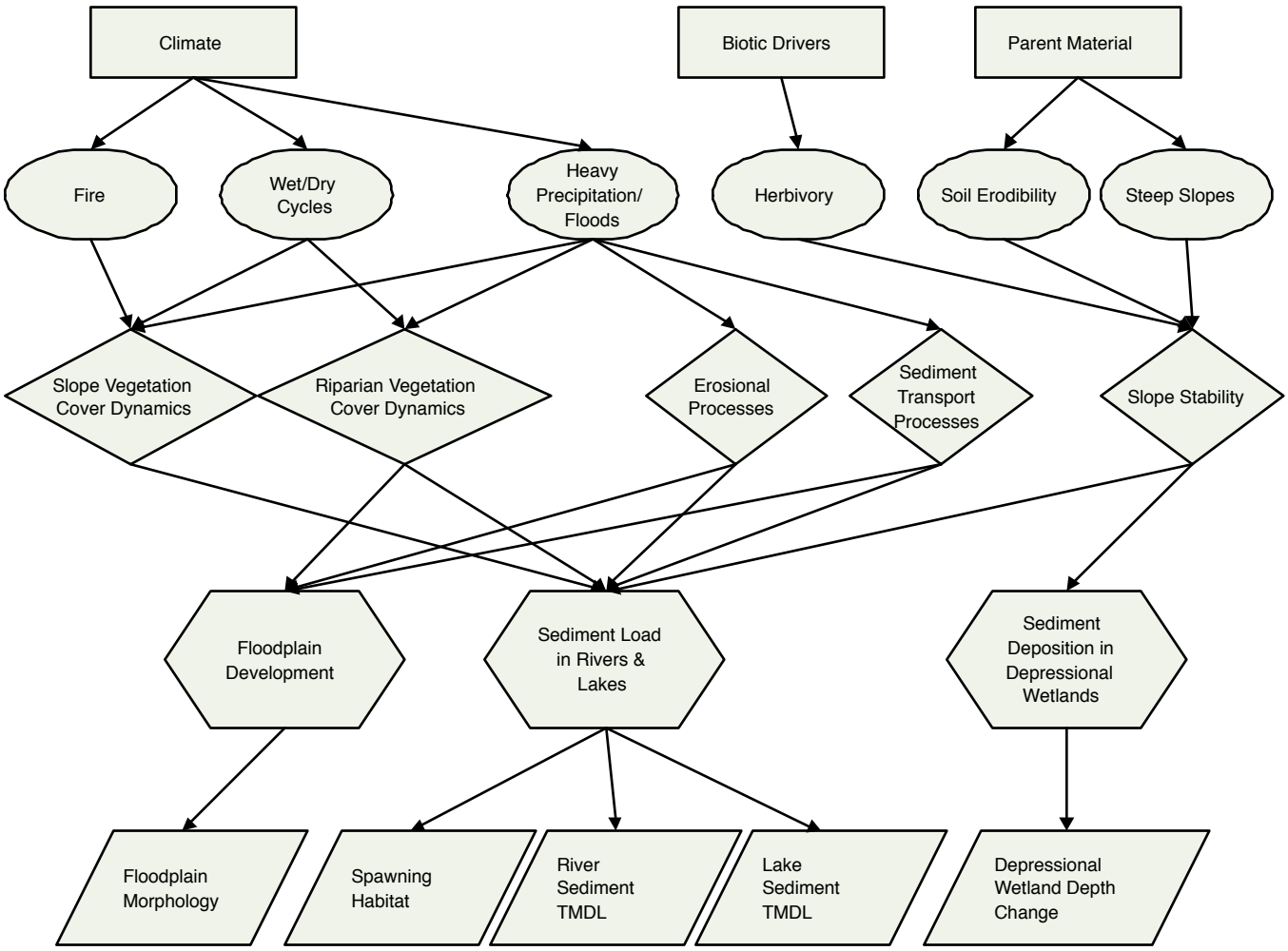
YNP FIGURE 3 Aspen sub-model.



YNP FIGURE 4A Aspen communities time/space model



YNP FIGURE 5 Riparian and wetland sub-model.



YNP FIGURE 6 Erosion/sediment transport sub-model.

Conceptual Models for Dominant Vegetation, Aquatic and Geothermal Ecosystems in Bighorn Canyon National Recreation Area, Grand Teton National Park, and Yellowstone National Park

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AQUATIC ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Bob Hall)

The GRYN contains a diverse group of lakes, both natural and human-made. There are numerous glacier-carved lakes in high alpine areas of the Teton Range, and several large lakes formed from tectonic processes. Bighorn Canyon contains a large impoundment, and the top 8 m of Jackson Lake is regulated by a dam at its outlet. The large lakes contain substantial biological and economic resources. For example, Yellowstone lake has the largest population of Yellowstone cutthroat trout (*Onchorhyncus clarki bouvieri*) (Gresswell and Varley 1988). These lakes are used extensively for recreation, such as boating and fishing. Bighorn and Jackson Lake are used for water storage.

River ecosystems are equally diverse in the GRYN. Rivers ranges from large lake outlets (e.g. Snake and Yellowstone rivers, to many high-mountain streams, and geothermally influenced rivers in the Madison drainage and South Boundary area of YNP. High variation in groundwater source, parent material, and topography lead to high variation in the types of streams within GRYN. In terms of ecosystems functions such as whole stream metabolism and nitrogen processing, streams within GTNP are more variable than 11 streams within different biomes ranging from the tropics to Alaska (Hall and Tank 2003).

In this narrative I will only consider the aquatic part of rivers as the riparian section is covered elsewhere, though stressors to streams and lakes can come from habitat damage to the riparian zone.

Drivers

Lakes are formed by exogenous processes (glacial scour, plate movement, dams, differential cooling of lava in the case of Yellowstone lake), and these processes shape the morphometry of the lake which, in turn will determine most aspects of its function. Climate plays a large role in temperature, hydrology and mixing regime of lakes. Human activities can affect lakes by altering hydrology, climate, nutrient load and biotic assemblages. Drivers for rivers are similar to those for lakes, except with the fundamental difference that rivers morphology is a function of the hydrology (driven by climate) of the river and geology of the drainage basin as channel structure changes through time. Changes in climate will affect hydrology and temperature of rivers, and humans can strongly impact rivers by altering hydrology, geomorphology and biotic assemblages.

Stressors and impacts to ecological processes

A. TEMPERATURE:

Climate change may be an important stress to Yellowstone ecosystems over the long term. Lakes can be used as bellwethers of climate changes and will likely be affected by global climate change. Long term records of ice-out on lakes suggest warming of lakes (Likens 2000, Magnuson 2000) and effects of climate change in the watershed, e.g. increased fire frequency, may alter lake dynamics (Schindler et al. 1996). Increasing temperature will affect biota of rivers directly, e.g. by limiting distribution of coldwater species (Rahel et al. 1996). Alternatively increased temperature could provide for faster growth rates of fish in rivers and lakes, including invasive lake trout (Hill and Magnuson 1990), which may change predator-prey dynamics in lakes.

B. WATER LEVEL AND RIVER HYDROLOGY:

Lakes that are hydrologically managed (e.g. Jackson Lake, Bighorn lake) will have fluctuating water levels that can potentially lake food webs and ecosystem function. Lakes are linked to their shoreline and receive a fraction of their energy inputs from allochthonous inputs, coarse woody debris which provides habitat, and may control terrestrial predator interactions (Schindler and Scheuerell 2002). Changing water level may decrease allochthonous inputs and may limit access of the lake by terrestrial predators (e.g. otters).

Rivers can by altered hydrologically from dam operations (e.g. Snake River), which can alter biotic assemblages (Stanford and Ward 1989). Water removal for irrigation can reduce instream flows and flood peaks in the summer, (e.g. Gros Ventre River, Bighorn River, Shoshone River, and Spread Creek). Additionally climate change may alter stream hydrology (Poff 2002) which will affect all aspects of river ecosystem function (Meyer et al. 1999, Firth and Fisher 1992) ranging from food web interactions (Power et al. 1995) to nutrient cycling.

C. SEDIMENTATION AND GEOMORPHOLOGY:

An important stress, covered in the riparian narrative.

D. SOLUTE CONCENTRATIONS:

Solutes include all dissolved solids in water, which strongly affect lake ecosystems. Drought and fire change cation import to lakes (e.g. Schindler et al. 1996). High mountain lakes may be subject to acidification if they are poorly buffered; however western mountains tend to have lower acid inputs than Northeastern US Mountains. In the Snowy Range, SE Wyoming, despite low acid-neutralizing capacity of lakes, acidification is not yet evident because pH of precipitation is higher than that in the Eastern US (Reuss et al. 1995).

E. NUTRIENT LOADING:

Eutrophication from excess nutrients is a pervasive stress on many lakes and rivers in the US by increasing primary production, changing biotic assemblages and lowering water clarity; estimating the effects of this eutrophication has a long history (Smith 1998). Local development and atmospheric deposition can cause nutrient loading even in large mountain lakes such as Lake Tahoe. For example, increased N loading to Lake Tahoe has increased primary production and decreased water clarity (Goldman 1988). The effect of excess nutrients to rivers is much less well known; experimentally increased P loading to a tundra river increased primary productivity, moss biomass and secondary production (Peterson et al. 1993). Phosphorus is often considered the limiting nutrient for lakes and streams, however it is now recognized that nitrogen often limits production as well (Elser et al. 1990). Nitrogen is most likely to be the limiting nutrient for most lake ecosystems within the GRYN; almost all streams in GTNP are N limited (J. L. Tank and R. O. Hall unpublished data). Planktonic algae responded greatly to N additions in experimental bioassays showing that N was primarily limiting in Yellowstone and Jackson lakes (Interlandi and Kilham 1998), thus we suggest that N will be a more important pollutant than P in the GRYN.

In the West, there are areas with high N loading from atmospheric deposition, particularly near cities and areas downwind from power plants or intensive agriculture Fenn et al. 2003b). Loch Vale in Rocky Mountain National Park receives 3-5 kg N ha-1 y-1, (Baron et al. 2000), and this N has been implicated in changing the phytoplankton assemblages in these lakes (Wolfe et al. 2001). Lakes in the GRYN are fairly low-nutrient (Interlandi et al. 1999) thus they are likely to respond to small increases in nutrients similarly to Tahoe. Indeed, eastern Idaho and the Teton Range are projected to have high rates of N deposition (Fenn et al. 2003b). Primary sources would most likely be atmospheric deposition or from local inputs from towns and settlements within the parks. High mountain lakes could be most susceptible because they can receive high N loads from atmospheric deposition, and many lakes in the west have high nitrate concentrations (Fenn et al. 2003a), although there are almost no data represented in their paper from western Wyoming, despite have large high elevation areas with crystalline bedrock that is potentially susceptible to increased nitrate loading.. Although N deposition rates are low in areas far from cities (e.g. west slope of Colorado Rockies, Baron et al. 2000), deposition could increase as NOx emissions and local development increases (see Vitousek et al. 1997).

Rivers upstream of Bighorn canyon run through agricultural areas a have elevated nutrient loads ands N and P (Water Resources Division, National Park Service1998), which might contribute to the eutrophic nature of Bighorn Lake (Lee and Jones 1981).

F. EXOTIC SPECIES:

Exotic species are one of the most pervasive environmental problems in the US and the GRYN has received some well-publicized invasions that can potentially alter aquatic ecosystems. Lake trout (*Savelinus namaycush*) have invaded Yellowstone Lake and may lower native cutthroat trout populations (Stapp and Hayward 2002a, Ruzyicki et al. 2003) and may extend to predators outside the lake (Stapp and Hayward 2002b). Lake trout can consume 14% of juvenile cutthroat trout (*Onchorhyncus clarki*) populations per year, even when numbers are controlled by gill-netting. Whirling disease has also invaded rivers in Yellowstone which may impact cutthroat trout populations (Ruzyicki et al. 2003). New Zealand mud snails (*Potamopyrgus antipodarum*) have invaded many rivers in the GRYN and are likely having severe impacts. In Polecat Creek, New Zealand mud snails constitute 90% of invertebrate biomass, and represent the largest fluxes in the nitrogen cycle (Hall et al. in review). Secondary production of mud snails in Polecat Creek is one of the highest rates ever recorded for an aquatic invertebrate (Hall et al. in preparation). It is not likely that these will be the last invasions, as Simberloff and Von Holle (1999) suggest that invasions beget more invasions; evidence in the Great Lakes suggests that this hypothesis is true, as the invasion rate is increasing non-linearly (Ricciardi 2001).

Potential Indicators

Indicators can be integrative assessments of biological condition (Karr 1981, 1999) (i.e. looking for the effect). Measuring biotic condition is important because it represent the impact that managers and visitors to the parks care about: Are there fish to catch? Is there wildlife to observe? Is the lake clear? Also, biota can indicate multiple stressors and often provide better information on change than hard-to measure-stressors (such as episodic pollution events (Karr 1999). Alternatively we can examine the stressor itself. Measuring changes in the stressor (if possible) is important for 2 reasons: One is that it may be possible to detect change in the stressor long before there is an impact to ecological processes. For example, N inputs or temperature may increase before the biotic assemblage responds. Invasion of an animal to a new ecosystem can be detected more easily than the impact to native populations or ecosystem

processes. The other reason is that measuring the stressor may help to understand causes of observed biological changes. If lake clarity decreases concomitantly with nutrient loading, then increased nutrients are a strong causal hypothesis for this biological change.

a. Nitrogen inputs

Justification: Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. Given that most N loading to Yellowstone and Teton Parks is via atmospheric inputs (as opposed to urbanization or agriculture), measurement of nitrogen concentrations in precipitation may detect early changes to these inputs. There are few NADP sites in the GRYN and the one in Yellowstone is a low elevation where concentration and of nitrate and volume of precipitation are expected to be low. There are few high-elevation sites for N deposition in the intermountain west (Fenn et al. 2003b), thus inputs on N and changes of those inputs are relatively unknown for the GRYN.

Examples of specific measures: Annual wet and dry deposition of N at a few high and mid elevation sites within the GRYN.

b. Nitrogen concentrations in aquatic ecosystems

Justification: Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. High alpine watershed lose most of their nitrogen during snowmelt (e. g. Reuss et al. 1995), and losses are proportional to inputs (Williams et al. 1996), despite processing of N in the shallow soils. Stream monitoring can detect long-term trends in deposition (Likens et al. 1996), and may provide a means to detect watershed-level response to N additions (Williams et al. 1996).

Examples of specific measures: Temporal sampling of stream water N throughout the year in Teton Range streams, Bighorn River and Lake and possibly some Yellowstone rivers. Surveys of N concentrations in lakes.

c. Water Temperature

Justification: Global climate change may increase temperatures of lakes and streams which may alter animal habitat and interactions. Additionally, geologic change (e.g. earthquake in Firehole River basin) may alter groundwater inputs with corresponding temperature changes in rivers. Measurement of temperature may be able to detect these changes which can be linked to any biological changes.

Examples of specific measures: Hourly recording of temperature in lake epilimnia and rivers via inexpensive recording thermometers. Ice out dates for major lakes.

d. Surface hydrology

Justification: Hydrology of lakes and rivers in the GRYN can change from direct human modification (e.g. impoundments, water abstraction) or via changes in climate (Meyer et al. 1999). This monitoring is already occurring for several of the rivers in GRYN, e.g. Snake, Bighorn, Madison, Yellowstone, and 2 of the lakes, Jackson and Bighorn.

Specific measures: Lake water level and large river discharge.

e. River morphology and habitat assessment (as specified in riparian narrative)

f. Algal species composition and biomass

Justification: Increased nutrients of changes to the food web (e.g. Carpenter et al. 1985) may change algal biomass, water clarity and species composition. Research in Yellowstone Lakes has shown that diatom species compositions predictably respond to slight changes nutrients according to their physiology (Interlandi et al. 1999) and these changes in assemblages may be sensitive indicators to nutrient inputs and associated climate change (Kilham et al. 1996). Algal species in high-elevation lakes can also signal changes in nutrient concentrations (Wolfe et al. 2001).

Specific measures: Chlorophyll a concentrations of algae in lakes. Secchi disk measurements (a measure of water clarity). Algal (mostly diatoms and some cyanobacteria) assemblage structure.

g. Cutthroat trout responses to exotic predators.

Justification: Exotic lake trout and whirling disease can potentially lower densities of native Yellowstone cutthroat trout in Yellowstone Lake; these effects may cascade to streams and predators outside of the lake (Stapp and Hayward 2002).

Specific measures: Long-term quantification of Yellowstone cutthroat trout density, age structure, spawning and recruitment in Yellowstone Lake and its tributaries.

h. River invertebrate assemblages.

Justification: Stream invertebrate assemblages may change in response to exotic species, sedimentation, nutrient load or predator population change. Stream invertebrates are often used as measures of water quality (Karr 1999) and is the current approach used by the state of Wyoming for water quality anal-

yses (King 1993). They are sensitive indicators of change and they can integrate physical stressors that might otherwise be difficult to measure, and these changes can relate to changes in ecosystem function (Wallace et al. 1996). There are several approaches to using invertebrates to measure water quality; two current methods either develop a set of additive metrics (Kerans and Karr 1994), a local examples is Wyoming index of biotic integrity (WYIBI) (Stribling). Another method uses multivariate approaches to estimate predicted invertebrate assemblages which can be compared to measured assemblage structure e.g. Hawkins et al. (2000). Long term monitoring of invertebrates may be able to detect change in response to exotic mud snails, and new, unforeseen invasions

Specific measures: Invertebrate assemblage structure, following approaches of current bioassessment methods.

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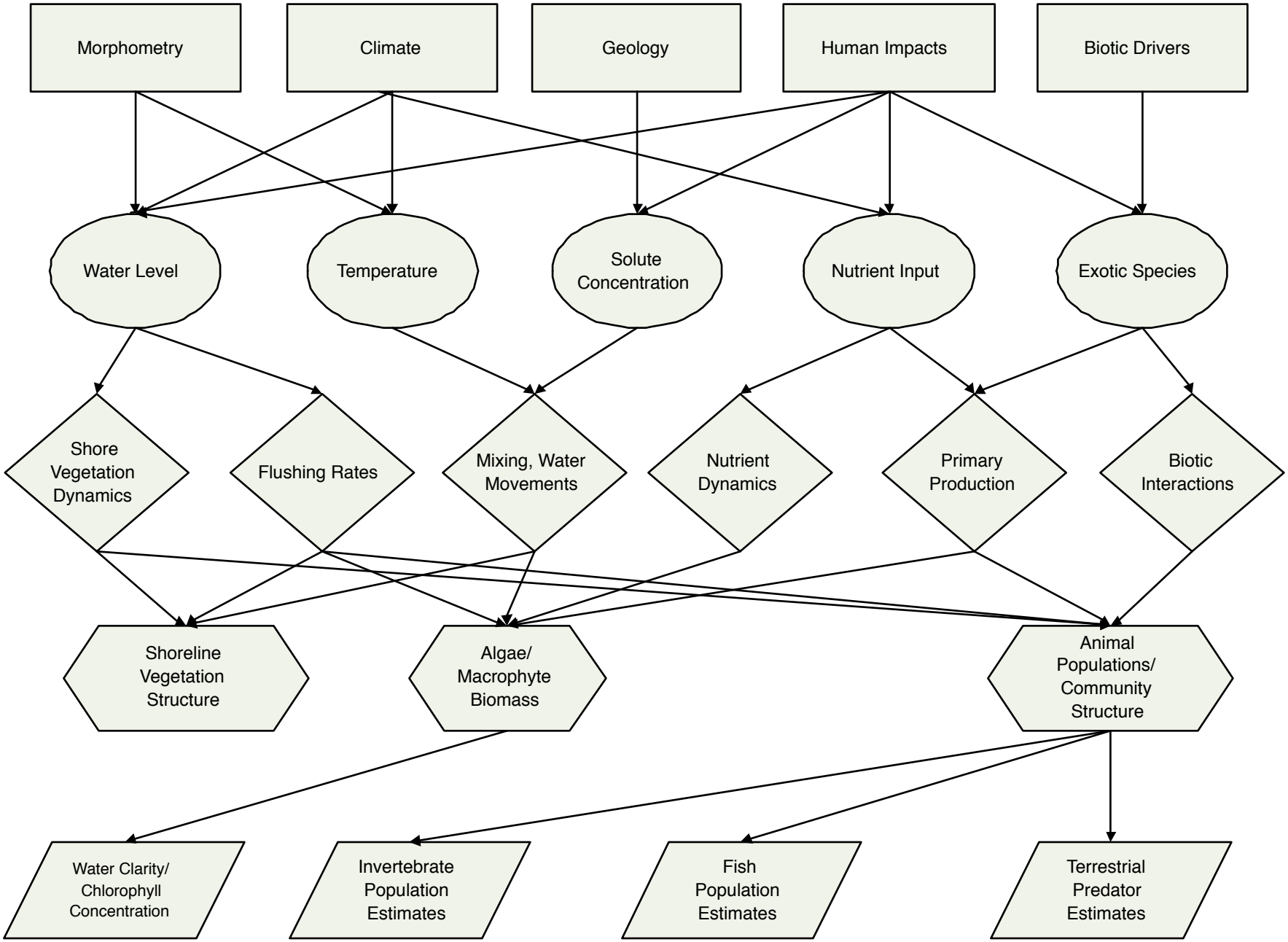

FIGURE 1 Lake model.

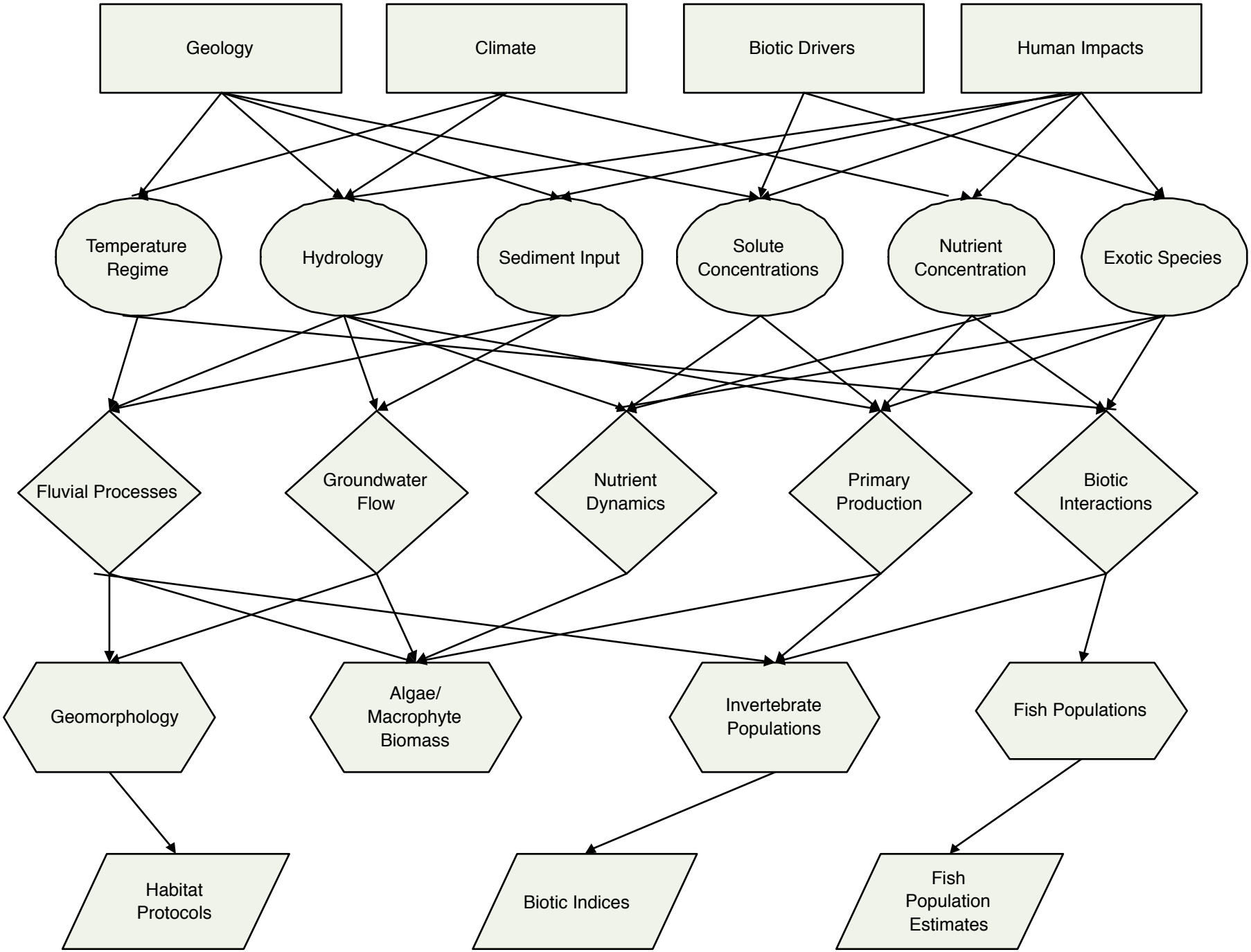

FIGURE 2 River model.

ALPINE-TIMBERLINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Duncan Patten)

Although the alpine and timberline ecosystems are closely linked, they represent quite different sets of dynamic processes which result in potentially different indicators. Consequently, to understand these systems and model them to address possible indicators (vital signs), they are treated in many of the discussions below and in conceptual models (Figures 3 and 7) as separate, but interrelated, systems.

The alpine ecosystem is one of the smallest in area within the GRYN. It occurs only at high elevations on summits, slopes and ridges above the local timberline (Billings 1988). The environments of the alpine ecosystem often are extreme with intense radiation, cold temperatures and wide temperature fluxes, extreme wind velocities, thin air, and often long-lasting snow and ice. Substrates in the alpine may be barren, rocky outcrops which create highly exposed environments, while other areas may have well developed soils, or substrates that are constantly being altered by frost action. Consequently, plants that survive in these extremes tend to grow near the ground, often in mats but also as isolated plants. Their productivity results from the combined stress of alpine environments (Scott and Billings 1964).

The sharpest environmental gradient in mountains is the ecotone between alpine and forest, the timberline zone. This ecotone is broadly defined as the upper limit of trees, a response to environmental stress (White 1996). It is related to the declining amount of biologically useful thermal energy with summer temperatures dictating the length of the growing season (Billings 1974). Physical factors such as weather, temperatures, snowdrifts, and soil conditions control whether woody forest species will establish and survive at high elevations. Trees growing at timberline grow at the same rate as several hundred meters below timberline (Paulsen et al. 2000), although isolated trees above the extensive timberline ecotone may have very slow growth, in part, because of foliage loss to wind and other factors. Treeline vegetation is sensitive to many environmental factors. Over a half century period, Klasner and Fagre (2002) saw changes in timberline forests in Glacier National Park with forests below the timberline becoming more dense and krummholz (twisted wood) stands becoming fragmented near trails.

Drivers and Related Stressors

Extreme environments of the alpine and timberline areas are common elements in these two systems allowing a combined discussion of the drivers. The drivers fall into five major categories: climate, geology, fire, human activities and biotic factors.

Climatic drivers or natural stressors are the most obvious set of parameters controlling processes at high elevations in the GRYN. At high elevations several factors become limiting and dominate physiological and growth processes of organisms (Tranquillini 1979). Temperature extremes with wide fluctuations play an important role both for organism survival but also physical processes. High radiation levels at high elevations can cause the ground surface to heat up during the day followed by rapid nighttime cooling. Extreme cold temperatures dictate physiological processes and are considered one of the primary causes of timberline, that is, only plants with metabolic systems that can function at very cold temperatures during the short alpine growing season can grow at these elevations. Temperature extremes may function synergistically with other natural stressors to create even more extreme conditions. For example, wind combined with low temperatures may limit high elevation forest growth.

Wind is a constant force in the alpine environment. It may cause alpine temperatures to become more extreme by breaking down the boundary layer formed on physical and biological surfaces. Consequently, low temperatures become more "penetrating" and potential for freezing increases, while daytime highs on ground and other surfaces may be far above ambient temperatures. Wind may bring warmer temperatures from lower elevations to the alpine. Wind also drives ice and snow which scour and abrade surfaces and plant tissues, and causes snow to accumulate. Snow drifts often do not melt until well into the alpine growing season limiting early phonological stages of alpine plants.

The thin air at high elevations results in two different environmental drivers. Thin air allows a greater amount of solar radiation, especially in the ultraviolet (UV). UV-B can differ by a whole order of magnitude between a dry environment at sea-level and high alpine environments (Caldwell et al. 1980). Alpine plants have adapted to high UV by either absorbing it in the epidermis or reflecting it off leaves or other plant parts. Thin air also means lower partial pressure of gases, CO2 being the one of concern. Low CO2 levels control photosynthetic rates, and yet, photosynthetic efficiency of alpine plants is often greater than low-elevation plants tested within the same low CO2 atmosphere.

Drought is a climatic factor that can influence both composition of alpine plant communities and timberline. Alpine zones range from

very wet to dry. Both extremes may produce conditions with low water availability, however, moisture gradients do create concomitant vegetation gradients in the alpine zone (Oberbauer and Billings 1981).

Fire is not a common driver in alpine ecosystems; however, in the past it was common in GRYN forests and thus played a role in modifying timberline forests. Forest fires in the montane and subalpine forests often reached to timberline destroying living timberline trees, or burning dead and down trees at that elevation zone. Evidence of the location of timberline may have been destroyed or reduced by fires reaching timberline. Remains of burned trees are used to determine extent of timberline forests. Dendrochronological techniques are used to date remnants of timberline forests allowing establishment of dates of forest encroachment into the alpine or withdrawal from alpine/timberline ecotones.

Disease is a natural occurrence in most ecosystems; however, disease and insect infestations, although cyclical, can alter the structure of alpine and timberline vegetation. Several types of conifer insect infestations and diseases have altered timberline forests, for example, bark beetle and bud worm. The cyclical nature of these diseases and infestations do not permanently alter the forest as it normally recovers at the end of the cycle.

High elevation ecosystems are permanently under environmental stress as environments at these elevations do not allow robust vegetation development, either in the alpine or at timberline. Climate, geology, fire, human activities and biotic factors all play a role in creating stressful conditions. Here the term stressful applies not only to the normal extremes at these elevations but also to changing environments that may be natural or of human origin.

Climate and the resulting local weather conditions constantly influence alpine and timberline ecosystems. Many of these conditions are discussed above; however, long-term climatic cycles may ameliorate timberline environments and allow trees to grow at higher elevations. On the other hand, long-term colder and drier conditions may play a reverse role and cause the forest line to retreat in elevation. Recent human influence of the world climate may influence these long-term climatic patterns and indirectly alter "normal" timberline fluctuations. Climate models may allow predictions of possible climate change and thus concomitant changes in timberline elevations.

Short-term warm/cold cycles, sometimes only 24 hours long, may cause disruption of wet alpine soils, resulting in churning of soil particles and instability of the substrate. These disturbance can form small, fine soil "frost boils", extensive "rock nets", and solifluction terraces (Johnson and Billings 1962). Climatic changes that might prevent short-term freeze/thaw cycles, or extend the period between a thaw and freeze period, may alter the extent of frost action soils and greatly change the types of alpine vegetation establishing in these areas.

High elevations have thin air, consequently, the partial pressure of photosynthetic gases (i.e., CO2) is low resulting in the need for photosynthetically efficient plants. Reduced CO2 may not be considered a stressor as it is normal in the alpine zone, however, human caused increases of atmospheric CO2 may result in reduced need for photosynthetic efficient plants and possible changes in alpine plant communities. Also, timberline trees may produce more growth under an increased CO2 environment and better withstand the extreme environmental gradient at the alpine/timberline ecotone.

Wind also is a normal part of the alpine/timberline environment (Hadley and Smith 1986). . Climate models do not predict local wind patterns or velocities, but it is probable that with climate change, including changes in temperature gradients, wind patterns and velocities could change.

High elevations are known for high levels of radiation and the magnitude of UV is discussed above. However, human caused reduction in stratospheric ozone has increased the amount of UV entering the earth's atmosphere. Consequently, elevations that already receive high levels of UV can be expected to have increasing UV levels which will directly affect most biotic functions and survival of high elevation organisms. Eventual UV resistant adaptations may develop but this type of evolutionary process is long-term and plant community changes may take place before UV resistant adaptation does.

Fire has been mentioned as a normal part of forest dynamics directly influencing the timberline forest stands. However, fire suppression has modified the occurrence and extent of fires in the GRYN area directly changing an important timberline environmental factor. Reduced fires or possibly more extensive wildfires resulting from long-term fire suppression and fuel build up must be considered an environmental stressor of timberline forests even if fires are a normal part of forest dynamics.

Topography, that is, slope aspect and angle, is a relatively stable part of the alpine environment. Some changes occur under frost action solifluction (soil surface movement), but stability is the norm. It is included here as a stressor because at high elevations small changes in topography alter the extremes of the environment. Thus, plants growing in the shelter of an organic mound, or behind a rock in the alpine zone cannot grow out in an exposed location. The very

limitations created by topography can be stressful to alpine plants.

Alpine vegetation is one of the most sensitive vegetation types in the Rocky Mountains (Billings 1973). It grows only in sheltered areas or on deeper soils that have existed for some time. Its sensitivity to external physical stress is illustrated recently by the loss of alpine communities in areas where there is high human use (Cole and Monz 2002). Human trampling loosens the plant surface, especially cushions or mats, making it susceptible to wind scour (Hartley 1976, Jackson 1998). National parks have put in trails with off-trail foot traffic excluded with the hope of protecting alpine plant communities in heavy human use areas. Increasing human use can only exacerbate human impacts.

Grazing (wild and domestic) alters composition of alpine areas through plant consumption and trampling. In the GRYN parks, grazing is limited to wild animals, but adjacent alpine areas (e.g., Beartooth Plateau) shows evidence of long-term erosion and trail development where domestic livestock have grazed. Although this is not as significant a stressor as some of the climatic factors, it works synergistically with other factors in the alteration of the alpine vegetation community.

Introduction of exotic plants in the alpine/timberline zone does not play as important a role in vegetation community modification as found in lower elevation zones. However, care should be taken to avoid introduction of exotic species, especially where trails and roads have been established in these high-elevations.

Disease is evident in all biotic communities of the GRYN. In alpine/timberline areas disease can be found in timberline forests, and in high elevation ungulate populations. White pine blister rust has become a disease of concern in the high elevation forests of the GRYN. Whitebark pine, a timberline species, has become infected over the past several decades (Kendall and Keane 2001). Although the magnitude of the disease is less in the GRYN than in areas like Glacier National Park, it still has potential of eliminating or greatly reducing the whitebark pine community, thus eliminating whitebark pine seeds, a primary food source for grizzly bear. Disease in the alpine community, although probably present, does not have the potential yet of greatly altering that community.

Processes, Outcomes and Indicators

Interaction of several stressors influence alpine and timberline processes (Figures 3 and 7). These interactions can be represented in several process submodels which explain in greater detail how factors influence each other.

A. ALPINE ZONE PROCESSES, OUTCOMES, AND INDICATORS

1. Soil frost dynamics.

Interaction of temperature changes and soil moisture greatly modifies areas of the alpine zone through cyropedogenic processes (Johnson and Billings 1962). Cryopedogenic or soil frost action causes water to shrink and expand thus moving soil particles around. In some cases these processes are limited to small areas called "frost boils" where larger soil particles are pushed outward. These frost churned soils create instable locations that often prevent establishment of vegetation and long-term stability of the alpine vegetation community. Soil frost action can also sort larger rocks creating what are called "rock nets" or "rock polygons" in the alpine zone. In this case, sod may develop between the rocks and dense alpine plan communities establish. Alpine soils on steeper slopes my form "solifluction terraces" when the soil frost action expands the wet soils and gradually moves them down slope. These terraces are usually covered with alpine vegetation.

2. Scree slope dynamics.

Many alpine and subalpine slopes are steep and relatively unstable. These scree and fellfield slopes often cannot support vegetation, although in some cases pockets of alpine herbs or shrubs may find sufficiently stable sites to establish (Griggs 1956). Again, thaw-freeze action can maintain instability of these slopes.

3. Alpine vegetation dynamics.

Alpine plant communities are a product of all of the factors (and stressors) that influence the mountain plant communities found above timberline. Winds, high UV, wide temperature fluctuations, human and animal use, disease and introduced species all play a role, but the magnitude of that role varies. If future climatic changes reduce the potential for thaw-freeze actions, then those plants dependent on disturbed soils may decline. Increased human and animal activities in the alpine zone will also alter the vegetation composition of alpine communities. Consequently, plant species composition of in the alpine zone becomes a measure of the synergistic effects of all of the stressors.

The primary outcome of the several process models is vegetation composition and cover and shows the importance of environmental stress on plant communities (Kammer and Mohl 2002). Scree slopes and greatly altered frost action areas will have little vegetation cover, while alpine areas with well developed soils may have a continuous,

dense plant cover. Changes in these vegetation characteristics in response to environmental stresses thus becomes indicators of the influence of these stressors on the alpine zone.

B. TIMBERLINE PROCESSES, OUTCOMES AND INDICATORS

1. Timberline elevation dynamics.

Timberline, that is the elevation location of the ecotone between forest and alpine vegetation, has fluctuated over the past millennia (Carrera et al. 1991). The fluctuation is mostly driven by climatic factors, warmer or cooler climates, and/or wetter or drier climates (Hessl and Baker 1997). Human induced climate change may cause a rise in the elevation of timberline, if warmer is expected. Although this change is slow, evidence of past location of timberline can be found in presence of remnants of trees well up in the alpine zone. Dating of these trees can establish the time when forests occurred at higher elevations (Graumlich 1991, 1994). Establishment of a long-term record of timberline fluctuations may be a useful indicator of natural and human-induced influence on timberline forests.

2. Timberline woody plant dynamics.

Composition of timberline forests varies according to the combined influence of those factors that limit forest species from advancing upwards on a mountain. For example, protective structures such as rocks and coarse stable soils may allow forest species to establish at high elevations. Lack of these conditions may prevent forests from establishing higher, unless climatic factors ameliorate. Fire and disease have recently become more important factors in modifying timberline forest location and composition. If white pine blister rust mostly eliminates whitebark pine, then timberline forests will be primarily spruce and fir, or may be reduced to dead and dying trees above the subalpine forest. Extensive fires, a result of forest fire suppression, may also reach into the timberline forest destroying the existing trees. Recovery from fires then will be a result of ability of timberline tree species to regain their normal elevation location, a process that is difficult because of the extreme environments at these elevations. Consequently, the composition of the timberline forest, a product of natural and human activities, may be a good indicator of changes occurring within the GRYN regions parks.

3. Alpine/Treeline Potential Indicators

The ecosystems that compose alpine and timberline areas have developed in extreme environments. Wind, cold and thin air characterize the extremes that control these ecosystems, and yet, human activities also have influenced their present state. Changing environments, both natural and human caused, may alter the future conditions of alpine and timberline zones. Consequently, the indicators selected for the vital signs program will give a warning of the gradual changes these ecosystems may have as a changing local and global environment alters the drivers that form these sensitive, high elevation ecosystems.

a. Timberline forest densities and health

Resource Monitored: Timberline forest, including large trees such as whitebark pine, and krummholz stands in exposed and protected areas.

Justification: Timberline in the Rocky Mountains, as in most temperate-zone mountains, has fluctuated in elevation over the past millennia. Changes in the elevation of timberline occur slowly; however, the actual elevation should be monitored (see another indicator). The forest trees and woody plants near timberline begin to show new recruitment at higher elevations, or decline in forest stature long before the actual timberline change stables for some time. Timberline is dynamic, and yet there are periods when it appears to be stable allowing long-term monitoring of forest conditions at or near timberline to show possible precursor forest modification prior to solid evidence of timberline change. Recently, introduced diseases (e.g., white pine blister rust) have initiated more rapid changes in timberline forest health. For this reason alone, timberline forests should be part of a long-term monitoring program.

Comment: The long-term dynamic nature of timberline and the variation of forest types require that any sampling of forest condition at or near timberline must include the variability of forest structure. Measurement of health of krummholz stands is quite different than measurement of health of high elevation whitebark pine stands.

Example of specific measurements for indicator: In randomly selected, representative timberline zones in the GRYN area, sampling transects within and just above the forest, and randomly selected krummholz patches should be monitored on a regular basis (e.g., 2-5 years). Forest transects will measure the density of living and dead trees and the condition (e.g., percent canopy dead). The cover and ratio of dead to living canopy should be measured in the krummholz patches.

b. Timberline elevation boundaries

Resource Monitored: Elevation where the forest ends and alpine tundra begins, and the highest elevation of krummholz patches.

Justification: The justification for monitoring timberline elevation is essentially the same as that for monitoring the timberline forests. Timberline is dynamic and has fluctuated in the past in response to long-term climate changes (i.e., warming and cooling, and/or wetter or drier periods). More recently, disease may be accelerating the rate of forest change which justifies monitoring not only the effects of the disease on the forest but how it may be altering the elevational dynamics of the ecotone between forest and alpine zones.

Comment: Monitoring changes in timberline elevation is obviously a long-term procedure. However, with more rapid changes in climate expected, elevational changes may occur more rapidly, especially upward encroachment of forest species. Thus, monitoring techniques should be established to address the upward encroachment expected from a warming climate without forgetting to monitor potential downward changes or forest withdrawal which may result from other factors such as disease or other human induced influences.

Example of specific measurements for indicator: Monitoring elevational limits of forest species is easily done by establishing markers (stakes and GPS) at representative timberline locations. Aspect (compass direction) plays an important role in elevation of timberline, thus markers should be at all aspects. Markers should be place at the extent of any upward forest reproduction, edge of mature forest, and highest elevation of krummholz patches. The long-term aspect of timberline change does not require frequent measurement, but annual (or 2-3 year) reconnaissance of timberline edge relative to the markers is necessary.

c. Alpine plant community characteristics

Resource Monitored: Alpine vegetation on different substrates in the alpine zone.

Justification: The extreme environments of the alpine zone limit the types of plants that can survive. In most cases alpine plants are low in stature, often in cushions, or isolated in microhabitats where environmental extremes are attenuated. Different alpine plant communities occur on stable and unstable soils, the latter being scree slopes and frost altered ground. Human activity, especially recreation, but also livestock use of alpine vegetation and introduction of exotic plants, has modified alpine plant communities. These pressures will unlikely decrease and thus the alpine plant community can be expected to decline in cover and vigor. Once lost, alpine vegetation takes decades or more to reestablish. Monitoring of select alpine plant communities may offer shorter notice of change than casual observation of the alpine zone.

Comment: Monitoring alpine plant communities will require establishment of sampling locations in a variety of habitats. Some habitats appear to be more stressed by human use and these might have priority over others that continue to be unaltered. However, assuming that some plant communities are more resistant or resilient to human use and changes in other driving variables such as changing climate should not cause these communities to be omitted from a monitoring program. The interval between monitoring for these plant communities might be longer than the more sensitive, less resistant communities.

Example of specific measurements for indicator: Establish randomly selected quadrats (plots) on different alpine plant community types: meadow, scree slope, wind blown semi-barren coarse soils, solifluction terraces, and high-organic wet soils, and frost-boil areas. Set priorities on sensitivity of each type based on literature and early monitoring. Monitor plant composition and cover (including density of patches where dispersed, a form of frequency measurement). Monitoring should be done annually until evidence of sensitivity is established and then longer-term monitoring can be established for more resistant and/or resilient plant community types.

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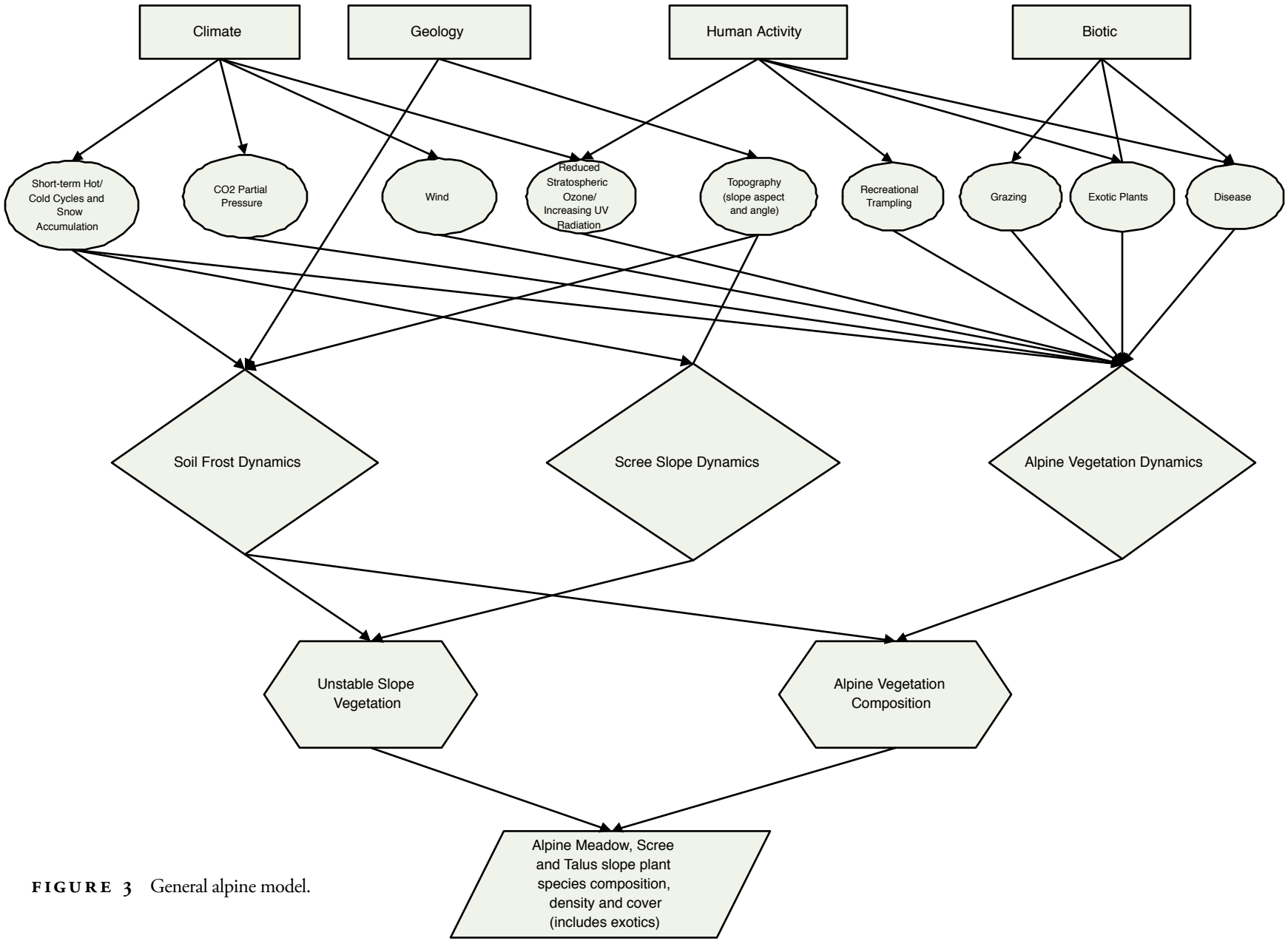

FIGURE 3 General alpine model.

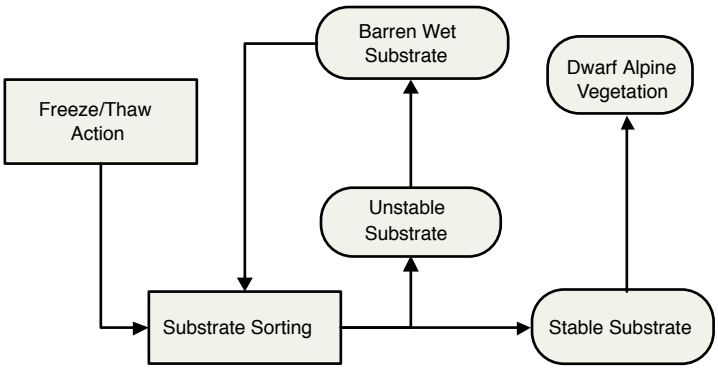

FIGURE 4 Alpine soil frost dynamics submodel.

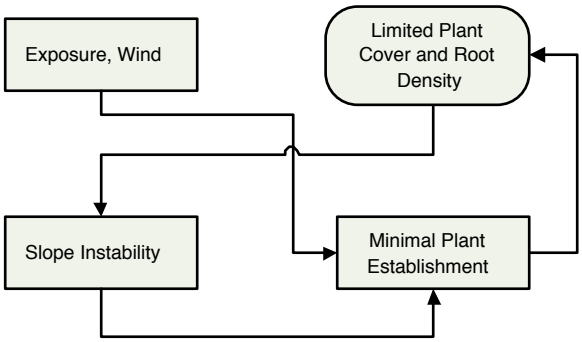

FIGURE 5 Alpine scree slope dynamics submodel.

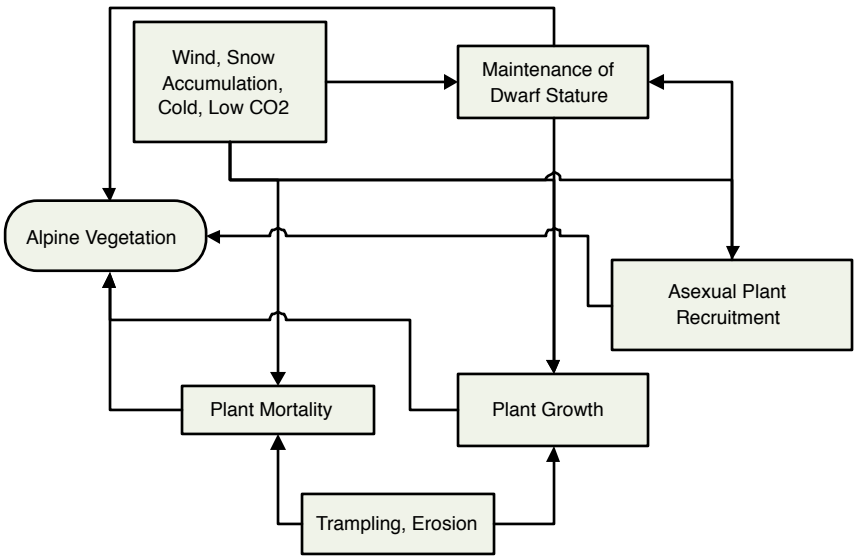

FIGURE 6 Alpine vegetation submodel.

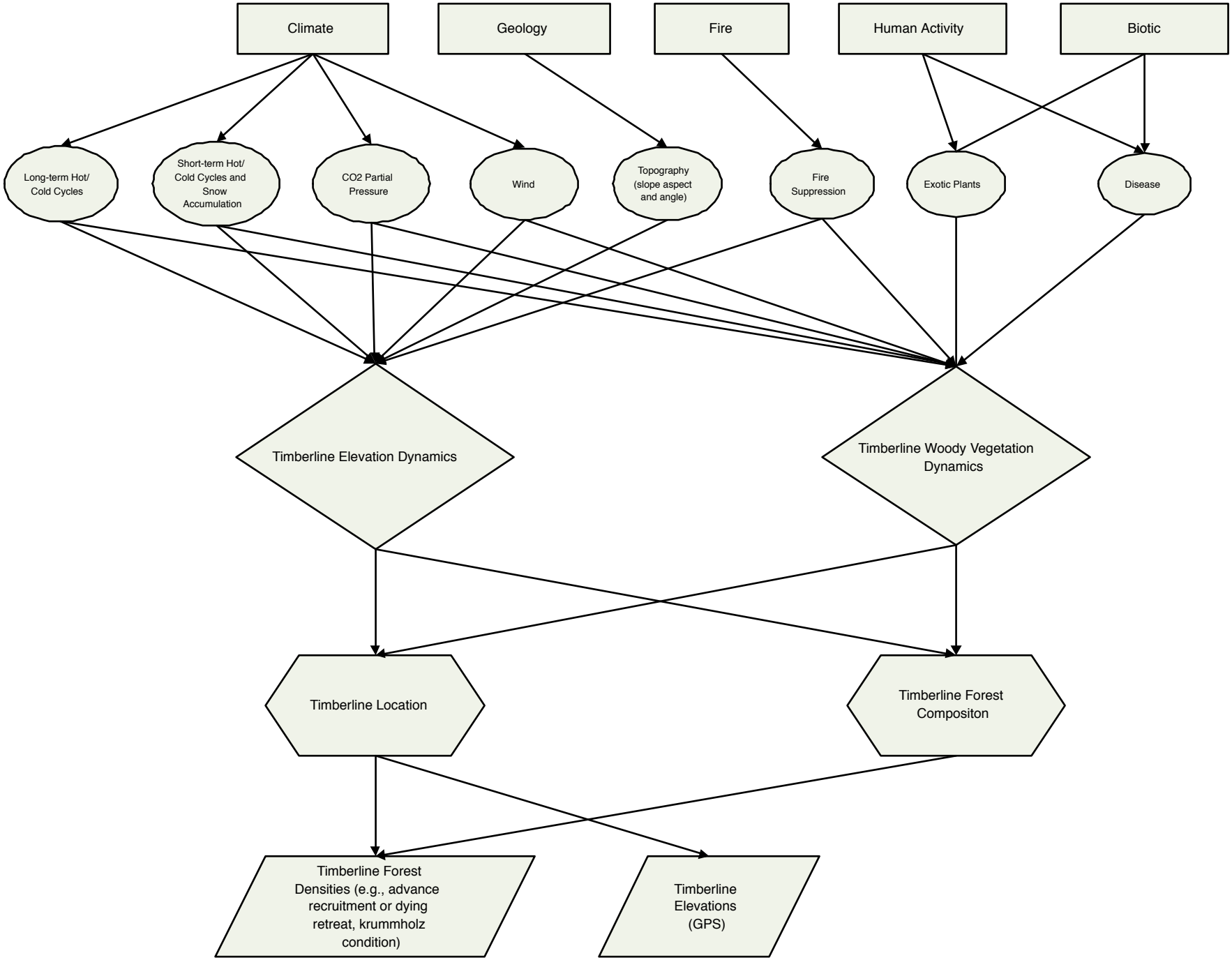

FIGURE 7 General alpine timberline model.

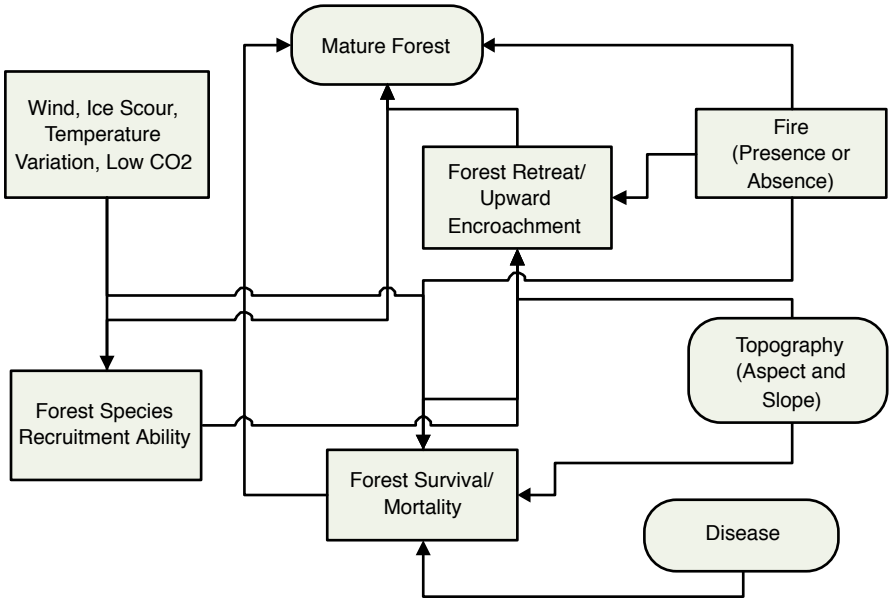

FIGURE 8 Alpine timberline elevation submodel.

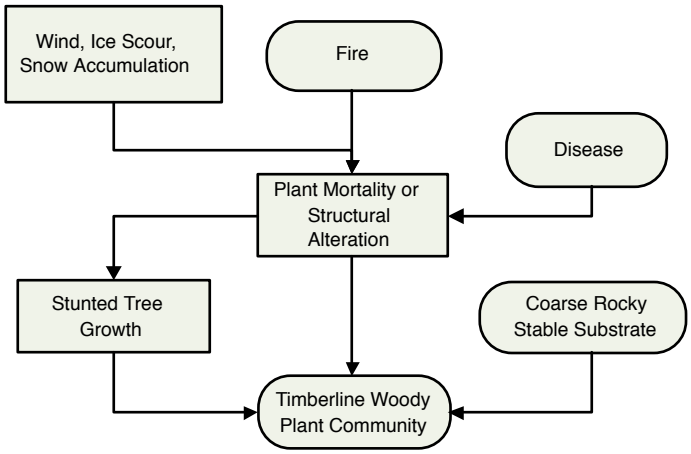

FIGURE 9 Alpine woody vegetation dynamics submodel.

ASPEN ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(authors: Duncan Patten and Dan Tinker)

Overview of Aspen Ecosystems

A. GENERAL CHARACTERISTICS OF ASPEN ECOSYSTEMS

Aspen (*Populus tremuloides*) is an important component of landscapes in the Greater Yellowstone Ecosystem (GYE), but is absent or rare in the Bighorn Canyon region (Knight et al. 1987). Notably, aspen is the only native upland deciduous tree found in Yellowstone National Park (YNP). Aspen stands play important ecological roles, supporting high numbers and diversity of breeding birds (DeByle 1985) and providing critical habitat and an important source of forage for summer and winter browsing ungulates (Olmsted 1979). Aspen stands throughout the GYE appear to have been declining through the 20th century and the causes and consequences of this apparent decline have caused considerable discussion (Schier 1975, Olmstead 1979, Bartos and Hinds 1985, Boyce 1989, Kay 1990, Bartos et al. 1994, Romme et al. 1995, Baker et al. 1997). In the northern range of YNP, aspen occurs in relatively small stands and is associated with more mesic conditions. However, aspen stands in the GYE are often not as complex or robust as stands in the mid-intermountain regions of Utah and Colorado (Mueggler 1988).

In the Rocky Mountain region and in the GYE, aspen is primarily a clonal species which reproduces almost exclusively via root sprouting and produces stands composed of stems from only one or a few genetic individuals (Barnes 1966, McDonough 1985, Tuskan et al. 1996). Aspen most commonly regenerates by means of vegetative sprouting from the root system following disturbances such as fire that kills the mature trees (See also Aspen-Fire Dynamics Submodel). These shoots grow rapidly and rely upon the root system of the parental tree for growth for the first 25 years (Zahner and DeByle 1965). However, rare episodes of seedling recruitment sometimes occur (Jelinski and Cheliak 1992), including widespread establishment of aspen seedlings in the GYE following the 1988 fires (Kay 1993, Romme et al. 1997, Stevens et al. 1999).

Aspen, like most Populus species, is recognized as a preferential browse species for ungulates during the growing season and even in winter (Olmstead 1979). In fact, in many parts of the GYE, elk commonly browse nearly all root sprouts present in aspen stands (Romme et al. 1995, Larsen and Ripple 1999). Several studies have suggested that elk browsing is the primary cause for the lack of aspen regeneration in the GYE (Beetle 1974, 1979, Krebill 1972, Kay 1990, Bartos et al. 1994).

B. FIRE EFFECTS IN ASPEN ECOSYSTEMS

Fire is the primary disturbance agent in aspen forests of the GRYE, where large, infrequent, stand-replacing fires dominate the fire regime, and human efforts at fire suppression have historically had little effect (Romme and Despain 1989). Because of its ability to resprout following disturbance (See Aspen-Fire Dynamics Submodel), fire often facilitates secondary succession and the reestablishment of aspen. However, these stands are often eventually dominated by lodgepole pine, Engelmann spruce, or subalpine fir after several decades. Fire suppression in the GRYE may lead to a reduction in the abundance and vigor of many of the aspen stands (Knight 1994).

Conceptual Model Development

A. DRIVERS

Climate, working with soils and topography, creates appropriate site conditions for establishment and/or maintenance of aspen communities. Aspen communities are found in mesic sites and may be in riparian locations. Climate of the GRYE is characterized by long, cold winters, and cool, dry summers. Much of the precipitation falls in the form of snow and summers may be dry. Winter snowpack melts rapidly in May and June, wetting low areas and recharging groundwater which provides much of the water available for growth of aspen. Seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes which influence the presence of aspen.

Soils across GRYN area are diverse, a product of highly variable parent materials. For example, soils across much of YNP are mostly volcanic in origin, while glacial outwash and older Precambrian material dominates the Grand Teton landscape (Knight 1994). In Yellowstone, two different parent materials, derived from underlying bedrock, determine the soil characteristics. Differences in these parent materials lead to variation in soil texture, and therefore, water holding capacity, as well as nutrient supply and availability (see Soil and Ground Water Processes Submodel).

Fire is also an important driver in aspen ecosystems, and the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. Aspen reproduction may be closely aligned with fire dynamics (see Aspen-Fire Dynamics Submodel).

Aspen is susceptible to several biotic drivers. The Browse Dynamics Submodel illustrates how large ungulate herds, as well as domestic animals in surrounding national forests, may utilize aspen shoots and suckers for forage. Management policies of the ungulates may influence the magnitude of impacts of herbivory. Other biotic drivers include such phenomena as beaver dams, competition from vegetation (See Aspen/Vegetation Submodel), and insect herbivory. These drivers may directly and indirectly affect many ecological processes in aspen ecosystems as described below.

B. STRESSORS AND ECOLOGICAL RESPONSES

Beaver dams may affect aspen growth and establishment through herbivory and tree removal, as well as influencing availability of soil and ground water, important components of mesic sites selected by aspen. Herbivory of aspen sprouts and bark stripping by ungulates, often the result of limited forage during severe winters, may greatly reduce long-term establishment of mature aspen stands (Kay 1997). Similarly, reduction in vigor of adult and sprout aspen is possible as a result plant competition and of other forms of herbivory.

Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Fires managed for fuel reduction or wildfires that are allowed to burn will alter availability of aspen for forage, but also stimulate aspen reproduction, both sexual and asexual.

Droughts, and other forms of wet and dry climatic cycles, affect aspen systems directly through alteration of surface and ground water processes, and the concomitant effects on plant growth and reproduction (See Aspen Growth and Reproduction Submodel). Indirectly, such climatic events may alter the establishment and survival of aspen through impacts on natural fire dynamics.

C. INDICATORS

Many non-vegetative components of aspen communities are important indicators of community structure and function. The presence, or relative abundance of some of the associated populations of faunal assemblages such as songbirds, amphibians, or ungulates, may serve as indicators of community integrity by their use of aspen stands. The absence of some of these assemblages may represent a decline in community health. Population estimates of selected major taxa such as birds or ungulates, as well as measures of stand use through behavioral studies, are useful measures for monitoring these assemblages.

The structure and function of aspen communities is important for understanding the condition of many aspen stands. For example, aspen may function as riparian species when elevated groundwater levels create moist soil conditions. In drier areas, the size and abundance of aspen sprouts and seedlings, which are rare, may serve as indicators of future stand development. Given the abundance and impact of large herbivores, and the rarity of establishment by seed, aspen seedlings or sprouts that survive to heights greater than browsing abilities of ungulates could signify significant recruitment into new or mature stands.

Measuring browsing effects by both large and small herbivores within mature aspen stands, as well as on new seedlings, provides a quantitative assessment of impacts on aspen such as truncated growth. These measures may also indicate the likelihood that root sprouts and suckers or new seedlings will be recruited into an adult growth form. Other browsing effects such as gnarling of mature trees may quantify browsing pressure within specific stands.

Landscape-scale parameters such as the spatial pattern of aspen stands across the GRYE, helps quantify and characterize heterogeneity in landscape structure, which influences many important ecosystem functions. In addition, topographic and elevational analyses may identify potential sites for future aspen recruitment by delineating more potentially moist sites from drier sites.

1. Associated Animal Populations

Resource Monitored: Faunal community structure

Justification: Many non-vegetative components of aspen communities are important indicators of community structure and function. These components intimately occupy niches within the aspen community and thus may change as the aspen community changes. The presence, or relative abundance of some of the associated populations or faunal assemblages such as songbirds, amphibians, or insects, may serve as indicators of community integrity by their use of aspen stands. The absence of some of these assemblages may represent a change or decline in aspen community health.

Example of Specific Measurements of this Indicator: Population estimates of selected major taxa such as birds, as well as measures of their use of particular stand structural niches.

2. Aspen community parameters

Resource Monitored: Ecosystem structure and function.

Justification: Aspen may function as riparian species when elevat-

ed groundwater levels create moist soil conditions. In addition, the size and abundance of aspen sprouts and seedlings, which are rare, may serve as indicators of future stand development. Given the abundance and impact of large herbivores, and the rarity of establishment by seed, aspen seedlings or sprouts that survive to heights greater than browsing abilities of ungulates could signify significant recruitment into new or mature stands.

Example of Specific Measurements of this Indicator: Belt transect or quadrat estimates of sprout or seedling presence and size. Associated measurements should include, soil moisture measurements and community descriptions through plant surveys.

3. Browsing Effects

Resource Monitored: Ecosystem structure

Justification: Measuring browsing effects by both large and small herbivores within mature aspen stands, as well as on new seedlings, provides a quantitative assessment of impacts on aspen such as truncated growth. These measures may also indicate the likelihood that root sprouts and suckers or new seedlings will be recruited into an adult growth form. Other browsing effects such as gnarling of mature trees may quantify browsing pressure within specific stands.

Example of Specific Measurements of this Indicator: Repeated measures of sprout and seedling heights within a given stand or plot. An alternative metric would be repeated measurements of percent browsing on representatively selected sprouts and seedlings.

4. Landscape parameters

Resource Monitored: Ecosystem structure and function.

Justification: The spatial pattern of aspen stands across the Greater Yellowstone landscape influences many important ecosystem functions. In addition, topographic and elevational analyses may identify potential sites for future aspen recruitment by delineating moist sites from drier sites.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software (FRAGSTATS) and GIS. Vegetative cover most common base map used.

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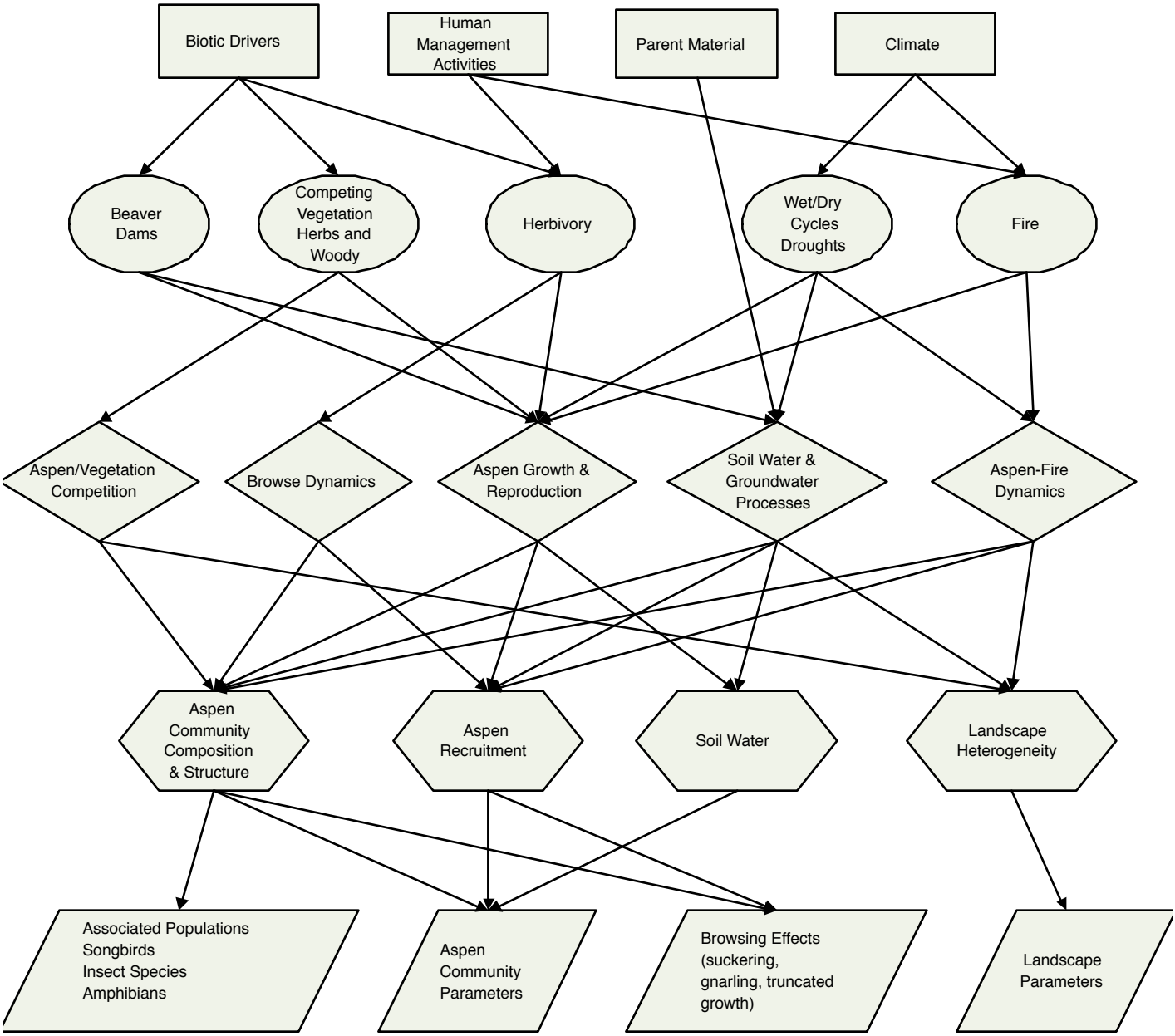

FIGURE 10 General aspen model.

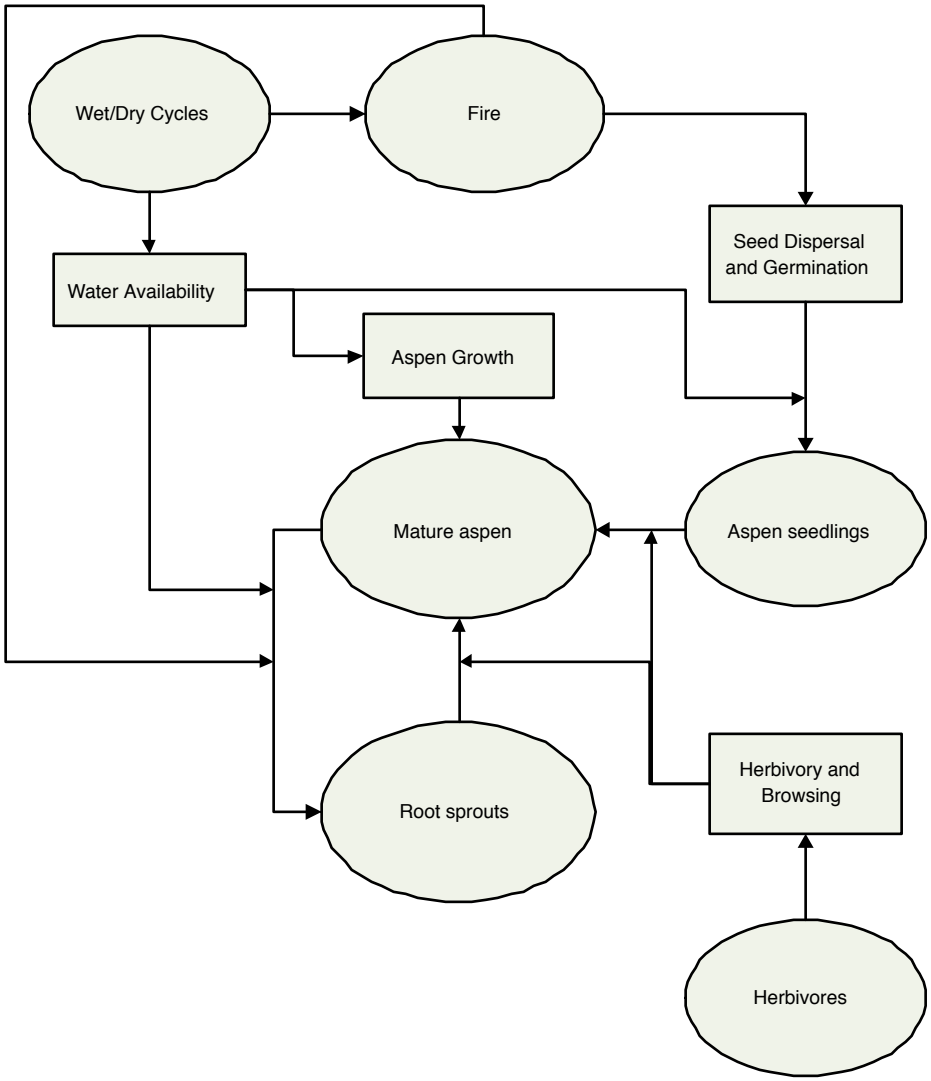

FIGURE 11 Aspen growth and reproduction submodel.

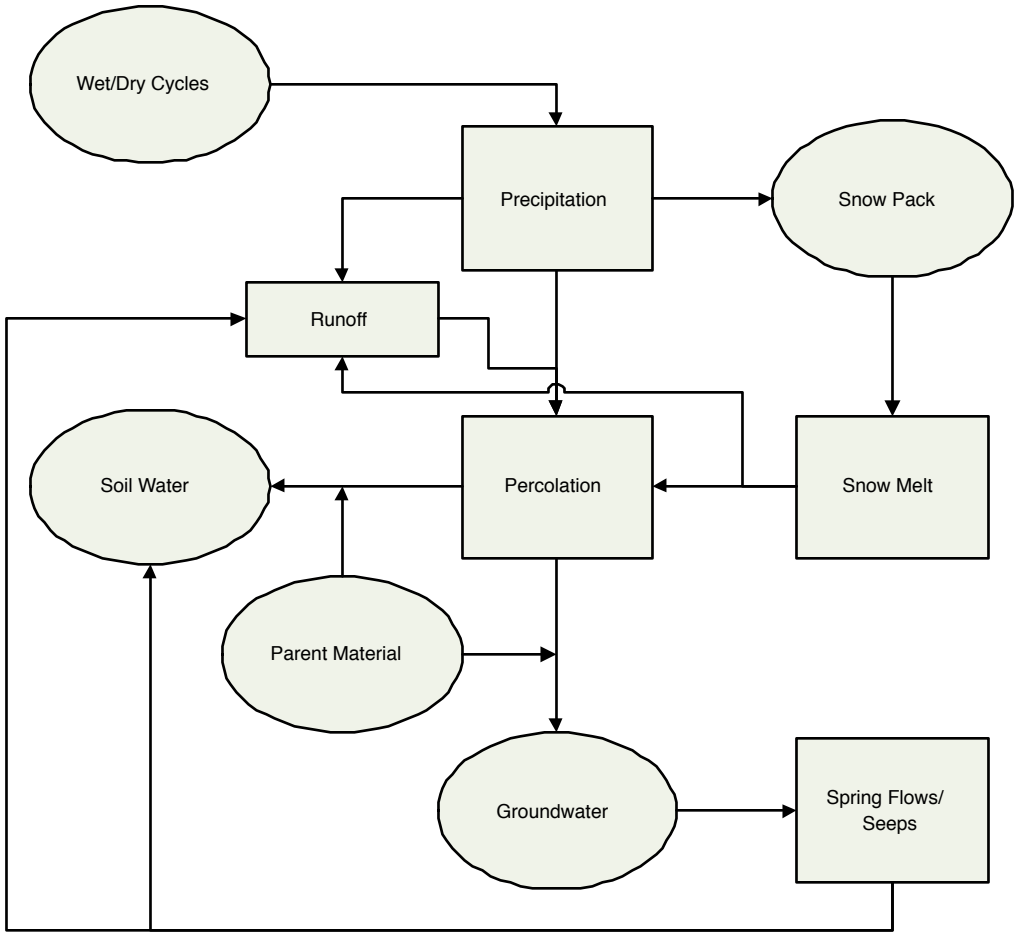

FIGURE 12 Aspen soil and groundwater processes submodel.

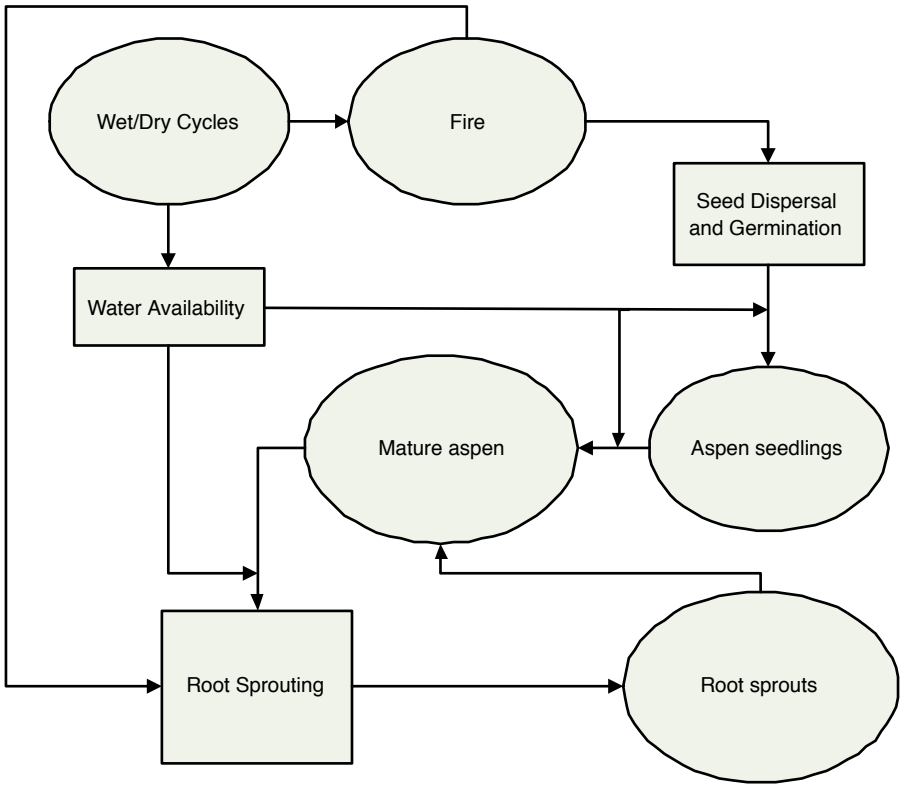

FIGURE 13 Aspen fire dynamics submodel.

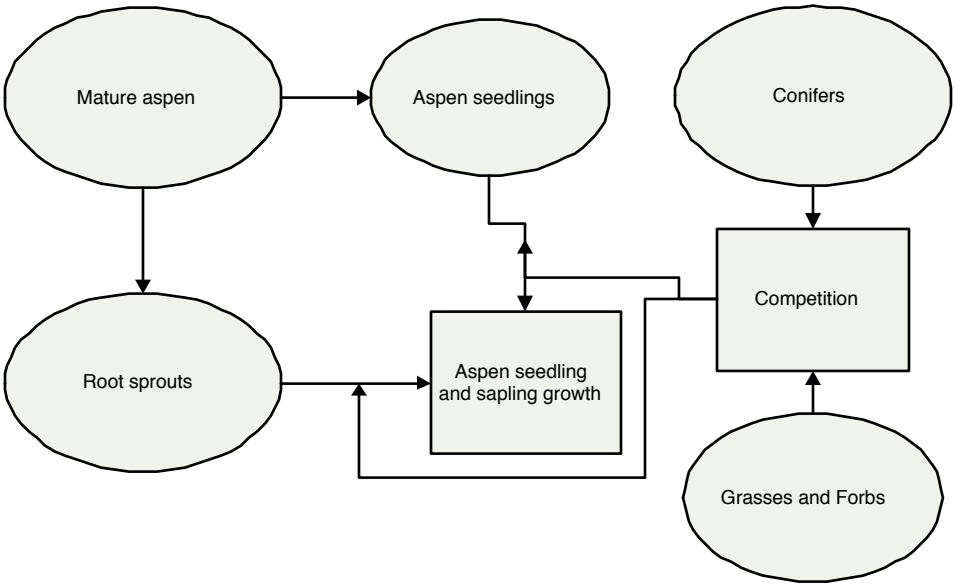

FIGURE 14 Aspen vegetation composition submodel.

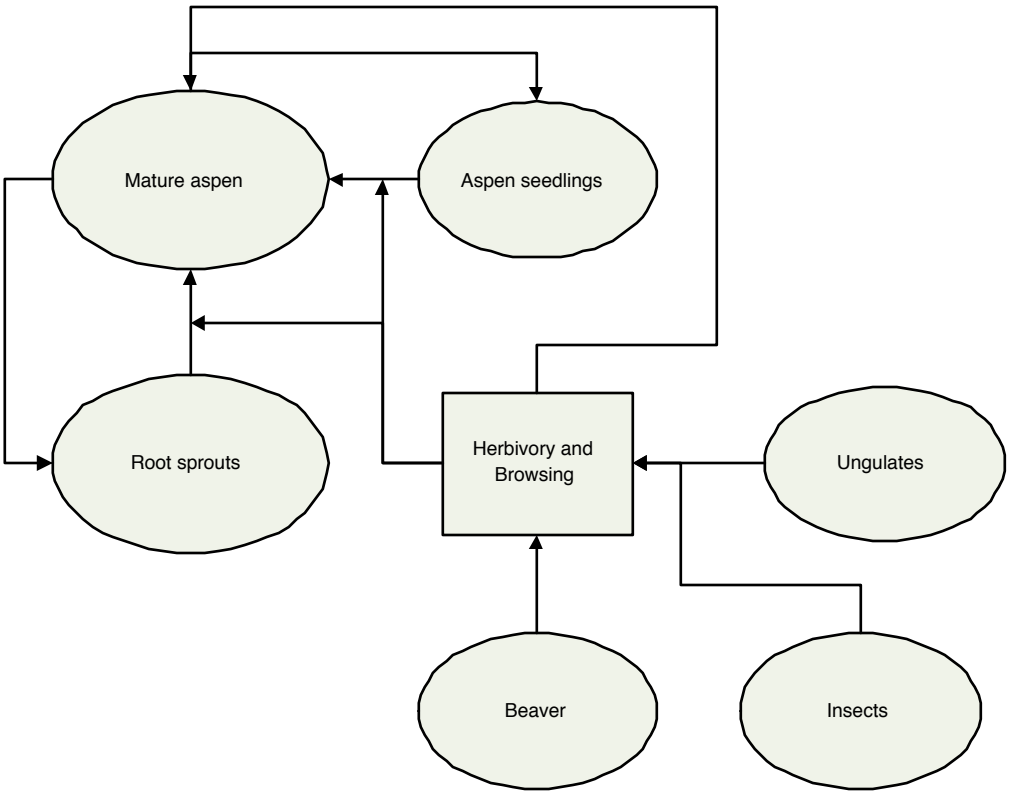

FIGURE 15 Aspen browse dynamics submodel.

DRY WOODLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Cathie Jean)

Dry Woodlands are a characteristic feature of Bighorn Canyon National Recreation Area (BICA), occupying 40% of the land area (Knight et al. 1987) between 1127–1545m elevation. Dry woodlands in the Wyoming Basin are found on shallow, coarse-textured rocky sites on fractured bedrock (Wight and Fisser 1968). This environment has an inverse texture effect; roots penetrate deep in the fractured bedrock to underground water sources.

Knight et al. (1987) divide the dry woodlands into three types, mountain mahogany shrublands (*Cercocarpus ledifolius*), juniper woodlands (*Juniperus osteosperma*) and juniper / mountain mahogany woodlands based solely on the abundance of dominant species. Although the authors were unable to determine any environment differences that could distinguish a juniper site from a mountain mahogany site, the latter is more usually found on stepper, more barren sites. All three types of woodlands are present on a variety of geologic substrates (Knight et al. 1987). The dry woodland ecosystem as described here also includes stands of limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*).

The juniper zone is often considered low value but, nevertheless, it is an important component of the range complex by providing forage and shelter for wild game. The dry woodland ecosystem is important wildlife habitat for bighorn sheep (*Ovis canadenis*) mule deer (*Odocoileus hemionus*) and feral horses (*Equus caballus*). Dry woodlands provide thermal cover for wildlife, although a dense woodland cover is a barrier to bighorn sheep as sheep are more secure in open habitats where they can see predators.

Bighorn sheep reintroduction efforts in the Bighorn and Pryor Mountains and surrounding areas by the Wyoming Department of Game and Fish and subsequent dispersal from translocations have resulted in the Bighorn Canyon bighorn sheep population (Sloan 1995 as cited in Gudorf et al. 1996). These sheep occupy areas adjacent and within the dry woodland ecosystem.

Drivers

Dry woodlands were formally restricted to rocky – fire free settings – largely controlled by geology and topographic position. Modern distribution of juniper species is traditionally attributed to overgrazing and fire suppression, however historic invasions could also mark the current progress of continued migration resulting from climate fluctuation (Betancourt 1987).

Drought in combination of fire suppression and grazing favor an increase in juniper cover and invasion into new sites. Grass and shrublands are vulnerable to juniper invasion, especially where herbivory results in a decrease of palatable plants which can lead to an increase of woody species or where herbivory results in the redistribution of fine fuels (Waugh 1986 as cited in Knight et al 1987) and a subsequent change in burn patterns. Fire suppression can accelerate succession grassland or shrublands to woodlands in two ways: directly preventing mortality in young, more easily burned juniper stands and indirectly by favoring the development of shrublands that serve as nurse plants for juniper seedling survival (Wright et al 1979). Once juniper is established, it is self-perpetuating as it competes well for available light, water and nutrients.

Stressors and Ecological Responses

A. FIRE SUPPRESSION AND GRAZING:

Fire suppression and grazing of palatable plants can lead to an increase in juniper cover and invasion of juniper into grassland and shrublands. This phenomenon is documented throughout the western states (see Burkhardt and Tisdale 1976). Furthermore, grasses are reduced due to juniper invasion (Jameson 66, 70 as cited in Knight et al 1987) and quality forage habitat for Bighorn Sheep and other wildlife is diminished. Low forage availability creates a need for Bighorn Sheep to forage further from escape terrain, thus increasing susceptibility to predators. Juniper leaf litter is high in phytotoxic chemicals (Jameson, 66, 70 as cited in Knight et al 1987) and this may further restrict available forage.

B. HUMAN ACTIVITIES AND LAND MANAGEMENT:

The decline and elimination of bighorn sheep from most of their historical range (Buechner 1960 as cited in Gudorf et al 1996), during the past century is believed to be attributed to human activities and land management practices that alter bighorn sheep habitat (Gudorf et al 1996). The steep, rugged escape terrain in Bighorn Canyon and its tributaries are a critical feature of bighorn sheep habitat. The openness of plant communities, or horizontal visibility, is fundamental determinant of bighorn sheep habitat quality (Gudorf et al 1996). Natural succession of dry woodlands into these habitats will make them increasingly less suitable for bighorn sheep as the thicker vegetation will obscure visibility and reduce forage availability.

C. HORSE GRAZING:

Wild horse herbivory in the Pryor Mountain Wild Horse Range and its effect on range and forage condition is a concern to wildlife and park managers. Fahnestock and Detling (2000) investigating the effects of short- and long-term ungulate grazing on plant species cover and composition found that long-term ungulate herbivory has significantly reduced grass cover and increased plant species diversity at some sites, especially lowlands in the Pryor Mountain Wild Horse Range.

3. Potential Indicators:

a. Extent and distribution of woodlands

Resource Monitored: Juniper and mountain mahogany woodlands in BICA

Justification: The spatial distribution and density of juniper and mountain mahogany woodlands influence habitat quality for Bighorn Sheep in Bighorn Canyon NRA. As forage grasses are reduced due to juniper invasion (Knight et al. 1987), quality forage habitat is diminished. Low forage availability creates a need for sheep to forage further from escape terrain and increases the chance of predation. Dry woodlands have the capability to both increase thermal cover, a valuable asset during the winter months, and the decrease security for bighorn sheep.

b. Ungulate population abundance, distribution, productivity

Resource Monitored: Demographic parameters (survivorship and population structure) of Bighorn Sheep.

Justification: The decline and elimination of bighorn sheep from most of their historical range (Buechner 1960 as cited in Gudorf et al 1996), during the past century is believed to be attributed to human activities and land management practices that alter bighorn sheep habitat (Gudorf et al 1996). Environmental stressors and management actions affect vital rates directly. Concerns persist regarding habitat quality, predation and disease and the effect on population viability in BICA.

c. Dry woodland community structure and composition

Resource Monitored: Abundance of potential forage for bighorn sheep and other wildlife species

Justification: Forage for wild and native ungulates is a management concern in BICA because of increased cover and density of juniper woodlands, increased pressure on available forage due to competition with feral horses and the spread of exotic species.

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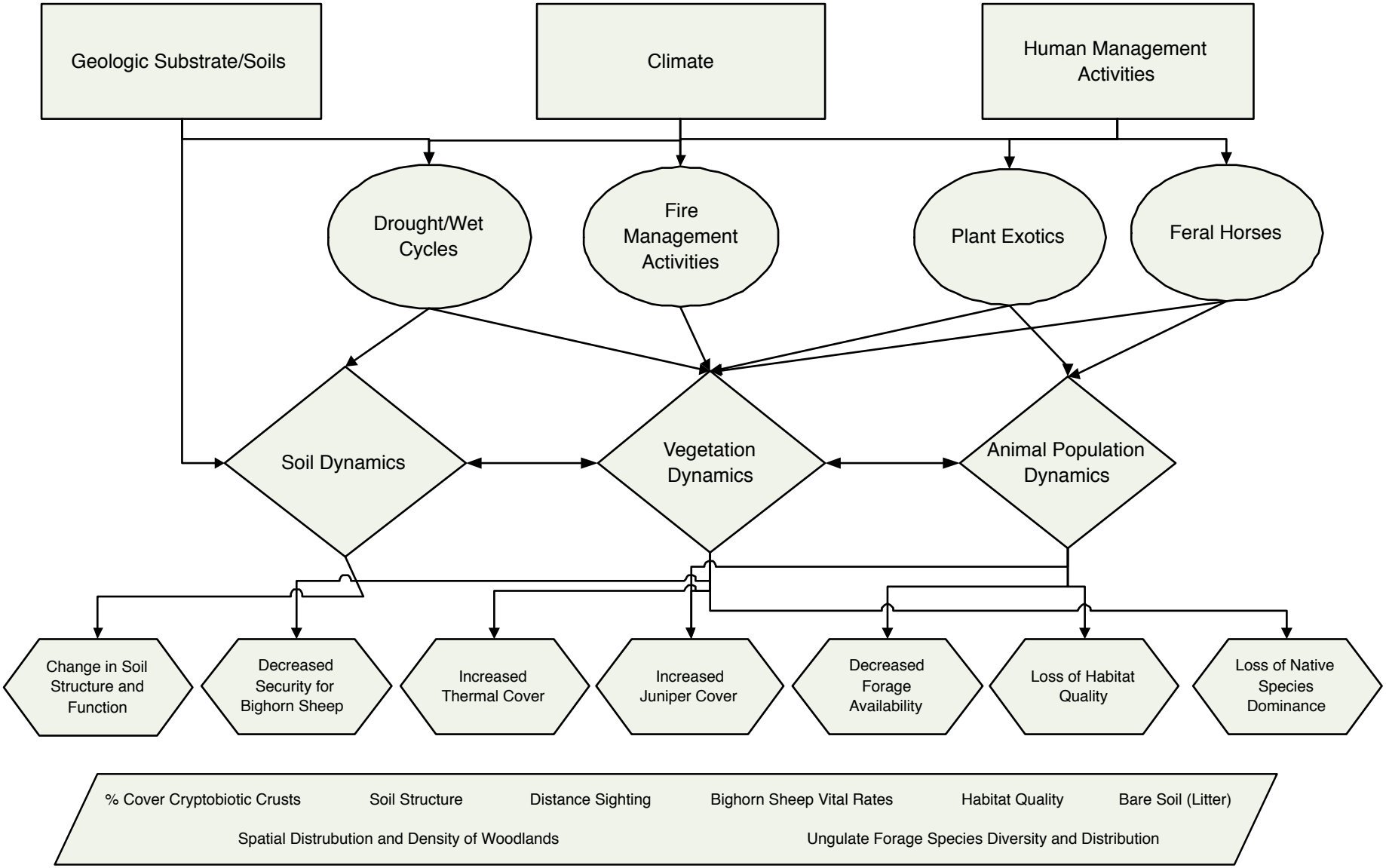

FIGURE 16 Dry woodland model.

GEOTHERMAL ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(authors: Hank Heasler and Cheryl Jaworowski)

In this paper, we present two conceptual models: a geologic conceptual model and a vital signs conceptual model. The geologic conceptual model of Yellowstone's geothermal system and processes is well understood. Among geologists, it is standard practice to draw schematic or geologic cross sections of the Earth that summarize geologic knowledge and earth processes. In geologic cross sections or schematic diagrams, the bottom of the diagram shows the deepest portion of the Earth and the top of the diagram represents the Earth' surface. In contrast, the vital signs conceptual model places Yellowstone's magma chamber (deepest portion of the Earth) at the top of the diagram as the driver for the model. We inverted the well-accepted geologic conceptual model of Yellowstone and generated a vital signs conceptual model that integrates with ecological conceptual models of Yellowstone.

Geological Conceptual Model

The geologic conceptual model of Yellowstone's geothermal system is well documented (Fournier and others, 1994; Smith and Siegel, 2000; White and others 1975). A partially molten (10-30% molten) magma chamber (45 by 30 miles wide and 3-8 miles deep) exists beneath Yellowstone National Park (Smith and Siegal, 2000). The magma chamber beneath Yellowstone National Park is in contact with a self-sealing high temperature and high concentration brine (See Figure 17). The brine exits in a porous rock layer between 1.5 to 3 miles deep. This tectonically sensitive brine may leak geothermal fluids to a high temperature reservoir. Geothermal fluids from the high temperature (~350°C) reservoir may discharge directly to the surface as hydrothermal features with unusual chemistry such as Beryl Springs. Or fluids from the high temperature reservoir may first discharge to medium temperature reservoirs (~250°C) and subsequently to the Earth's surface as neutral chloride springs. Medium temperature reservoirs may discharge fluids (water or gases) to low temperature (~150°C) reservoirs. Low temperature reservoirs may discharge fluids (water or gases) to the Earth's surface and form acid sulfate springs. Precipitation of silica and zeolites along fractures provides a self-sealing mechanism. The competing effects of a self-sealing mechanism and earthquakes control the upflow of geothermal fluids to reservoirs.

Acid sulfate thermal springs, neutral chloride thermal springs, mud pots, paint pots geysers, or fumaroles exist where there is an appropriate combination of water chemistry, plumbing, heat, and hydrology. Neutral chloride springs represent unrestricted discharge of thermal waters from reservoirs. Above the local water table where there is more heat than water, steam vents to the surface forming fumaroles. At the Earth's surface, oxidation of H2S will form acid sulfate springs. Additionally, acidic waters will cause chemical decomposition of the bedrock, generate clay minerals and form mud pots or paint pots (with ferric-oxides). A key to understanding the geochemistry of thermal waters in the Upper Geyser Basin is knowledge of dissolved gases such as CO2 (Fournier and others, 1994). In the Upper Geyser Basin, the amount of boiling (no boiling to maximum boiling) in the intermediate reservoirs determines the chemical composition of thermal waters in the shallow, low temperature reservoirs and ultimately the geochemistry of thermal springs at the Earth's surface. Annual, generally widespread changes in thermal features in the Norris Geyser Basin are the result of changes in the potentiometric surface of cold water adjacent to or interconnected with the hydrothermal system (Fournier and others, 2002). Thus, to understand short-term cyclical and catastrophic changes as well as long-term changes that may be natural or anthropogenic to the Yellowstone hydrothermal system both cold ground water and hydrothermal systems the must be monitored and assessed.

Rainfall and snowmelt (meteoric waters) from the Earth's surface may recharge fluids in the low temperature, medium temperature or high temperature reservoirs. The amount of meteoric waters entering the various subsurface reservoirs depends upon the amount of precipitation falling over the Yellowstone National Park. During times of glaciation, the balance between meteoric waters entering subsurface reservoirs and fluids from the magma chamber changes. During the last glacial maximum (Pinedale), geochemical evidence indicates that cold-water recharge entered the hydrothermal system (Fournier and others, 1994). As the glaciers melted, fluid flow reversed and became a hydrothermal system dominated by discharge. Changes in the magma chamber itself also affect the release of geothermal waters and gases. Thus, monitoring hydrothermal waters in Yellowstone's geyser basins will yield information about the mixing of fluids and the health of the geothermal system.

Vital Signs Conceptual Model

A. THE DRIVER: YELLOWSTONE'S MAGMA CHAMBER

Yellowstone's magma chamber is the ultimate geophysical driver of the vital signs conceptual model (See Figure 27). Geothermal fluids convect towards the surface via fracture systems that are self-sealing and tectonically sensitive. Geothermal fluids from deep, intermediate and shallow depths mix and interact with meteoric waters and eventually are discharged as hydrothermal features in Yellowstone's geyser basins.

B. STRESSORS

Precipitation, climate change, volcanic activity, earthquakes and human activity affect thermal feature chemistry, thermal feature extent, hydrothermal fluids, and thermal feature temperature. Yellowstone National Park has two distinct climates within YNP (Despain, 1987) and YNP is located near the boundary between regional atmospheric flow patterns. Depending upon where this boundary is located the annual climate and precipitation may be above or below normal precipitation in different areas of the park. Climate and weather (precipitation) directly influence the amount of "cold" meteoric waters in thermal areas. Earthquakes and volcanic activity can rejuvenate thermal features by opening new pathways for fluids or close existing thermal pathways. Human activities such as geothermal development, oil & gas exploration, the drilling and production of water wells or vandalism may affect the fluid flow of thermal features.

C. EFFECTS

Stressors affect changes in the chemistry of thermal features, extent of thermal features, fluid flow, and temperature of thermal features.

D. OUTCOMES

Acid sulfate thermal springs, neutral chloride thermal springs, mud pots, geysers, fumaroles and heated ground are consequences of Yellowstone's magma chamber and its stressors.

Measures or Vital Signs

The following vital signs are measures of Yellowstone's geothermal systems: chloride flux, the temperature of well waters, water levels in wells, the spatial extent of features, and the heat flux.

E. VITAL SIGNS

1. Chloride Flux

Over 94% of the chloride in waters originating in Yellowstone is of magmatic origin (Norton and Friedman, 1985). A study of variations in chloride flux can be used to establish a baseline for measuring the interaction of the deep geothermal waters with the surficial geothermal system. In addition, chloride flux baseline information may be used to assess any future adverse impacts on the Park's thermal features that may be caused by commercial development of geothermal energy, gas, oil and groundwater adjacent to the Park.

Resource Monitored: Thermal Features (mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs)

Justification: The chloride flux method for estimating geothermal activity in YNP has been extensively peer reviewed, accepted, and published (Fournier and others, 1976, Norton and Friedman, 1985; Friedman and Norton, 1990; Norton and Friedman, 1991; and Friedman and others, 1993). In addition, 19 years of chloride flux data exists for Yellowstone's major rivers-the Fall, Madison, Snake, and Yellowstone.

2. Heat Flux

Yellowstone's heat flux has been estimated using the chloride flux method, airborne sensors and satellite images. Increased heat flux in an area may indicate changes in subsurface hydrothermal activity. Additionally, warm ground affects the health of vegetation, migration of animals, and safety of park visitors.

Resource Monitored: Heated Ground

Justification: The chloride flux method for estimating heat flux in YNP has been extensively peer reviewed, accepted, and published (Fournier and others, 1976, Norton and Friedman, 1985; Friedman and Norton, 1990; Norton and Friedman, 1991; and Friedman and others, 1993). Remote sensing is a cost-efficient method to map and monitor heated ground. In the early days of remote sensing, Haze (1971) estimated heat flow and geothermal resources. In 2002, Watson and others used Landsat 7 sensors to estimate ground that was snow-free or minimal snow cover due to thermal activity. In the winter and spring, animals make use of thermal areas with minimal snow cover. In 2002, thermal airborne sensors were flown over the Mammoth-Norris corridor. Mapping new areas of heated ground and yearly changes in the heated ground can assist with maintenance of roads and visitor safety.

3. Temperature of Water in Wells

In Yellowstone National Park, water can come from several sources: a high temperature, deep reservoir (~350°C), medium temperature, intermediate depth reservoirs (~250°C), or low temperature, shallow reservoirs (~150°C). Water from the high temperature reservoir di-

rectly connected to the magma chamber may be discharged as the unique thermal feature known as Beryl Springs. Water from medium temperature reservoirs may be directly discharged to the surface and form neutral chloride thermal features or flow to low temperature reservoirs. Water from the low temperature reservoirs may be directly discharged to the surface and form acid sulfate springs.

Resource Monitored: Groundwater system associated with thermal features

Justification: In Yellowstone, human activities such as road construction can adversely impact unique thermal features such as Beryl Springs or the many neutral chloride and acid sulfate springs. Potential threats outside of Yellowstone (geothermal development, oil and gas development, groundwater development) may also affect Yellowstone's thermal features.

4. Water Level in Wells

Water levels in wells respond to variations in climate, precipitation, geothermal development or development of petroleum resources adjacent to the Yellowstone National Park. Monitoring of water levels in wells will capture changes in the groundwater system. Comparison of water levels with meteorological data, seismic data, ground deformation or recent earthquakes will aid in distinguishing natural changes in thermal features from climatic change or human causes (geothermal, oil or gas wells outside of Yellowstone).

Resource Monitored: Groundwater system associated with thermal features

Justification: Comparison of water levels in wells will aid in distinguishing natural changes in thermal features from climatic change or human causes (geothermal development, oil or gas wells, groundwater development).

5. Spatial Extent of Thermal Features

Geologists use various visible, infrared, and microwave sensors to map surficial deposits, flow structures in lava flows, faults, fractures, ash flows, basalts, rhyolites, andesites, and allow lithologic discrimination of sedimentary rocks. Additionally, visible, infrared, thermal and microwave sensors (AVIRIS, TIMS, LANDSAT and RADAR) can detect subsidence, predict movements of animals, discriminate between healthy versus stressed vegetation, map active hot springs, map hydrothermal mineralization, and generate detailed mineral maps of specific areas (Dzurisin and others, Evans, 1988; 1990; Kokaly and others 1998; Kokaly and others 1999; Kruse, 1997, Shafer, 1998; Wicks and others, 1998).

Resource Monitored: Thermal features (mud pots, geysers, fumaroles, neutral chloride thermal springs and acid sulfate thermal springs)

Justification: Remote sensing technologies are a cost-efficient method of mapping and monitoring the spatial extent of thermal features. Change detection maps of thermal features can aid the assessment of natural changes versus human-caused changes of thermal areas. Maps derived from remote sensing technologies have applications to geology, hydrology, geobiology, archeology, and ecology. Additionally, these colorful images can be used by park interpreters to educate visitors and by park managers to inform politicians or other resource managers.

F. SUMMARY

We propose to monitor the following vital signs as indicators of the thermal activity and integrity of Yellowstone's geothermal areas: (1) chloride flux, (2) the temperature of water wells, (3) water levels in wells, (4) the spatial extent of thermal features, and (5) heat flux.

A more complete discussion of methodology proposed for monitoring Yellowstone National Park's geothermal resources can be found in the draft version of "A Geothermal Monitoring Plan for Yellowstone National Park", March 2003 by H. Heasler, C. Jaworowski, and D. Susong.

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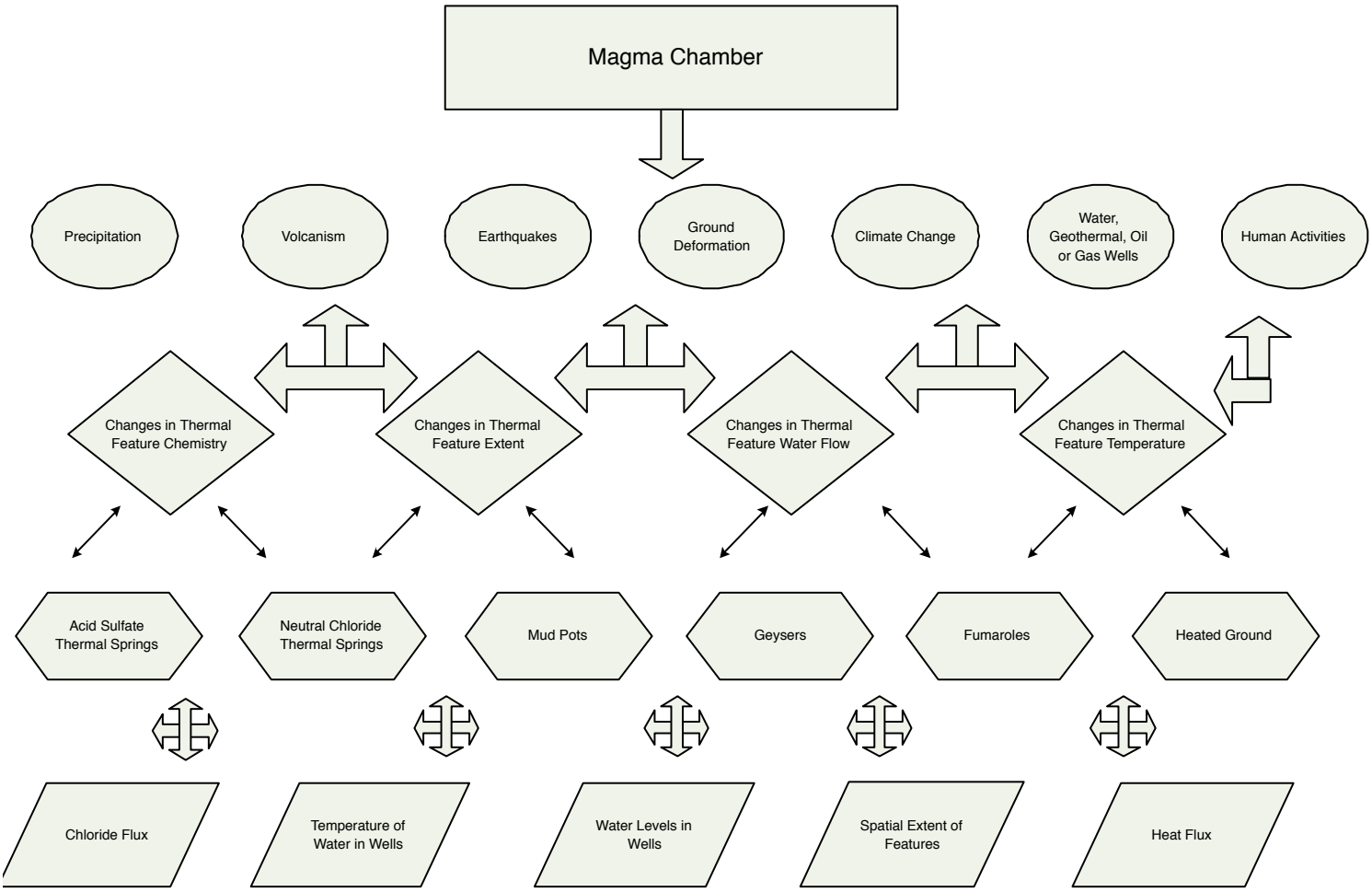

FIGURE 17 Geothermal model.

GRASSLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Glenn Plumb)

Grass plants evolved between seventy to eighty million years ago with adaptations that allow them to survive under intense and frequent disturbances including tremendous removal of living phytomass (e.g. fire and herbivory) and drought. Grasses often grow in vast concentrations, most often in semi-arid climates (Brown 1985) with a fairly uniform and continuous cover. Grasslands are the largest of the four major natural vegetation formations covering the planet (Gould 1968) and have certain characteristics in common, including a rolling to flat topography with precipitation between ten and 40 inches per year distributed unevenly with seasonal peaks followed by extended periods of drought (Sims 1988). Historically, grasslands covered up to 800 million ha in North America (Kuchler 1964) and still remain the largest native biome covering approximately 125 million ha (USFS 1980). Although most grasslands were historically located on extensive plains, relatively small pockets of mountain grasslands and grassland-forest combinations occur in the western coniferous forests (Sims 1988). Grasslands are dominated by grasses and grass-like plants (e.g. Cyperaceae) with particular grassland's biomass dominated by fewer than 6 species (Coupland 1974). Yet, typically grasses contribute less than 20% of the total vegetative species richness to a grassland community. Forbs (non-grass-like herbs) are seasonally important along with dwarf shrubs and occasional trees (Coupland 1979). Grassland plants invest carbohydrates in structural development early in the growing season when moisture is adequate and thus during successive drought, grassland plants can utilize stored labile carbohydrates, decrease dark respiration and maintain gas-exchange process under stressed water potentials. Nutrient uptake is rapid when moisture is available and at these times, plants are most palatable and tolerant of herbivory with removal of phytomass often stimulating increased rates of photosynthesis by the remaining tissues and intercalary meristems of grasses permitting growth after herbivory (Risser 1985). Under periodic drought stress grassland plats close stomata with extensive leave curling to reduce water loss (Risser 1985).

Conceptual Model Development

1. DRIVERS

The climate of the GRYN parks is characterized by long, cold winters and cool, dry summers with much precipitation occurring as snowpack that melts rapidly April – June, depending on elevation providing much of the water available for annual growth in mountain grasslands. Snowpack generally begins to accumulate in October and November, reaches maximum in early to mid-April. Due to late-winter rates of accumulation, the annual snowpack can become isothermic before peak accumulation and thus melts rapidly beginning in May to July depending on elevation. Despain (1990) describes two major local climatic types as a valley type with peak precipitation coming in the spring and a mountain type with peak precipitation in the winter. Merrill and Boyce (1996) evidenced that mountain grassland seasonal biomass production was more correlated with climate and snowpack controls that the total number of herbivores occupying the grassland.

Soils of grasslands often differ markedly from those soils found under forest canopy due to variation in underlying depositional origins and the differences in soil formation processes unique to vegetation types (Coupland 1979). In grasslands, leaching is often limited due to general aridity and so grassland soils are often more basic with organic matter distributed throughout the soil profile. While many grassland soils are derived from glacial and associated outwash sand and gravel parent materials, the GRYN mountain grasslands are also heavily influenced by volcanic rhyolitic and andecitic parent materials (Despain 1990). The GRYN parks are also influenced by glacial depositional/windblown loess that was strongly influenced by the distribution and duration of glacial icecaps (Despain 1990).

2. STRESSORS AND ECOLOGICAL RESPONSES

Frank and McNaughton (1992) examined the interactive roles of large animal herbivory and drought on mountain grasslands and found that although the process of aboveground net primary productivity, large herbivore consumption and dung deposition varied widely among different grassland sites, grassland production and consumption, and consumption and dung deposition were positively correlated across sites. Despite the evidenced role of herbivory and dung deposition in controlling site-level production, they also concluded that climate is the principal driving variable of ecosystem processes and that direct and indirect effects of single-season drought will persist for several years after the event. Frank and McNaughton (1993) concluded that in the absence of drought, herbivory at the site level can result in a compensatory growth response and hence stimulate mountain grassland productivity due in part that the migratory behavior of native ungulates tracks young, high quality forage as it varies temporally

and spatial along an elevational gradient across these ecosystems. The nutrient dynamics of mountain grasslands that support abundant migratory large-body sized wildlife are generally poorly understood (Frank et al. 1994), but evidence from Yellowstone National Park suggests that grazers are important component of mountain grassland N budgets with 1) landscape position and soil water affecting nutrient dynamics, 2) annual mineralization positively associated with soil N content, 3) the proportion of soil N mineralized negatively correlated to soil C/N, and 4) rates of nitrogen mineralization higher in mountain grasslands than in other temperate grassland ecosystems, possibly due to grazers promoting N cycling.

Detling (1998) reviewed the effects of mammalian herbivores on GRYN park grassland plant species composition, biomass, productivity and nitrogen cycling and concluded that patch dynamics controlled by local small mammal soil disturbances, fire, grazing, and urine/dung deposition underpinned temporal and spatial variability in grazing intensity and facilitated N mineralization and persistence of grassland communities. The role of fire in mountain grasslands was also examined by Norland et al. (1996) who concluded that forage biomass decreased where moderate soil heating occurred, forage quality (N and digestibility) increased, herbivore diets and habitat use patterns did not change, but that large herbivore use of riparian shrubs did increase. Simulation model experiments by Turner et al. (1994) explored the effects of fire size, fire pattern and winter severity on large herbivore foraging and population dynamics on a mountain grassland. Although, fire pattern (clumped vs fragmented) and winter severity seemed to control temporal and spatial variation in grassland foraging and habitat use patterns, the interactions between fire scale and grassland spatial patterns suggest that fire size along is not sufficient to predict grassland response and ungulate survival. A review of ecological stressors and responses in a mountain grassland in northern Yellowstone National Park (YNP 1997) concluded that 1) large ungulate herds and intensive grazing did not appear to be affecting native or Alpha diversity (Singer 1996), 2) there is no consistent effects of large animal grazing on forbs (Coughenour et al. 1995, Reardon 1996), 3) soil bulk densities were higher on grazed areas (Lane 1990, Lane and Montagne 1996) and soil moisture levels were unaffected by grazing (Lane 1990, Coughenour 1991, Singer and Harter 1996), 4) accumulated organic litter was greater in ungrazed sites and exposed bare ground was higher in grazed areas (Frank 1990, Singer 1996), and 5) mountain grassland root biomass and nitrogen exhibited no responses to grazing (Merrill et all 1994).

3. INDICATORS

Grasslands of the GRYN are characterized generally by montane communities dominated by varying levels of perennial C4 graminoids, C3 graminoids, forbs and dwarf or small shrubs with local sites often dominated by either C4 or C3 graminoids. There are few if any sites that would be characterized as true short or mixed grass prairie. Aboveground vegetative biomass production is a cumulative process within a single growing season, with peak biomass roughly equivalent to Annual Net Primary Production (Briggs and Knapp 1995). In these montane systems, peak vegetative biomass production occurs dependent on elevation and aspect controls on soil temperature and precipitation regimes. Grassland annual aboveground vegetative biomass production responds directly to a suite of intra- and inter-annual primary stressors including grazing (e.g. herbivory), fire, drought, snowpack, and in some circumstances trampling by hoofed medium and large herbivores, and directly reflects the primary photosynthetic capacity that can be quantified across multiple spatial and temporal scales. Although climate has been described as the primary driving variable of montane grassland processes (McNaughton and Frank 1992), each park has qualitative and quantitative models to partition the interactive effects of these multiple primary stressors. Extra-normal variation in grassland vegetative biomass capacity will be a direct response indicator of both short and long term stressor effects. Multiple factors can control and limit ANPP at larger scales in grasslands including fire, climatic variability, and various activities by herbivores, with soil nitrogen and water limitations often operating at local scales. Knapp et al. (1998) suggest that these scale-dependent controls on ANPP underpin patterns of temporal switching among limiting resources that results in non-equilibrium behaviors in which transient periods occur where no resources are limiting. Thus, ANPP becomes a reliable predictive ecological indicator only with long-term records and a non-equilibrium perspective.

In GRYN montane grassland communities, vegetative biomass production is underpinned by temperature and soil moisture availability that are generally controlled temporally by delayed onset of the growing season according to increasing elevation. Onset and timing of herbivory of the annual increment of primary vegetative production by large and medium sized herbivores is generally synchronized with onset of seasonal "growth pulse" of green-up as it moves from winter ranges to higher elevation summer ranges. Migratory native GRYN herbivores (e.g. elk, bison) often utilize the initial green-up phase but move to higher elevations prior to onset of plant

reproduction. Non-migratory GRYN herbivores (e.g. wild horses) will sustain utilization of montane grasslands until current annual growth or residual cover is depleted. Frank (1990) showed that seasonal utilization of montane grasslands could stimulate total annual productions beyond levels of ungrazed sites. Thus, offtake as a measure of the amount of annual vegetative growth increment that is removed by these native large and medium sized herbivores can serve as a variably important stressor on the resiliency of montane grasslands. Although, short-term interannual variation in vegetation offtake can be explained by inherent variability of climate and herbivory interactions, long-term trends and patterns of montane grassland resiliency can be inferred from measures of offtake as an integrative indicator of whether there are immediate or long-term concerns for residual effects of overgrazing of these systems. Unlike fire or climatic influences that can generate some levels of uniform grassland vegetation responses, seasonal grazing of montane grasslands can generate patchy heterogeneity. Overlaid on these patterns of heterogeneity are heterogeneous patterns of trampling, urine and dung deposition and the issues of patchy compensation and even overcompensation by grazed plants. Thus, although annual temporal and spatial patterns of offtake can be variable, long-term measurements of offtake can be an important integrative ecological indicator of grassland nonequilibrium dynamics.

The availability and cycling of nutrients, especially N, is a primary controlling stressor on grassland community structure and function, and in turn are directly affected by variation in ecosystem processes such as vegetation production and decomposition (Blair et al. 1998). Variation in N availability can determine and limit productivity, species composition, and plant physiological responses to disturbances and rates of litter decomposition. Additionally, N cycling processes can be directly altered by human activities such as prescribed fire and external influences such as climate and topography (Turner 1997). Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, grassland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry. In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane grasslands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane grasslands operate as a nonequilibrium system in which the relative importance of N varies in space and time (Knapp and Seastadt 1998).

The native species richness of montane grasslands are often characterized by a matrix of widely distributed, temporally stable, and abundant "core" species, a second tier of localized, less abundant, and temporally dynamic and somewhat unpredictable "satellite" species (subdominant graminoids and forbs). The exotic species richness of montane grasslands often follows a two-tiered similar pattern with species such as timothy, smooth brome, bluegrass and annual bromes dominating some landscapes while other montane grassland landscapes include only few subdominant exotic forbs. These "satellite" species suggest a subdominant role for non-equilibrium dynamics in the persistence of native montane grassland community abundance and distribution. By contrast, the spatial and temporal stability of the "core" species richness suggests a certain dominant equilibrium dynamic to native montane grassland community abundance and distribution. Still, although there can be a dominant equilibrium matrix of montane grassland species, these systems are far from static and can be disrupted severely by the emergence of dominant exotic species described above. Indeed, the increasing presence of exotic species, described above, has greatly altered some GRYN grassland communities. Thus, long-term measures of native and exotic species abundance and distribution can serve as an important integrative ecological indicator to asses the interplay between equilibrium and nonequilibrium processes that regulate montane grassland plant species persistence and coexistence. For this vital sign to be useful, GRYN parks will need robust models of the relationship between montane grassland condition and exotic species presence and resultant effects on broader ecological processes and outcomes.

Research from a variety of grassland types indicates that there are important mechanisms by which the dominant disturbance regimes

(e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of grassland small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance, whereas sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and that when coupled to measures of grassland production and offtake could serve as key integrative ecological indicators. There is some evidence that grassland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane grassland animal populations and communities. Hence, the spatial and temporal variation in population abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

a. Grassland Annual Net Primary Productivity – ANPP (e.g. Aboveground Vegetation Production, Photosynthetic Capacity)

Justification: Grasslands of the GRYN are characterized generally by montane communities dominated by varying levels of perennial C4 graminoids, C3 graminoids, forbs and dwarf or small shrubs with local sites often dominated by either C4 or C3 graminoids. There are few if any sites that would be characterized as true short or mixed grass prairie. Aboveground vegetative biomass production is a cumulative process within a single growing season, with peak biomass roughly equivalent to Annual Net Primary Production (Briggs and Knapp 1995). In these montane systems, peak vegetative biomass production occurs dependent on elevation and aspect controls on soil temperature and precipitation regimes. Grassland annual aboveground vegetative biomass production responds directly to a suite of intra- and inter-annual primary stressors including grazing (e.g. herbivory), fire, drought, snowpack, and in some circumstances trampling by hoofed medium and large herbivores, and directly reflects the primary photosynthetic capacity that can be quantified across multiple spatial and temporal scales. Although climate has been described as the primary driving variable of montane grassland processes (McNaughton and Frank 1992), each park has qualitative and quantitative models to partition the interactive effects of these multiple primary stressors. Extra-normal variation in grassland vegetative biomass capacity will be a direct response indicator of both short and long term stressor effects.

Comment: Multiple factors can control and limit ANPP at larger scales in grasslands including fire, climatic variability, and various activities by herbivores, with soil nitrogen and water limitations often operating at local scales. Knapp et al. (1998) suggest that these scale-dependent controls on ANPP underpin patterns of temporal switching among limiting resources that results in non-equilibrium behaviors in which transient periods occur where no resources are limiting. Thus, ANPP becomes a reliable predictive ecological indicator only with long-term records and a non-equilibrium perspective.

b. Grassland Vegetation Annual Offtake (e.g. Current year growth utilization by primary consumers)

Justification: In GRYN montane grassland communities, vegetative biomass production is underpinned by temperature and soil moisture availability that are generally controlled temporally by delayed onset of the growing season according to increasing elevation. Onset and timing of herbivory of the annual increment of primary vegetative production by large and medium sized herbivores is generally synchronized with onset of seasonal "growth pulse" of green-up as it moves from winter ranges to higher elevation summer ranges. Migratory native GRYN herbivores (e.g. elk, bison) often utilize the initial green-up phase but move to higher elevations prior to onset of plant reproduction.

Non-migratory GRYN herbivores (e.g. wild horses) will sustain utilization of montane grasslands until current annual growth or residual cover is depleted. Frank (1990) showed that seasonal utilization of montane grasslands could stimulate total annual productions beyond levels of ungrazed sites. Thus, offtake as a measure of the amount of annual vegetative growth increment that is removed by these native large and medium sized herbivores can serve as a variably important stressor on the resiliency of montane grasslands. Although, short-term interannual variation in vegetation offtake can be explained by inherent variability of climate and herbivory interactions, long-term trends and patterns of montane grassland resiliency can be inferred from measures of offtake as an integrative indicator of whether there are immediate or long-term concerns for residual effects of overgrazing of these systems.

Comment: Unlike fire or climatic influences that can generate some levels of uniform grassland vegetation responses, seasonal grazing of montane grasslands can generate patchy heterogeneity. Overlaid on these patterns of heterogeneity are heterogeneous patterns of trampling, urine and dung deposition and the issues of patchy compensation and even overcompensation by grazed plants. Thus, although annual temporal and spatial patterns of offtake can be variable, long-term measurements of offtake can be an important integrative ecological indicator of grassland non-equilibrium dynamics.

c. Grassland Nitrogen (e.g. availability, inputs, loss and associated processes)

Justification: The availability and cycling of nutrients, especially N, is a primary controlling stressor on grassland community structure and function, and in turn are directly affected by variation in ecosystem processes such as vegetation production and decomposition (Blair et al. 1998). Variation in N availability can determine and limit productivity, species composition, and plant physiological responses to disturbances and rates of litter decomposition. Additionally, N cycling processes can be directly altered by human activities such as prescribed fire and external influences such as climate and topography (Turner 1997). Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, grassland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry.

Comment: In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane grasslands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane grasslands operate as a nonequilibrium system in which the relative importance of N varies in space and time (Knapp and Seastadt 1998).

d. Grassland Vegetation Community Structure (Patterns of abundance and distribution)

Justification: The native species richness of montane grasslands are often characterized by a matrix of widely distributed, temporally stable, and abundant "core" species, a second tier of localized, less abundant, and temporally dynamic and somewhat unpredictable "satellite" species (subdominant graminoids and forbs). The exotic species richness of montane grasslands often follows a two-tiered similar pattern with species such as timothy, smooth brome, bluegrass and annual bromes dominating some landscapes while other montane grassland landscapes include only few subdominant exotic forbs. These "satellite" species suggest a subdominant role for non-equilibrium dynamics in the persistence of native montane grassland community abundance and distribution. By contrast, the spatial and temporal stability of the "core" species richness suggests a certain dominant equilibrium dynamic to native montane grassland community abundance and distribution. Still, although there can be a dominant equilibrium matrix of montane grassland species, these systems are far from static and can be disrupted severely by the emergence of dominant exotic species described above.

Indeed, the increasing presence of exotic species, described above, has greatly altered some GRYN grassland communities. Thus, long-term measures of native and exotic species abundance and distribution can serve as an important integrative ecological indicator to asses the interplay between equilibrium and nonequilibrium processes that regulate montane grassland plant species persistence and coexistence.

Comment: For this vital sign to be useful, GRYN parks will need robust models of the relationship between montane grassland condition and exotic species presence and resultant effects on broader ecological processes and outcomes.

e. Grassland Insect and Vertebrate Community Structure

Justification: Research from a variety of grassland types indicates that there are important mechanisms by which the dominant disturbance regimes (e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of grassland small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance. Sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and that when coupled to measures of grassland production and offtake could serve as key integrative ecological indicators.

Comment: There is some evidence that grassland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane grassland animal populations and communities. Hence, the spatial and temporal variation in population abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

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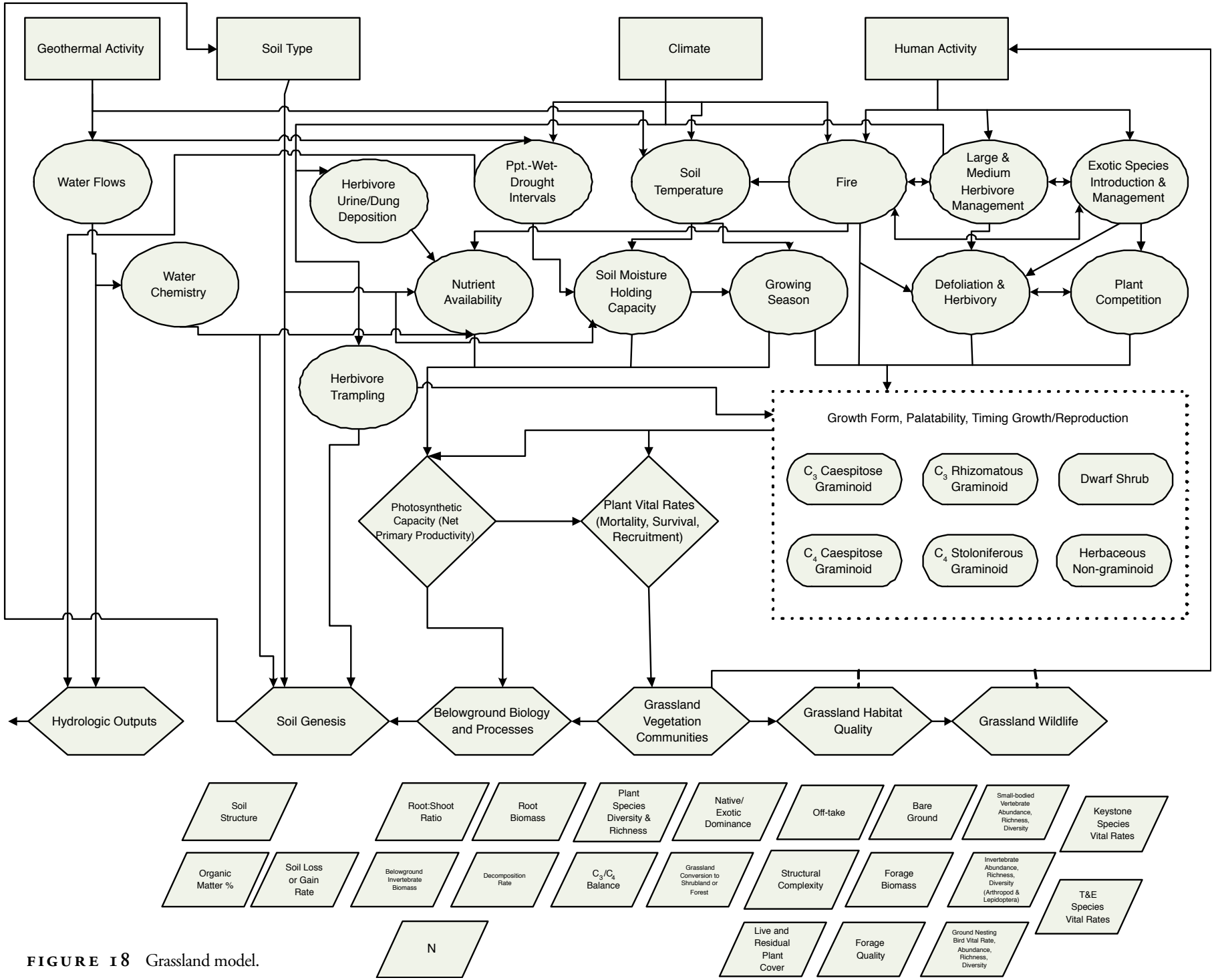

FIGURE 18 Grassland model.

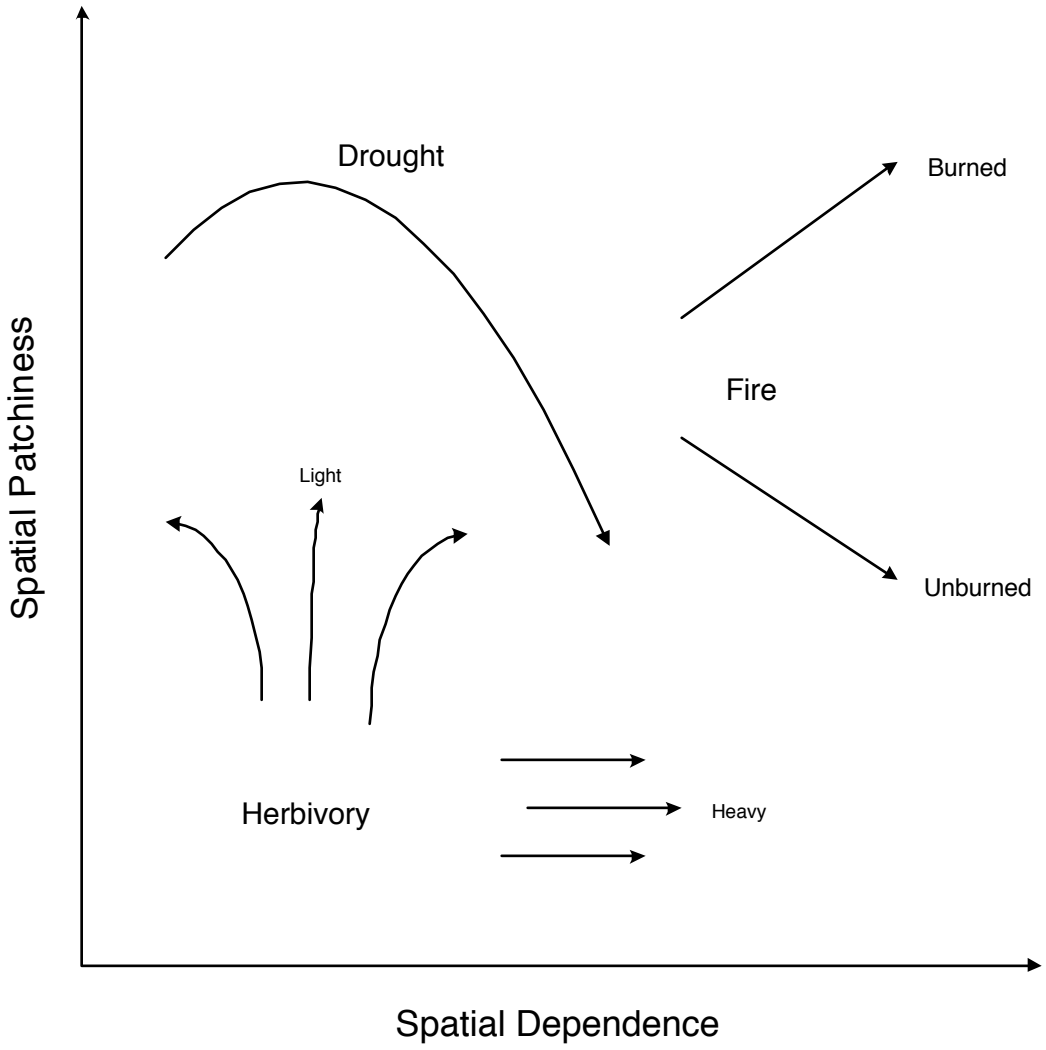

FIGURE 19 Grassland net primary productivity submodel (adapted from Briggs 1998).

SHRUBLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Glenn Plumb)

Many shrubland communities area characterized by a matrix of shrub growth forms and interspaces that may be occupied by variable levels of native graminoids and herbaceous non-graminoid cover. The floristic composition of shrubland interspace communities can be heavily controlled by moisture competition and allelopathy. The natural evolutionary resilience of shrubland communities can be altered under severe disturbance regimes such as fire in fire-intolerant communities or excessive grazing/trampling by large herbivores. The natural resilience of shrubland communities can be further stressed by the introduction of aggressive exotic plant species into these interspaces. Foremost among these aggressive exotics is Bromus tectorum that can, by virtue of completing its annual growth cycle by early summer, outcompete native C3 or C4 graminoids through moisture competition. This continuous fine fuel layer can then facilitate increased fire frequency and intensity, reducing fire-intolerant shrub species, resulting in reduced soil organic matter and nutrient pools and a spiral of downward ecosystem degradation. Shrubland interspaces are often characterized by either a microcryptic crust dominated by mosses, lichens, and algae between the perennials or abundant exposed mineral soil surface between the perennials. Excessive grazing or trampling of microcryptic crusts can predispose shrubland communities to invasion by aggressive exotic species. Thus, for shrubland exotic species to serve as a meaningful ecological indicator, there needs to be relatively strong models that predict the interactive relationships between natural system resilience, excessive disturbance, and the ecology of exotic species.

Woody, lignified or partially lignified shrubs provide food or feeding sites, security, and breeding areas for aboveground and belowground small vertebrates and insects in montane shrubland communities. Research from a variety of shrubland types indicates that there are important mechanisms by which the dominant disturbance regimes (e.g. fire, grazing, drought, trampling, wallowing) can have important interactive effects on the emergent spatial and temporal patterns of populations and communities of small mammals, birds and insects. Variation in scale-dependent effects on abundance and distribution of taxon can be attributed to variation in food and/or habitat requirements (generalist versus specialist), differences in vagility (e.g. flying versus walking), differences in life span (annual vs. perennial) and combinations of these factors. Additionally, population-level mechanisms that underpin fire- or grazing- induced dynamics on animal populations or communities are often taxon- and species-specific. For example, many species of grasshoppers overwinter as eggs in soil and are mobile as adults and spring conditions may be independent of grasshopper abundance, whereas sedentary insect species that are above ground during fires can suffer catastrophic mortality (Fay and Samenus 1993). Thus there exists opportunity to identify taxon that are relatively tightly coupled to key ecosystem stressors and serve as key integrative ecological indicators. There is some evidence that shrubland small mammals, birds and insects conform to Hanski's (1982) core-satellite hypothesis wherein these communities are characterized by several abundant, widely distributed, and relatively stable species, accompanied by a larger number of rare, localized, and dynamically variable species. Thus, the temporally variable patterns in species abundance, distribution and diversity are influenced strongly by changes in the distribution and abundance of rare species. Climate and topographic influences can also control spatial and temporal heterogeneity in montane shrubland animal populations and communities. Hence, the spatial and temporal variation in population abundance and community structure require multifactoral explanations (Kaufmann et al. 1998) and may make single-limitation explanations for population and community dynamics unrealistic (Belovsky and Joern 1995).

In montane shrublands primary production is segregated into patches of relatively high (undershrub) and low (interspace) long-term response and it follows that nutrient cycling will be anisotropic. As shrubs or shrub patches accumulate under-canopy litter, nutrient pools will also collect there. These spatial patterns occur because of absorption of nutrients that extend beyond plant crown area, N fixation by the plant or associate symbiotic organisms and net import of N by fauna using shrubs for nesting, resting, roosting, feeding or burrowing, and deposition of litter and soil by wind and water. Thus, long-term measurements of N cycling processes and outcomes can provide the basis for evaluating the role of natural or anthropogenic stressors on ecosystem function, small and large scale redistribution or transport of N between summer and winter ranges, shrubland plant and animal communities, and abiotic ecosystem characteristics such as soil chemistry. In GRYN parks there are important and sizeable large and medium body-sized herbivore populations that are very important components of nitrogen cycle processes and outcomes. In addition to local defoliation processes

and outcomes, redistribution of N through urine and feces, these herbivores play an important role in stimulating patterns of aboveground and belowground production. They also contribute to nutrient cycling through the return of carcasses to these systems. Despite these important processes, N limitation is not a universal feature of montane shrublands and that its relative importance can vary with influences of fire, grazing, elevation, topography and precipitation regimes. This loose coupling of relationships is due to the potential for the direct influences of these same variables under variable environmental and management regimes. Thus N cycling process and outcomes reinforce the viewpoint that montane shrublands might operate as a nonequilibrium system in which the relative importance of N varies in space and time.

Adequate vegetation cover is one of the most critical aspects of any watershed ecosystem in terms of upland water infiltration and sediment yields. The natural evolutionary vegetal cover resilience of shrubland communities can be altered under severe disturbance regimes such as fire in fire-intolerant communities or excessive grazing/trampling by large herbivores. The natural resilience of shrubland community vegetal cover can be further stressed by the introduction of aggressive exotic plant species. Alteration and loss of shrubland understory vegetal cover will increase overall soil erosion processes and outcomes. Montane shrubland communities with moderate to steep slopes will be most stable where shrub roots permeate soils to the geologic parent material. A diverse cover of both deep-rooted shrubs and shallow-rooted shrubs will serve to minimize soil erosion processes and outcomes. Thus, measures of soil erosion processes and outcomes can be strongly indicative of important declines in vegetal cover and the interactive processes that underpin such declines. Not all shrubs provide a positive feedback to erosional processes. Some shrubs have chemicals in their foliage or litter that can lead to hydrophobic soil surfaces resulting in less infiltration and xerification of microsites. Indeed, not all erosional processes and outcomes should be seen as outside the natural range of variability for montane shrubland communities. Cupped interspace depressions arising from differential erosion (aggregation, infiltration, growth and soil genesis) have been occurring at the microsite level for extended intervals in shrubland communities.

Some structural characteristics of montane shrublands can be coupled closely with spatial organization of growth forms and the interplay of ecosystem functional attributes that center around energy flow and nutrient and water cycles. The primary character involved in shrublands is that of dispersion (West 1989) that underpins the aggregation and deviation from random spatial arrangement. The vertical and horizontal structures of a variety of shrublands are remarkably similar across relatively undisturbed examples. In sagebrush steppe, shrubs have a cover of 10%-80%, depending on site and successional status (West 1988) with a herbaceous stratum that can reach 30-40 cm during the growing season. On many sagebrush steppe sites, cover usually exceeds 80% and can exceed 200%. Measures of shrubland cover and vertical or horizontal structure can track the tendency for stable shrubland community structure and function. Thus, measurable deviation in these parameters could provide a relatively rapid integrative assessment of shrubland community stability. Shrub non-random aggregation can serve as the grit starting a pearl (Vasek and Lund 1980), the nucleus of successional change and ecosystem development (West 1989) that leads towards system stabilization.

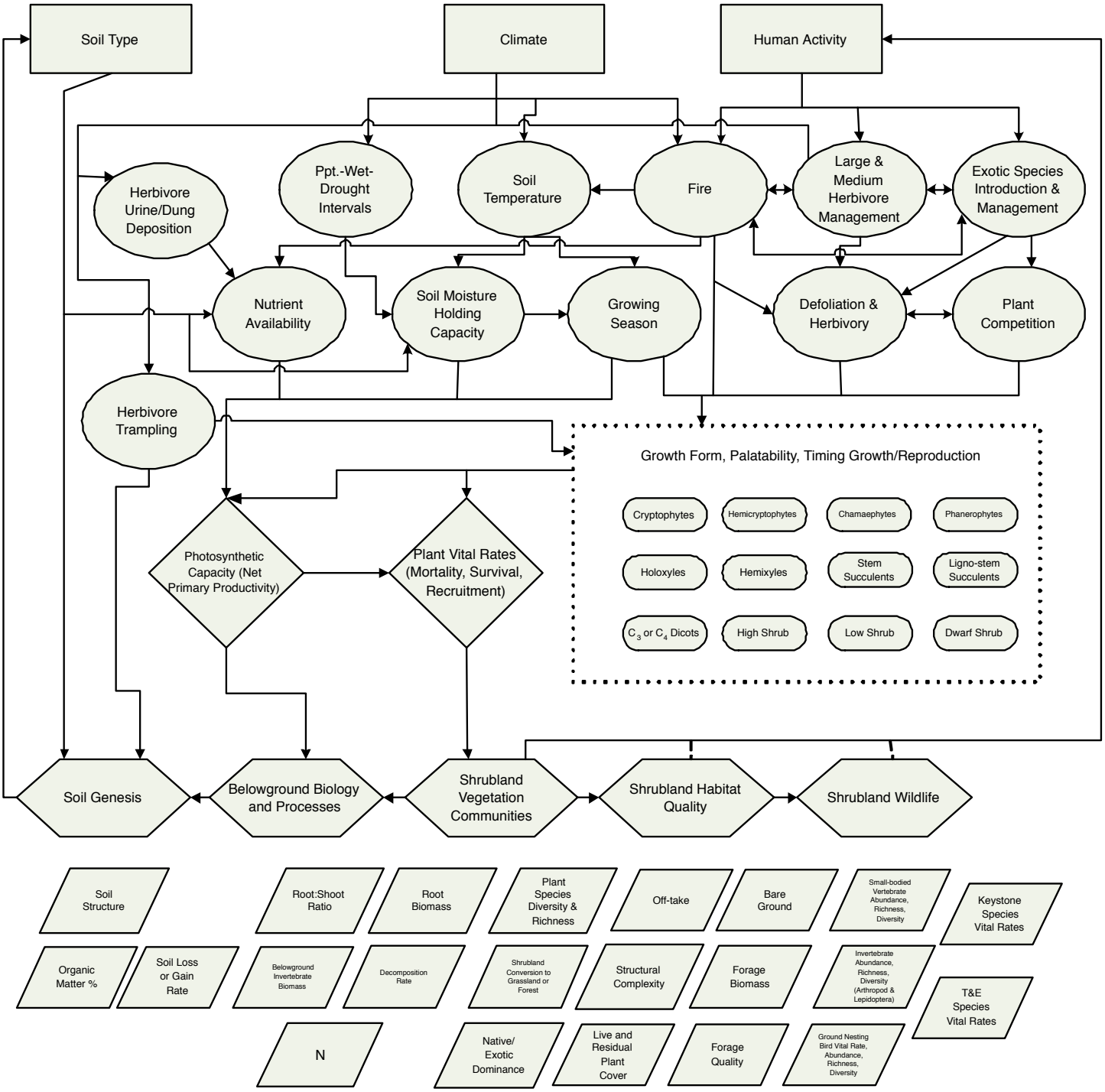

FIGURE 20 Shrubland model.

LODGEPOLE PINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Dan Tinker)

Lodgepole pine (*Pinus contorta var. latifolia*) is the most common tree in the northern Rockies, especially in northern Wyoming. These montane forests range from 1,800-3,200 m in elevation in the GRYE. Although commonly described as a seral, or pioneer species that often gives way to Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*) during later stages of succession, climax stands of lodgepole pine may be found on very dry and nutrient-poor sites, where other tree species are unable to survive (Moir 1969; Despain 1983; Lotan and Perry 1983). Lodgepole pine usually forms relatively young, even-aged stands as a result of regeneration following severe fires (see below), but older, uneven-aged stands may exist at higher elevations where fire frequency is low (Despain 1990).

Fire is the primary disturbance agent in lodgepole pine forests of the GRYE. Large, infrequent, stand-replacing fires dominate the fire regime, and human efforts at fire suppression have historically had little effect (Romme and Despain 1989). Lodgepole is a fire-adapted species, rather than fire-resistant, due to its relatively thin bark and the production of serotinous cones. These serotinous cones remain closed at maturity, and only open to release their seeds when exposed to very high temperatures, such as fires will create (Lotan 1975). Following stand-replacing fires, seedlings establish quickly, usually within two years, creating new stands where post-fire seedling density may vary by six orders of magnitude (Turner et al. In review).

Conceptual Model Development

A. DRIVERS

The parent materials for soils across the subalpine plateaus of YNP, where lodgepole pine dominates the vegetation, are mostly volcanic in origin. Two different parent materials, derived from underlying bedrock, determine the soil characteristics in Yellowstone. Rhyolitic soils are found most often on drier sites, and are typically very nutrient limited. Andesitic soils are relatively more fertile, and often occur at higher elevations (Despain 1990). Differences in these parent materials is responsible for soil texture, and therefore, water holding capacity, as well as nutrient supply and availability. Rhyolitic soils are more sandy while andesitic soils contain much more clay (Despain 1990). Calcium is ten times more abundant in soils derived from andesite (Despain 1990).

Yellowstone's climate is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in lodgepole pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes.

Topography on the subalpine plateaus in Yellowstone is quite varied. Much of the landscape is dominated by gently rolling hills, however, steep canyons and mountains may break up the continuous nature of the plateaus. Topographic effects on snow accumulation and on the spread of natural disturbances such as fire or exotic species may be significant.

Biotic drivers such as insects, plant pathogens and disease, and herbivory by both ungulates and insects may directly and indirectly affect many ecological processes in lodgepole pine ecosystems. As more fully described below in the section on Stressors, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation and net primary productivity.

Given the importance of fire in lodgepole pine ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

B. STRESSORS AND ECOLOGICAL RESPONSES

Drought, snowpack, and windstorms, all driven by weather and climate, affect many important ecosystem processes. Drought will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al in press). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Windstorms may cause large blowdowns, such as the 6,000-ha event that occurred in the Teton Wilderness in 1987. These events directly affect forest and landscape structure through widespread tree mortality and creation and accumulation of large quantities of coarse woody debris (CWD). Large areas of uprooted

trees may also allow for the invasion of new plant species, and may also affect the growth rates of the new and existing species.

Biotic stressors, primarily insects and plant pathogens, have important effects in lodgepole pine forest ecosystems (Romme et al. 1986; Veblen et al 1991). Openings may be created in the forest canopy through tree mortality, which can result in increases in understory vegetation production (Knight 1994). Plant parasites, such as dwarf mistletoe and comandra blister rust, are also common in these forests. Mistletoe may reduce tree growth or even result in tree death, and has been labeled the most important problem in lodgepole pine forests (Knight 1994). The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, resulting in the death of thousands of trees (Despain 1990). This, in turn, also leads to changes in CWD biomass and distribution, plant species composition and productivity, and fuel availability, as well as broad-scale changes in landscape patterns (Romme et al. 1986). Herbivory, both by insects and ungulates, may reduce plant cover and may result in the mortality of young seedlings and saplings (Houston 1982; Singer et al. 1989).

Abiotic stressors such as wildfire, and human-induced changes to the ecosystem via management impacts can also alter ecological characteristics of lodgepole systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Notably, fire regimes seem to be the controlling mechanism for the production of serotinous cones (see section on fire regime), which is the most important predictor of postfire seedling density, and therefore productivity (Tinker et al. 1994; Turner et al. 1997; Turner et al. in review). Also, fire clearly can eliminate plant cover, but also provides new substrate for rapid reestablishment of residual plants (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels.

C. INDICATORS

The vegetation dynamics of lodgepole pine ecosystems are fairly well-understood (Turner et al. 1997) and the composition of the forest plant community composition, as well as the proportions of exotic and native species, could provide an excellent index of ecosystem structure and function. Similarly, plant species diversity, and the historic range of variability in this measure, will also allow for relatively straightforward assessment of ecosystem stability. The amount and distribution of forest floor litter and coarse woody debris are critical for key forest floor ecosystem processes such as decomposition and mineralization (Tinker and Knight 2000), and are directly linked to the availability and loss of essential nutrients from the soil (Knight 1994). All of these indicators are easily measured, and reflect the potential for the ecosystem to maintain long-term site productivity. Similarly, an excellent measure of potential ecosystem productivity is leaf area index, or LAI, which is the square meters of leaf area per square meter of forest floor). LAI is highly correlated with aboveground net primary productivity (ANPP) as well as evapotranspiration, and is routinely estimated through the use of remotely sensed data. Finally, landscape structure and forest stand age structure are also easily quantified through the use of geographic information systems and software designed to characterize landscape structure (McGarigal and Marks 1995). The historic range of variability in landscape structure has been recently described for portions of the Greater Yellowstone Ecosystem (Tinker et al, in press) and monitoring landscape heterogeneity may provide a much needed broad-scale assessment with which to compliment the finer, stand-level metrics.

1. Plant community composition

Resource Monitored: Flora – plant species presence and abundance

Justification: Lodgepole pine communities are relatively uniform systems (Knight 1994). Departures from the natural range of variability in community composition may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for plant reestablishment (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank.

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate current ecosystem conditions.

Example of Specific Measurements of this Indicator: Total species present and estimate of percent cover of each in relation to expected species present within the community. Common measures include quadrat and relevé methods.

2. *Plant species diversity*

Resource Monitored: Flora - Biodiversity

Justification: High species diversity may maintain ecosystem stability through redundancy of the ecological roles of different species.

Comment: This is a very easy indicator to measure and has much public appeal, and is likely a priority of many agencies.

Example of Specific Measurements of this Indicator: Common measures include quadrat and relevé methods.

3. *Forest floor litter and coarse woody debris (CWD)*

Resource Monitored: Ecosystem structure - forest floor structure; ecosystem processes

Justification: Forest floor litter and coarse woody debris play important ecological roles in lodgepole pine systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991).

Comment: Lodgepole pine systems are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes.

Example of Specific Measurements of this Indicator: Litter depth and biomass; CWD biomass and percent cover. Common measures include line intercept method for CWD percent cover, planar intercept for CWD biomass, and randomly placed measures of litter depth, with subsamples for dry weight.

4. *Landscape structure and heterogeneity*

Resource Monitored: Landscape structure – patchiness, fragmentation, core habitat, patch edge density

Justification: The spatial pattern of lodgepole pine landscapes influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987).

Comment: Disturbance is now considered an integral part of lodgepole pine ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such as net primary productivity, animal movement, forage availability, and habitat.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software and GIS, such as FRAGSTATS (McGarigal and Marks 1995) or r.le (Baker and Cai 1992) programs; vegetative cover most common base map used.

5. *Leaf area index (LAI)*

Resource Monitored: Ecosystem structure and function - primary productivity

Justification: Leaf area index is highly correlated with net primary productivity, a critical ecosystem process that describes the accumulation of biomass over some time period. Productivity reflects many current conditions within ecosystems such as climatic trends. Leaf area index is relatively easy to measure with today's remote sensing technology and, given its strong relationship to primary productivity

Comment: Because of its relationship with aboveground net primary productivity, estimates of LAI provide maximum information about the productivity of the ecosystem with a single measure. Leaf area index is also a good surrogate for photosynthetic capacity (greenness)

Example of Specific Measurements of this Indicator: Remotely sensed data such as NDVI (Normalized Difference Vegetation Index) may be used. These data are inexpensive and are published on a regular basis.

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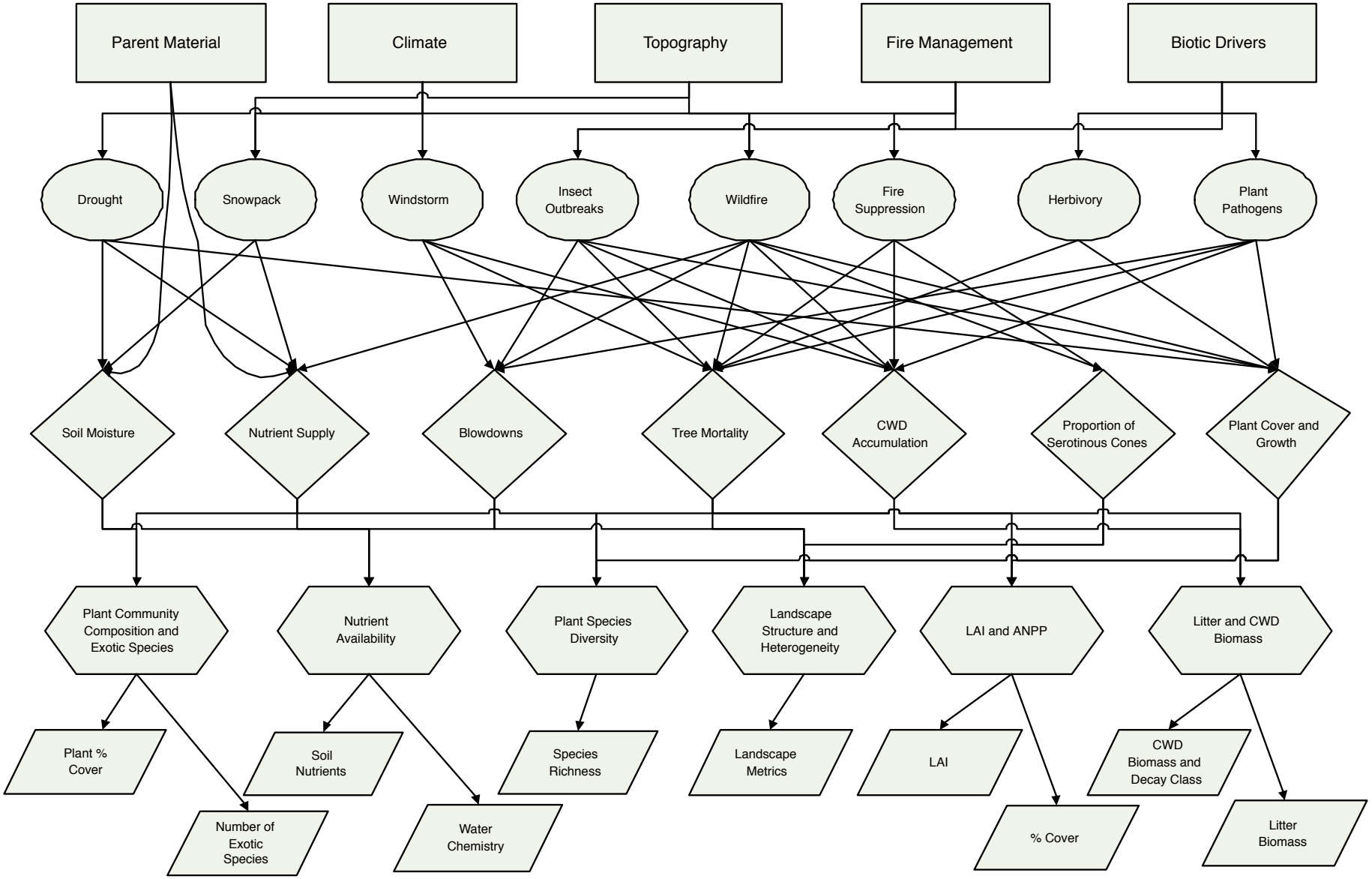

FIGURE 21 Lodgepole model.

MIXED CONIFER ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Dan Tinker)

For the purposes of this document, mixed conifer forests are considered to be forest types that are dominated by species other than lodgepole pine (*Pinus contorta var. latifolia*) or aspen (*Populus tremuloides*). This would include primarily Douglas-fir (*Pseudotsuga menziesii*) forests and spruce-fir (*Engelmann spruce* (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*)) forests. Notably, all of these forest types may contain some component of the other, and may also contain individuals of limber pine (*Pinus flexilis*) lodgepole pine or aspen; however, in many areas, Douglas-fir forests occur at lower elevations than lodgepole pine forests, and spruce-fir forests are typically found to occur at higher elevations than lodgepole pine (Peet 2000). These montane forests are relatively ubiquitous in the GRYE, and range from 1,800-3,200 m in elevation. In BICA, mixed conifer forests are found primarily on the eastern slopes of East Pryor Mountain, in the western portion of the Bighorn Canyon Recreation Area.

Fire regimes are quite different between Douglas-fir forests and spruce-fir forests, and are addressed separately here. Douglas-fir trees produce very thick bark, enabling individual trees to survive many surface fires (Veblen and Lorenz 1986). Crown fires also occur periodically in Douglas-fir forests, and fire return intervals have been estimated from 20-25 years in northern areas of Yellowstone National Park (Houston 1973) up to 60 years in northwest Montana (Arno and Gruell 1986). Because spruce-fir forests are often the climax condition of stands that began as lodgepole pine, fire return intervals for spruce-fir forests are more similar to lodgepole pine, and may be even longer than 100-300 years at higher elevations where spruce and fir dominate the forest composition (Knight 1994).

Conceptual Model Development

Many of the drivers, stressors, and ecological responses in mixed conifer forests are similar to those in lodgepole pine forests, because of the coexistence of many of the species.

A. DRIVERS

Yellowstone's climate is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in lodgepole pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes. Precipitation in BICA is quite variable, with the northern end of the Area receiving over 19 inches of precipitation per year, while the drier southern end receives, on average, only slightly more than seven inches per year (Knight et al. 1987). The climate is relatively more cool and moist at higher elevations, where mixed conifer forests occur. Because of its effects on precipitation, growing season, and tree mortality in both the GRYE and the BICA, elevation is also an important factor in determining the occurrence of wildfires.

Given the importance of fire in mixed conifer ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

Biotic drivers such as insects, plant pathogens and disease, and herbivory by both ungulates and insects may directly and indirectly affect many ecological processes in mixed conifer ecosystems. As more fully described below in the section on Stressors, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation, changes in plant species composition, and net primary productivity.

The parent materials for soils across much of the Greater Yellowstone Area are largely volcanic in origin. Two different parent materials, derived from underlying bedrock, determine the soil characteristics in Yellowstone. Rhyolitic soils are found most often on drier sites, and are typically very nutrient limited. Andesitic soils are relatively more fertile, and often occur at higher elevations (Despain 1990). Differences in these parent materials is responsible for soil texture, and therefore, water holding capacity, as well as nutrient supply and availability. Rhyolitic soils are more sandy while andesitic soils contain much more clay (Despain 1990). Calcium is ten times more abundant in soils derived from andesite (Despain 1990).

In the BICA, mixed conifer forests on East Pryor Mountain occur primarily on shallow soils, where fractured bedrock reservoirs may serve as water sources during an otherwise dry growing season (Knight et al. 1987).

B. STRESSORS AND ECOLOGICAL RESPONSES

Drought, snowpack, and windstorms, all driven by weather and climate, affect many important ecosystem processes. Drought will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced

soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al. 2003). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Windstorms may cause large blowdowns, such as the 6,000-ha event that occurred in the Teton Wilderness in 1987. These events directly affect forest and landscape structure through widespread tree mortality and creation and accumulation of large quantities of coarse woody debris (CWD) and standing dead trees. Large areas of uprooted trees may also allow for the invasion of new plant species, and may also affect the growth rates of the new and existing species.

Abiotic stressors such as wildfire and human-induced changes to the ecosystem via management impacts can also alter ecological characteristics of mixed conifer forest systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Also, fire clearly can eliminate existing plant cover, but also provides new substrate for rapid reestablishment of residual plants, as well as the establishment of seral species such as aspen and lodgepole pine (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels.

Biotic stressors, primarily insects and plant pathogens, have important effects in mixed conifer forest ecosystems (Romme et al. 1986; Veblen et al 1991). Openings may be created in the forest canopy through tree mortality, which can result in increases in understory vegetation production (Knight 1994). Plant parasites, such as dwarf mistletoe and comandra blister rust, are also common in many of these forests. The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, resulting in the death of thousands of trees (Despain 1990). This, in turn, also leads to changes in CWD biomass and distribution, plant species composition and productivity, and fuel availability, as well as broad-scale changes in landscape patterns (Romme et al. 1986). Herbivory, both by insects and ungulates, may reduce plant cover and may result in the mortality of young seedlings and saplings (Houston 1982; Singer et al. 1989).

Nutrient availability can be important for determining the proportions of spruce and fir in many mixed conifer forests. On sites where nutrients are limiting, as is common on many of the drier sites at lower elevations in the GRYE, lodgepole pine may be the only coniferous tree that is able to survive; on more nutrient rich sites, spruce and fir will generally be more abundant in mature forests (Peet 2000).

C. INDICATORS

Departures from the natural range of variability in plant community composition in mixed conifer ecosystems may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for herbaceous and shrubby plant reestablishment, as well as invasion by exotic species (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank. High population levels of spruce beetle or budworms within a stand may indicate that a stand has relatively low growth rates, which is often indicative of low vigor. Spruce beetles typically attack older stands that contain a high proportion of Engelmann spruce in the canopy. If stand-replacing fires are reduced through fire suppression, these older, senescent stands may facilitate increases in beetle population numbers. The density of standing dead trees, or snags, is an indicator of the amount of chronic, baseline mortality occurring within a stand, or across the landscape, and can help predict areas where beetle infestations may increase. Forest floor litter and coarse woody debris play important ecological roles in mixed conifer systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991). Mixed conifer systems in the Greater Yellowstone Ecosystem and in BICA are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes. The heterogeneity of mixed conifer landscapes influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987). Disturbance is now considered an integral part of mixed conifer ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such

as net primary productivity, animal movement, forage availability, and habitat. Along with landscape metrics, an understanding of the age structures of the mixed conifer forests provides insights into the long-term effects of fire suppression, grazing, and other human influences within the ecosystem.

1. Plant community composition and exotic species

Resource Monitored: Flora – plant species presence and abundance

Justification: Departures from the natural range of variability in community composition in mixed conifer ecosystems may indicate structural and functional changes in the ecosystem resulting from natural perturbations such as drought, fire, or windstorm, or human-caused disturbances or alterations such as non-prescribed fire or fire management (Pickett 1976). Vegetative reproduction following disturbance is the most common mechanism for herbaceous and shrubby plant reestablishment (Anderson and Romme 1991) and departures from this contribution may indicate considerable degradation of the seed bank.

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate current ecosystem conditions.

Example of Specific Measurements of this Indicator: Total species present and estimate of percent cover of each in relation to expected species present within the community. Common measures include quadrat and relevé methods.

2. Beetle and budworm population levels

Resource Monitored: Insect fauna

Justification: High population levels of spruce beetle within a stand may indicate that a stand has relatively low growth rates, which is often indicative of low vigor.

Comment: Spruce beetles typically attack older stands that contain a high proportion of Engelmann spruce in the canopy. If stand-replacing fires are reduced through fire suppression, these older, senescent stands may facilitate increases in beetle population numbers.

Example of Specific Measurements of this Indicator: Surveys of actual numbers through the use of insect traps, or surveys of beetle evidence within a stand, which may serve as a proxy of beetle populations.

3. Understory Plant species diversity

Resource Monitored: Flora – Biodiversity

Justification: High species diversity may maintain ecosystem stability through redundancy of the ecological roles of different species.

Comment: This is a very easy indicator to measure and has much public appeal, and is likely a priority of many agencies.

Example of Specific Measurements of this Indicator: Common measures include quadrat and relevé methods.

4. Snag Density

Resource Monitored: Ecosystem Structure

Justification: This measure is an indicator of the amount of chronic, baseline mortality occurring within a stand, or across the landscape, and can help predict areas where beetle infestations may increase.

Example of Specific Measurements of this Indicator: Common measures include belt transect, quadrat, and relevé methods.

5. Forest floor litter and coarse woody debris (CWD)

Resource Monitored: Ecosystem structure - forest floor structure; ecosystem processes

Justification: Forest floor litter and coarse woody debris play important ecological roles in mixed conifer systems (Tinker and Knight 2000). CWD may provide habitat for many organisms (Harmon et al. 1986), and many decomposers such as bacteria and fungi derive energy and nutrients from decaying forest floor materials (Frankland et al. 1982). CWD and litter are also important inputs to soil organic matter (Edmonds 1991).

Comment: Mixed conifer systems in the Greater Yellowstone Ecosystem are often nitrogen- and nutrient-limited. Forest floor litter and CWD provide critical raw organic material for decomposition and mineralization processes.

Example of Specific Measurements of this Indicator: Litter depth and biomass; CWD biomass and percent cover. Common measures include line intercept method for CWD percent cover, planar intercept for CWD biomass, and randomly placed measures of litter depth, with subsamples for dry weight.

6. Landscape structure and heterogeneity

Resource Monitored: Landscape structure – patchiness, fragmentation, core habitat, patch edge density

Justification: The spatial pattern of mixed conifer landscapes influences many important ecosystem functions such as habitat use and foraging patterns (Pearson 1993; Turner et al. 1994), nutrient movement (Peterjohn and Corell 1984), and disturbance dynamics (Turner 1987).

Comment: Disturbance is now considered an integral part of mixed conifer ecosystems. Various disturbance types such as fire, insect outbreaks, windstorms, and earthquakes may significantly alter landscape structure in these ecosystems. This, in turn, will likely influence future processes such as net primary productivity, animal movement, forage availability, and habitat.

Example of Specific Measurements of this Indicator: Metrics commonly quantified using landscape description software and GIS, such as FRAGSTATS (McGarigal and Marks 1995) or r.le (Baker and Cai 1992) programs; vegetative cover most common base map used.

7. Age structure of forest

Resource Monitored: Ecosystem structure

Justification: Along with landscape metrics, an understanding of the age structures of the mixed conifer forests provides insights into the long-term effects of fire suppression, grazing, and other human influences within the ecosystem.

Example of Specific Measurements of this Indicator: Age determination using tree increment borers to estimate the age of dominant trees within a stand.

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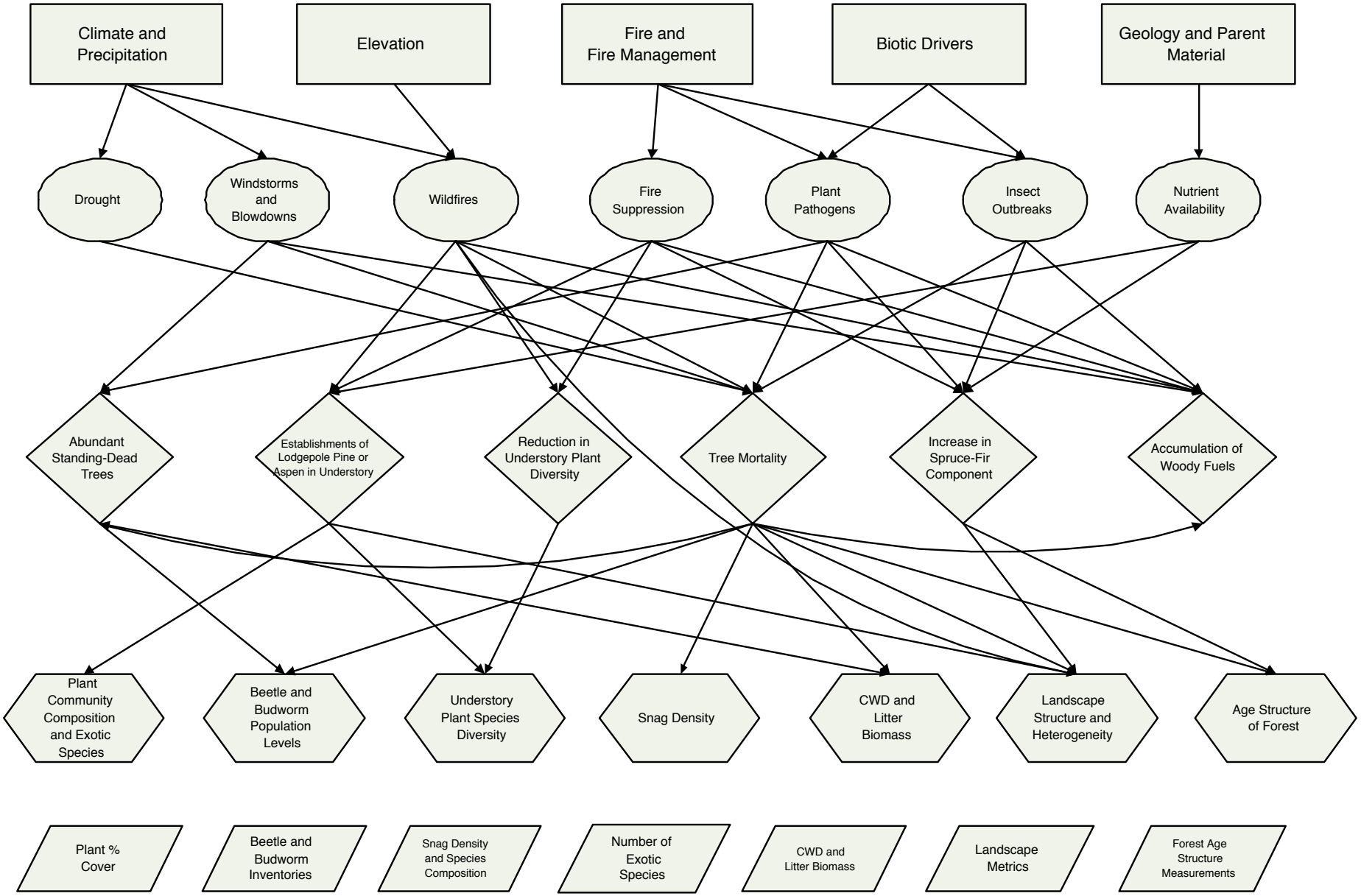

FIGURE 22 Mixed conifer model.

PONDEROSA PINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Dan Tinker)

Ponderosa pine woodlands occur only along the fringes of the eastern Rocky Mountains (Peet 2000) and, specifically within the GRYE, only in the Bighorn Canyon Recreation Area. These relatively open community types do not occur in the mountains of western Wyoming in GTNP or YNP, but exist on lower elevation sites where summer precipitation is higher and the growing season is longer (Knight 1994). The importance of ample summer precipitation for the establishment and maintenance of Ponderosa pine woodlands is illustrated by its absence in the southern portion of the BICA, where summer precipitation is ~30% of that of the more mesic northern portions of the Area, where it is currently found. Many Ponderosa pine woodlands in the Western U.S. have undergone dramatic transformation as a result of successful fire suppression and the introduction of grazing by domestic cattle (Peet 2000). This often results in a change to more of a true forest condition, rather than a woodland, or savannah physiognomy. Mechanisms for this shift are thought to be either a reduction in the density of grasses (Savage and Swetnam 1990) or increased establishment of seedlings following fires (Marr 1961).

While many Ponderosa pine communities of the southwestern U.S. have experienced frequent, low-intensity fires that often limit regeneration, pine woodlands in more northerly latitudes such as in BICA may have evolved with longer fire-return intervals, on the order of 25-40 years (Rowdabaugh 1978; Laven et al 1980).

Conceptual Model Development

A. DRIVERS

The climate of the BICA area is often described as temperate and semi-arid. As noted earlier, the occurrence of critical summer precipitation limits the distribution of ponderosa pine to the more northern areas of the Area, where annual precipitation averages 49 cm; approximately two-thirds of this falls during spring and early summer, and the rest as snow (Knight et al. 1987).

Given the importance of fire in ponderosa pine ecosystems, the management of prescribed fires and wildfires can dramatically influence tree regeneration, as well as many other natural ecosystem processes. Some of the indirect effects of fire suppression will be discussed below in subsequent sections.

The biotic drivers may, in the case of BICA, be among the most important in the development, maintenance, or loss of ponderosa pine woodlands. Biotic drivers such as insects, plant pathogens and disease, and cattle grazing may directly or indirectly affect many ecological processes in ponderosa pine ecosystems. As more fully described below in the section on Stressors, these biotic drivers can lead to extensive episodes of tree mortality or creation of dense doghair stands, both of which can affect critical processes such as coarse woody debris accumulation and stand density.

B. STRESSORS AND ECOLOGICAL RESPONSES

As previously mentioned, summer precipitation, and its effect on soil moisture, is very important for the establishment and growth of ponderosa pine (Knight 1994). Successive drought years may result in the mortality of mature trees and particularly seedlings, even though young trees are somewhat drought resistant (Wellner 1970). Many human activities, including fire suppression, introduction of exotic plant species, and grazing by domestic cattle currently affect many aspects of ponderosa pine woodlands in BICA. For example, because historic frequent fires normally reduce the number of new seedlings that establish, elimination of these fires during the last century allows for the development of dense, doghair stands of ponderosa pine, which creates additional woody fuels for more severe crown fires (Knight 1994). Livestock or wild horse grazing may also improve conditions for seedling establishment through the removal of plant competition. Further, as mature trees die or are killed by pine beetles or other plant pathogens, invasion by exotic plant species may inhibit the germination and establishment of replacement trees, causing a shift in plant community composition and tree density. The pine beetle outbreaks may occur during years of inadequate precipitation, when mature trees are unable to produce sufficient resins to defend against beetle infestation (Knight 1994).

C. INDICATORS

Ponderosa pine is very sensitive to soil moisture availability. As an example, it is conspicuously absent from the southern end of the Bighorn Canyon, where summer rainfall is quite low, but is relatively abundant at similar elevations in the northern end of the canyon, where summer precipitation is much higher (Knight 1994). Ponderosa pine is also sensitive to cold pockets, such as collect in some drainages. However, many drainages in Bighorn Canyon contain ponderosa pine, where soil moisture availability is higher than surrounding uplands. Many ponderosa pine forests have dramatically increased in stand density as a result of fire suppression (Covington and Moore

1994). This is thought to be a significant departure from more park-like stand structure characteristic of pre-European settlement. If fire suppression continues, stand densities may continue to increase, resulting in an increased susceptibility to intense, stand-replacing fires. Exotic species composition and abundance is a critical issue in these ecosystems. Many ponderosa pines, especially in riparian areas and in drainages, are being eliminated in Bighorn Canyon by the invasion of exotic species such as tamarisk and Russian olive (Laura Gianakos, personal communication; personal observation, 2003). The proportion of standing dead trees serves as an indicator of both the susceptibility to intense, stand-replacing fires, which is not the typical fire regime for most ponderosa pine stands, as well as a response variable to mountain pine beetle infestation. The suppression of fire may allow mortality from beetle outbreaks to increase, as well as increase the risk of severe fires.

1. Soil Moisture

Resource Monitored: Ecosystem structure and function.

Justification: Ponderosa pine is very sensitive to soil moisture availability. As an example, it is conspicuously absent from the southern end of the Bighorn Canyon, where summer rainfall is quite low, but is relatively abundant at similar elevations in the northern end of the canyon, where summer precipitation is much higher (Knight 1994).

Comment: Ponderosa pine is also sensitive to cold pockets, such as collect in some drainages. However, many drainages in Bighorn Canyon contain ponderosa pine, where soil moisture availability is higher than surrounding uplands.

Example of Specific Measurements of this Indicator: Seasonal soil moisture monitoring.

2. Stand Density

Resource Monitored: Ecosystem structure and function.

Justification: Many ponderosa pine forests have dramatically increased in density as a result of fire suppression (Covington and Moore 1994). This is thought to be a significant departure from more park-like stand structure characteristic of pre-European settlement.

Comment: If fire suppression continues, stand densities may continue to increase, resulting in an increased susceptibility to intense, stand-replacing fires.

Example of Specific Measurements of this Indicator: Belt transect measures of stand density, or other quadrat or plot measurements.

3. Exotic species composition and abundance

Resource Monitored: Flora – species composition and abundance.

Justification: Many ponderosa pines, especially in riparian areas and in drainages, are being eliminated in Bighorn Canyon by the invasion of exotic species such as tamarisk and Russian olive (personal observation, 2003).

Example of Specific Measurements of this Indicator: Plant species surveys and percent cover estimates using quadrats.

4. Proportion of standing dead trees

Resource Monitored: Ecosystem structure and function.

Justification: This serves as an indicator of both the susceptibility to intense, stand-replacing fires, which is not the typical fire regime for most ponderosa pine stands, as well as a response variable to mountain pine beetle infestation. The suppression of fire may allow mortality from beetle outbreaks to increase, as well as increase the risk of severe fires.

Example of Specific Measurements of this Indicator: Belt transects or other quadrat methods for quantifying density of live and dead trees.

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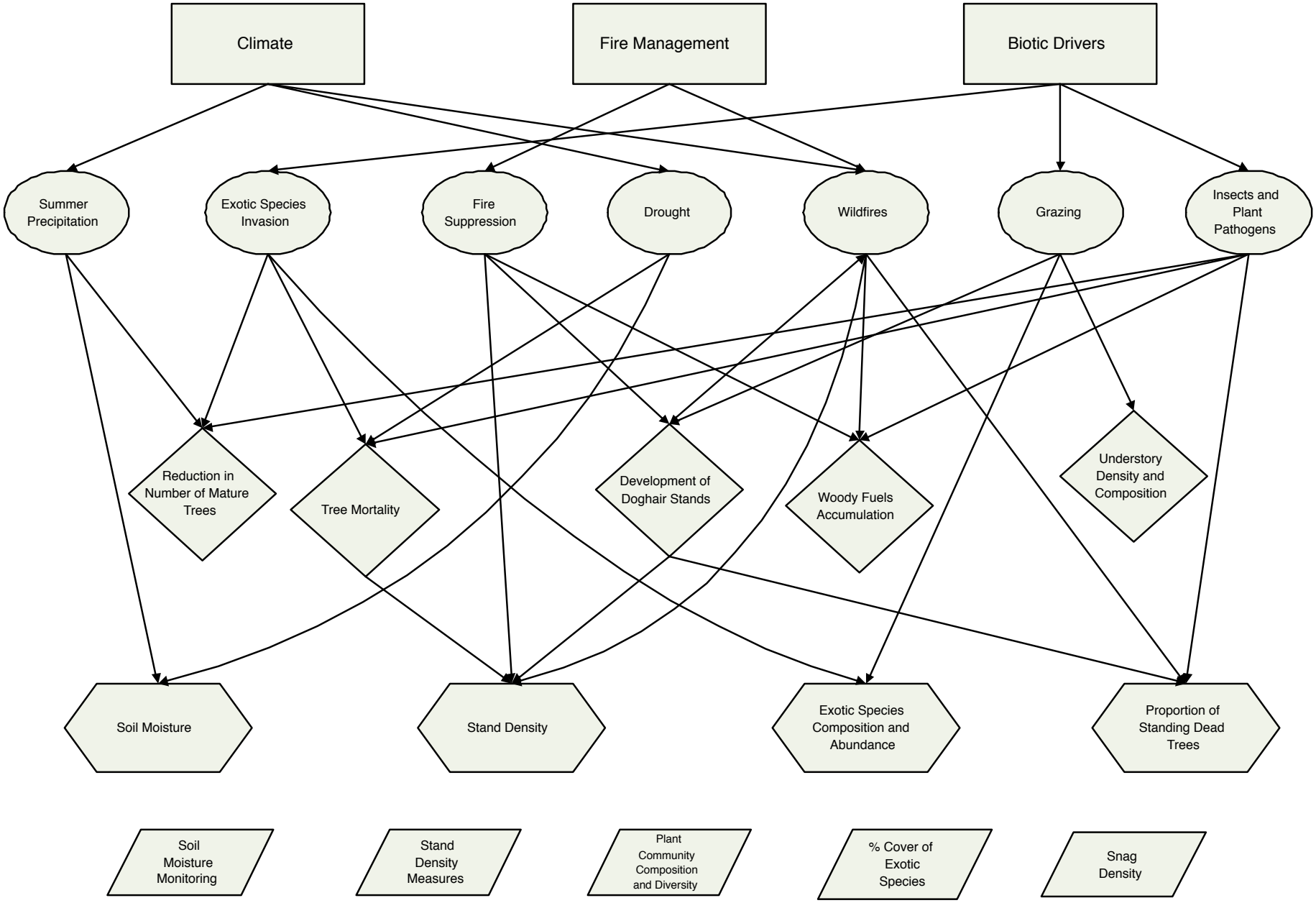

FIGURE 23 Ponderosa pine model.

WHITEBARK PINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Dan Tinker)

Whitebark pine (*Pinus albicaulis Elgelm.*) is a high-elevation tree of the Northern Rocky Mountains, forming open woodlands on relatively xeric slopes (Arno and Hammerly 1977). Whitebark pine is a member of the white pine group (*Pinus subgenus Haploxylon*), which also contains limber pine, and does not typically form continuous, closed stands characteristic of other montane forest species of the Northern Rockies (Peet 2000). Regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990). This form of avian dispersal of seeds often results in the germination and establishment of multi-stemmed trees (Furnier et al. 1987). The relatively large seeds serve as an important food source for at least 110 species of animals, including grizzly bears and red squirrels (Tomback 1989).

Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, but is more typically found as a climax species, since seedling establishment often ceases with the establishment of more shade-tolerant species such as Engelmann spruce and subalpine fir (Schuster et al. 1995). It is relatively abundant across the subalpine plateaus of YNP, but only comprises about 2% of the vegetation in GTNP (Greater Yellowstone Coordinating Committee 1987).

Because of higher elevations, lower fuel accumulations, and much bare ground below the canopy, whitebark pine ecosystems burn less frequently than other Rocky Mountain conifers (Peet 2000). Depending on the location and site conditions, presettlement fire return intervals ranged from 30-300 years (Morgan et al. 1995).

Conceptual Model Development

A. DRIVERS

Moisture and temperature are the two factors that largely control the occurrence of different habitat types in the region (Despain 1990). The climate of the Greater Yellowstone Area is characterized by long, cold winters, and cool, dry summers. Most of the precipitation falls in the form of snow. Winter Snowpack melts rapidly in May and June, providing much of the water available for growth in high elevation whitebark pine forests. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes.

Biotic drivers such as plant competition, insects, and plant pathogens and disease, particularly white pine blister rust may directly and indirectly affect many ecological processes in whitebark pine ecosystems. As more fully described below in the section on Stressors, these biotic drivers can lead to extensive episodes of tree mortality, which can affect critical processes such as coarse woody debris accumulation and net primary productivity.

Given the importance of fire in lodgepole pine ecosystems, the management of prescribed fires and wildfires may greatly influence many natural ecosystem processes. For example, large, intense crown fires may help control episodic outbreaks of Mountain Pine Beetle by burning entire stands where significant outbreaks have occurred. Many of the indirect effects of fire suppression will be discussed below in subsequent sections.

As mentioned earlier, the regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990).

B. STRESSORS AND ECOLOGICAL RESPONSES

Wildfire and management-related changes to the ecosystem such as fire suppression can also affect whitebark pine systems. Wildfire affects many aspects of these ecosystems, including both the volatization and creation of essential nutrients from the organic materials combusted or consumed by fire (Knight et al. 1991). Wildfire directly kills many trees during severe surface or crown fires, which results in significant additions to the CWD biomass of these forests (Tinker and Knight 2000). Also, fire clearly can eliminate plant cover, but also provides new substrate for rapid reestablishment of residual plants (Turner et al. 1997). If fire suppression efforts are successful, this will obviously result in a reduction of tree mortality and CWD accumulation, and may allow for the build-up of high levels of woody fuels (Keane 2001). In addition, removing fire from these systems may result in increases in late successional forest and replacement of whitebark pine by more shade-tolerant species such as subalpine fir and Engelmann spruce (Arno and Hoff 1990, Keane et al. 1994).

Drought and wind, snow, and ice abrasion, all driven by weather and climate, affect many important ecosystem processes. Drought

will affect soil moisture during the growing season, thereby affecting plant development and primary productivity, as well as forage abundance. Reduced soil moisture may also reduce nutrient supplies by a reduction in microbial activities such as decomposition and mineralization (Litton et al. 2003). Snowpack is the single largest contributor to soil moisture, and therefore water and nutrient availability during the growing season. Because many whitebark pine communities occur at higher elevations, where growing conditions are often quite harsh, abrasion from wind, snow and ice can affect tree growth and vigor, or in extreme conditions, may result in the mortality of individual trees.

Biotic stressors have also accelerated the successional process in many whitebark pine forests, largely through epidemic outbreaks of the exotic white pine blister rust and native mountain pine beetles (Keane 2001). Other plant parasites, such as dwarf mistletoe is also common in these forests. The native mountain pine beetle is present at low population levels most of the time (Brown 1975; Baker and Veblen 1990), but periodic outbreaks, such as occurred during the 1970s in YNP, may result in the death of numerous trees (Despain 1990). This, in turn, can also leads to changes in runoff and erosion in high-elevation stands, along with an increase in establishment of other tree species such as Engelmann spruce and subalpine fir (Keane et al. 1994; Arno 1986).

C. ECOLOGICAL INDICATORS

Clark's Nutcracker abundance is critical for the regeneration of whitebark pine, which occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990). Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, establishing in the newly burned forest floor, where cached seeds distributed by Clark's Nutcrackers can germinate and establish in the absence of competition (Tomback et al. 1993). The burned forest seedbed availability is therefore very important for the germination and establishment of new whitebark pine seedlings. Whitebark pine is considered a "keystone" species for upper elevation areas in the Greater Yellowstone Ecosystem (Tomback et al. 2001), and the monitoring of the density of high-elevation whitebark pine trees is likely a good indicator of population trends. Further, because of fire suppression and recent outbreaks of Mountain Pine Beetle and White Pine Blister Rust, whitebark pine is thought to be declining throughout the GYE (Tomback et al. 2001). Fire exclusion may have reduced fire frequency in many high elevation forests of the GYE, and consequently, the abundance of replacement tree species such as subalpine fir and Engelmann spruce may be another excellent indicator of population trends in whitebark pine (Arno 1986; Keane et al. 1994). The production of whitebark pine cones, and therefore seeds, is critical as forage for both Clark's Nutcrackers and Grizzly bears, as well as for the reestablishment of whitebark pine at both high and low elevations (Tomback et al. 2001). In addition, reduction of cone production can be an early indicator of infection by White Pine Blister Rust, which often kills cone-bearing branches prior to killing the entire tree (Tomback et al. 2001). Cone production in whitebark pine does not occur until trees reach the age of 20-30 years (Krugman and Jenkinson 1974). A significant reduction in cone – and therefore seed – production could represent a major shift in age classes at higher elevations. White pine blister rust is an exotic plant pathogen that only infects five-needle pines such as whitebark or limber pine (Tomback et al. 2001). In some areas of the Rocky Mountains, whitebark pine mortality has reached 90 percent (Keane et al. 1994). Monitoring of blister rust abundance and spread may help identify newly-developed strains of the organism, such as drought-tolerant strains that could accelerate the spread of the rust (Tomback et al. 2001). Finally, Whitebark pine in the Greater Yellowstone Ecosystem is a major food source for grizzly bears, which primarily forage on pine squirrel middens (Mattson et al. 1991) during the fall of the year. During years of low cone and seed production, grizzly bears will forage at lower elevations, searching for alternative sources of food. This low elevation foraging by grizzly bears in autumn can serve as a surrogate for estimates of annual cone and seed production. Grizzly bear foraging at lower elevations has historically resulted in increases in management actions, i.e., trapping and relocating, as well as increases in bear mortality (Mattson et al. 1992).

1. Clark's Nutcracker Abundance

Resource Monitored: Fauna – Seed disperser

Justification: Regeneration of whitebark pine occurs almost solely via seed dispersal by the Clark's Nutcracker (Hutchins and Lanner 1982). The birds will cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches will germinate and grow in the absence of shade and competition (Tomback et al. 1990).

Comment: This indicator is relatively well-understood and may therefore be most useful when attempting to evaluate future establishment of whitebark pine.

Example of Specific Measurements of this Indicator: Census measures of Clark's Nutcrackers could include simple counts or nesting successes.

2. *Burned forest seedbed availability*

Resource Monitored: Ecosystem structure and function.

Justification: Following intense fires in lodgepole or spruce-fir stands, whitebark pine may act as a seral species, establishing in the newly burned forest floor, where cached seeds distributed by Clark's Nutcrackers can germinate and establish in the absence of competition (Tomback et al. 1993).

Comment: Fire suppression may reduce the amount of available seedbed for whitebark pine establishment, especially at lower elevations, where it acts as a seral species.

Example of Specific Measurements of this Indicator: Landscape analysis using Geographic Information Systems to annually map the locations and extent of fires within the ecosystem.

3. *Low elevation foraging by grizzly bears in autumn*

Resource Monitored: Fauna – forage and behavior.

Justification: Whitebark pine in the Greater Yellowstone Ecosystem is a major food source for grizzly bears, which primarily forage on pine squirrel middens (Mattson et al. 1991) during the fall of the year. During years of low cone and seed production, grizzly bears will forage at lower elevations, searching for alternative sources of food. This presence at lower elevations can serve as a surrogate for estimates of annual cone and seed production.

Comment: Grizzly bear foraging at lower elevations has historically resulted in increases in management actions, i.e., trapping and relocating, as well as increases in bear mortality (Mattson et al. 1992).

Example of Specific Measurements of this Indicator: Monitoring grizzly bear movements and foraging habits during late summer and early fall using radio-collared bears and GIS.

4. *Density of high-elevation whitebark pine trees*

Resource Monitored: Flora – species abundance and density.

Justification: Whitebark pine is considered a "keystone" species for upper elevation areas in the Greater Yellowstone Ecosystem (Tomback et al. 2001).

Comment: Because of fire suppression and recent outbreaks of Mountain Pine Beetle and White Pine Blister Rust, whitebark pine is thought to be declining throughout the GYE (Tomback et al. 2001).

Example of Specific Measurements of this Indicator: Repeated measures of whitebark pine stand densities at high elevations using belt transects or remotely sensed data.

5. *Abundance of replacement tree species*

Resource Monitored: Ecosystem structure and function

Justification: Fire exclusion has reduced fire frequency in many high elevation forests of the GYE, and consequently, it is being replaced by shade-tolerant species such as subalpine fir and Engelmann spruce (Arno 1986; Keane et al. 1994).

Example of Specific Measurements of this Indicator: Repeated measures of high elevation community composition using belt transect surveys or remotely sensed data.

6. *Whitebark pine cone production*

Resource Monitored: Flora – regeneration and food source.

Justification: The production of whitebark pine cones, and therefore seeds, is critical as forage for both Clark's Nutcrackers and Grizzly bears, as well as for the reestablishment of whitebark pine at both high and low elevations (Tomback et al. 2001). In addition, reduction of cone production can be an early indicator of infection by White Pine Blister Rust, which often kills cone-bearing branches prior to killing the entire tree (Tomback et al. 2001).

Comment: Cone production in whitebark pine does not occur until trees reach the age of 20-30 years (Krugman and Jenkinson 1974). A significant reduction in cone – and therefore seed – production could represent a major shift in age classes at higher elevations.

Example of Specific Measurements of this Indicator: Repeated measures of stand-level cone production.

7. *Blister Rust abundance and spread*

Resource Monitored: Ecosystem structure and function – plant pathogens.

Justification: White pine blister rust is an exotic plant pathogen that only infects five-needle pines such as whitebark or limber pine (Tomback et al. 2001). In some areas of the Rocky Mountains, whitebark pine mortality has reached 90 percent (Keane et al. 1994).

Comment: Monitoring of blister rust abundance and spread may help identify newly-developed strains of the organism, such as drought-tolerant strains that could accelerate the spread of the rust (Tomback et al. 2001).

Example of Specific Measurements of this Indicator: Repeated collections and analysis of samples of infected branches or trees.

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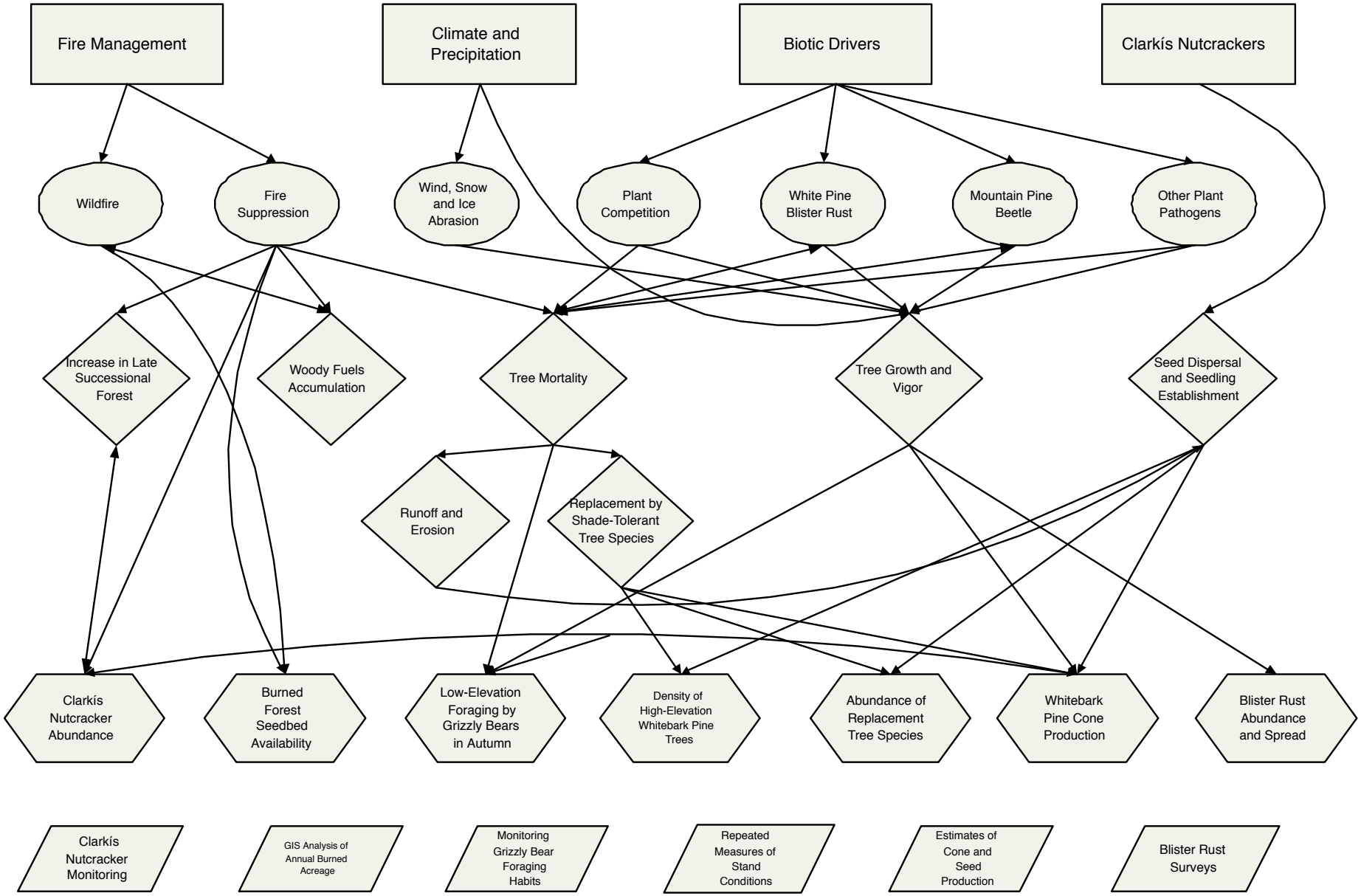

FIGURE 24 Whitebark pine model.

RIPARIAN/RIVERINE ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Duncan Patten)

Introduction

Riverine systems often include terrestrial habitat: riparian ecosystems, stream-edge wetlands and nearly-barren sediment deposits; and aquatic habitats. This discussion of riverine systems is limited to the terrestrial ecosystems. Riparian and edge-wetlands are grouped as riparian ecosystems. Riparian ecosystems, the transition from stream to upland, occupy a very small part of the landscape, often less than 1 %, and yet play an important role in stream dynamics, wildlife ecology, and biodiversity. (Naiman et al., 1993; Naiman and Decamps, 1997; Patten, 1998). In most cases riparian ecosystems occur on alluvial sediment deposits where the hydrological connection between river and alluvial groundwater supplement water available from precipitation (Gregory et al., 1991). Riparian ecosystems offer many ecological services and functions. These services and functions are closely related to the structure, composition and abundance of the riparian vegetation and its location within the landscape. Riparian ecosystems not only influence hydrologic and geomorphic processes, but are driven by these processes as well. This synergistic relationship between riparian vegetation and hydrogeomorphic phenomena complicates the understanding of riparian response to human activities. One important function of riparian systems is that of habitat for a wide variety of organisms. In semi-arid regions over 75% of animals species use riparian ecosystems for all or part of their life cycle (Brinson et al. 1981; Kondolf et al. 1996). Because of close affinity with various characteristics of riparian ecosystems, avian community composition often is used as a surrogate for condition of riparian systems (Anderson et al. 1983; Hunter et al. 1987).

The occurrence of most riparian communities in the Greater Yellowstone Network (GRYN) parks results from recruitment and survival of obligate riparian plant species in response to seasonal hydrological events, variation in groundwater depth, and availability of favorable fluvial geomorphic surfaces. For example, most cottonwood species recruit along streams on bare moist surfaces during the declining limb of spring high flows (Friedman et al., 1995; Scott et al., 1997; Stromberg et al., 1997). Willow species may follow a similar pattern but tend to spread clonally. Survival of these woody riparian species is dependent on maintenance of a high alluvial water table and avoidance of scour events such as floods and ice flows. Mortality, or inability to survive following recruitment, may result from a water table lowered below those tolerated by young or maturing plants (Rood and Mahoney, 1995). Other factors, especially those human controlled, also play a role in riparian decline throughout the West.

Landscape Diversity

The parks represented in the GRYN (i.e., Yellowstone, Grand Teton and Big Horn) have heterogeneous landscapes ranging from mountains to broad valleys and deep canyons. Consequently, streams and rivers flowing from the mountains transect a diverse geomorphology that creates steep gradients through shallow-bedrock narrow valleys as well as low-gradient, broad valleys with deep alluvial. Throughout this region, variability in valley morphology directly influences the extent and type of riparian communities (Patten, 1998). Streams flowing through broad valleys with low gradients may be lined by woody and/or herbaceous riparian vegetation. If the water table is shallow, wetland herbaceous plants (e.g., sedges and wetland grasses) may extend for some distance from the river creating fens in some areas. These wetland areas often are devoid of woody species because the herbaceous cover may prevent establishment of willows, cottonwoods or other woody plants. Willows (*Salix spp.*) and sometimes cottonwoods (*Populus spp.*) may occur near the stream where floods enhance their recruitment. Once established, these species may spread asexually and expand within the floodplain often occurring away from the stream as it migrates across the floodplain. Steep gradient mountain streams may have riparian communities of mixed willows and conifers but cottonwoods may occur on suitable sites at lower elevations. Other woody species such as dogwood (*Cornus spp.*) and alder (*Alnus spp.*) also occur along these higher gradient streams.

Elevational differences also may influence riparian composition and structure. High elevation streams may not support large woody species such as cottonwood for physiological reasons. Alpine streams only support wetland herbaceous species or, occasionally, dwarf willows. Shrub willows and alders may be common along upper elevation streams sometimes mixed with stream-side conifer communities. With decreasing elevation, low stature riparian woody vegetation gives way to, or mixes with deciduous tree species. The gradient in the northern Rockies and represented in some of the GRYN parks goes from cottonwood/willow forests at lower elevations through alder/willow communities to spruce/aspen communities into alpine wetlands.

Common Features

Structural similarities of riparian communities occur across the GRYN because they are related to successional dynamics which are driven by common fluvial-geomorphic processes. For example, point-bars, channel margin, and island deposits provide exposed sediment that supports young riparian plants along meandering and braided rivers throughout the region. Also, sediment accumulation on terraces accompanies aging of riparian vegetation and establishment of later successional species. Cottonwood species found along streams from different regions have been shown to have similar recruitment requirements (Bradley and Smith, 1986; Scott et al., 1996, 1997; Shafroth et al., 1995; Stromberg et al., 1997; Auble and Scott, 1998; Rood and Kalischuk, 1998; Shafroth et al., 1998). For example, recruitment of cottonwood and associated riparian species is most often tied to hydrological events (i.e., high flows) occurring during the period of seed dispersal. The timing and cause of these events may differ throughout the region, but early succession woody riparian species (e.g., cottonwood and willow) respond the same way to high flow, recruiting new seedlings on the receding limb of the high flow event. The year of recruitment may be delayed along GRYN Rivers because snow melt floods may extend beyond the seed dispersal period, and recruitment occurs during high flows in succeeding years. Other species, for example, shrubby cinquefoil (*Potentilla fruticosa*) and water birch (*Betula glandulosa*) are also found in the riparian zone responding to other factors such as very moist soil or snow bank accumulation.

Patterns of riparian communities along elevation gradients and geomorphic gradients are similar throughout most of the GRYN. This region is arid to semi-arid thus availability of water and similarity of riparian vegetation structure allow ready transfer of information developed in one area to another.

Drivers or Forcing Functions of Riparian Systems

Hydrological factors controlling riparian processes may be quite different between the mountainous, headwater parks of Yellowstone and Grand Teton, and Big Horn Canyon NRA. Snow and ice may play a predominant role in the Yellowstone and Grand Teton while storm events on the arid landscape of Big Horn may be the primary hydrological driver. Snowmelt in the headwater parks creates a reliable hydrographic peak while erratic storms and controlled mainstem flows produce uncertain hydrographs in Big Horn. Recruitment of many riparian species is triggered by or coincides with the spring snowmelt peak which occurs in May to June (Scott et al., 1993). However, the peak may extend beyond seed dispersal causing recruitment to be delayed by a year if peak flows of the succeeding year are sufficiently high. If insufficient, recruitment may be delayed further.

Heavy local storms may have greater impacts on stream flows in Big Horn than Yellowstone or Grand Teton. Less vegetative cover at Big Horn may result in flash floods in mountainous low order streams. Recruitment of spring seed-dispersal species such as cottonwood and willow is usually most successful when high spring flows that trigger riparian recruitment are followed by a relatively dry summer, and/or absence of large floods during the next year or two (Stromberg et al., 1991). Predicting future stream flows might allow projection of changes in riparian vegetation (Auble et al. 1994 Non-native species such as tamarisk (*Tamarix ramosissima*), Russian olive (*Elaeagnus angustifolia*), and many noxious weeds disperse seeds over long periods and thus take advantage of summer storms (Stromberg, 1998).

Riparian ecosystems of GRYN region may occasionally be scoured by flash floods but some are regularly affected by ice formation. Ice forms on the surface of rivers in the northern Rockies during extreme cold periods. During ice drives, ice may be elevated and scours the bank often well above levels of spring floods (Smith, 1980). Ice scour damages existing trees, removes riparian vegetation, forms new channels and controls the elevation of successful riparian recruitment (Johnson, 1994; Scott et al., 1997).

Geomorphic influences in the GRYN region may effect how successful recruitment might be for riparian species. Many riparian species require bare moist soil for recruitment (Stromberg et al., 1991; Scott et al., 1996). Many rivers of the north Rockies have gravel- or cobble-lined channels; however, fine sediment in these rivers may be held in overbank ice in winter and deposited in spring where riparian recruitment may occur. Fine sediments also are deposited within the interstices on the cobble and gravel bars.

River geomorphology, especially on smaller streams, is often controlled or altered by beaver activity (Naiman et al. 1986). Relatively permanent beaver dam structures collect sediment, altering sediment delivery downstream, and elevate local groundwater, enhancing growth and survival of most riparian species (Johnston and Naiman 1987). When beaver dam sites are active, beavers may alter the surrounding woody vegetation, harvesting and felling streamside trees and shrubs (Hall 1960). Eventual abandonment of beaver dam sites results in floodplains covered in fine sediments and a vegetational successional process that leads towards the vegetation that occurred prior to beaver arrival.

Environmental Stressors

A. HYDROLOGICAL STRESSORS.

Factors that have created and maintained riparian systems within the GRYN parks are changing. Most changes are tied to water and channel management, land use, ungulate management, and introduction of non-native species. Throughout the region, rivers have been managed to produce water for irrigation, generate hydroelectric power, and for flood control. This is especially true in Grand Teton and Big Horn parks. In Grand Teton NP the Snake River is dammed at Jackson Lake, retaining irrigation water to be used during the growing season downstream in Idaho. Short reaches of the Snake River channel are also stabilized within GTNP. In BICA, the Big Horn River is dammed both upstream of the park and within the park. Dams and their impoundments have greatly altered downstream ecosystems (Ligon et al., 1995; Dynesius and Nilsson 1994; Collier, et al., 1996; Shafroth, et al. 2002). They impound spring floods that normally would scour channels, deposit sediment, and produce riparian vegetation along the high water zone (e.g., Johnson, 1991). Dam releases to satisfy downstream water uses, exemplified by operation of Buffalo Bill and Boysen dams upstream of BICA and the Jackson Lake dam, often do not coincide with normal high flow periods for the river, eliminating recruitment enhancing high flows and often producing scouring summer flows (Fenner et al., 1985; Rood and Mahoney, 1990, 1995; Johnson, 1992; Dominick and O=Neill, 1998; Mahoney and Rood, 1998). Reduction of peak flows though may result in widespread narrowing of channels resulting in riparian vegetation establishment in areas that once were active channels (Johnson, 1994, 1998; Friedman et al., 1996, 1997, 1998; Shafroth et al., 1998). Even when dams allow normal flows for recruitment and maintenance of riparian species, the river below the dam may carry little sediment, material important for creation of recruitment sites (Scott et al., 1997).

Stream diversion for irrigated agriculture may reduce surface flows or effect local floodplain vegetation. Several irrigation take out channels on tributaries of the Snake River within Grand Teton NP may be modifying the adjacent riparian communities. Grand Teton NP still has remnants of past agricultural uses within those areas of the park added in the 1950s. Where agriculture existed near rivers, removal of floodplain vegetation may still be evident as the floodplains recover. Recreational use of riparian areas has been found to leave them vulnerable to over-use and degradation (Johnson and Carothers, 1982). Although limits on use of streamside areas may occur in some of the GRYN parks, BICA is established as a recreation area and potential heavy use along the Big Horn Lake margins may have deleterious effects. Effects of campers and day hikers on riparian vegetation along small mountain streams often are locally evident in Yellowstone and Grand Teton NPs.

B. BIOLOGICAL STRESSORS.

Ungulate grazing in riparian areas may disrupt the reproductive cycle of riparian trees such as cottonwoods, whose broad-leaved seedlings and saplings are extremely desirable forage. Removal of reproductive shoots also diminishes reproductive potential of willows (Kay 1994). Heavy ungulate use, both wild and domestic, of floodplains and riparian areas may greatly reduce riparian ground cover, destabilize streambanks, and increase sediment loads to streams (Patten 1968, Armour et al., 1991; Elmore, 1992; NRC 2002). Wild ungulate use in areas of Yellowstone NP, for example, the northern range, and Grand Teton NP, has altered the cover and structure of the riparian community (Singer et al. 1994, Singer 1996, Keigley 1997).

Beaver activity, although a normal component of riverine ecosystems in the GRYN parks, under specific conditions may be considered an ecosystem stressor. While beavers usually alter streams when occupying dam sites, or modify riparian vegetation whether housed in ponds behind dams or in stream banks, their absence may result in water table declines and associated long-term alteration or loss of riparian vegetation. Conversely, over-population of beavers in any reach of a river may cause major alterations of riparian vegetation through excessive harvesting of riparian woody plants. Several areas of the GRYN, for example, streams in the northern range of YNP, once supported extensive beaver populations but these are now absent (Bailey 1930, Wright and Thompson 1935, Jonas 1955). Also, continued beaver trapping outside the parks maintained low populations. Recently, however, beaver populations have dramatically increased in several areas of the GRYN parks. This recovery may ultimately result in "over-population" of beavers in some areas because many areas that once were suitable for beaver habitat in the region are no longer suitable for beaver population expansion because of unacceptable consequences of beaver activities in most areas of human habitation.

C. NON-NATIVE SPECIES AS STRESSORS.

Introduction of non-native species has greatly altered the west's riparian ecosystems and has become a major management issue in all three GRYN parks. Grazing and altered hydrology often favor the survival of introduced species (e.g., tamarisk) and allows thriving non-natives to

displace native species. Russian-olive and tamarisk are two non-native species that have greatly altered western riparian communities (Brock, 1984; Shafroth et al., 1995). 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). An example of major tamarisk invasion in these parks is the exposed lake bed in BICA where the Big Horn River enters the park. Here tamarisk has developed a dense cover of young invasive woody plants. Extended inundation may be the only way to eliminate this extensive stand of tamarisk. Herbaceous non-natives are also becoming prevalent in many riparian areas creating dense ground cover that competes with native species, increases fuel for fires, and may be enhanced by grazing (Stromberg and Chew, 1997). All the parks are now contending with increasing cover of non-native herbaceous plants. This has become a sufficiently important issue that the Biennial Science Conference in Yellowstone NP in 2001 (ref) emphasized this issue.

D. CLIMATE FLUCTUATION AS A STRESSOR.

Climatic fluctuations over the past century have resulted in changes in local watershed hydrology which directly affect the condition of riverine and riparian systems. Long-term droughts not only reduce stream flows but diminish groundwater supplies, lowering water tables which are critical sources of water for riparian phreatophytic plants (Stromberg et al. 1996, Shafroth et al. 2000). Human accelerated climate change may create more erratic climatic fluctuations and could potentially produce extended droughts, much longer than that of the 1930s and similar to the 30-50 year droughts of 300 years ago. Riparian communities within the GRYN parks will respond relatively quickly to extended drought periods, reducing cover to only those areas that can maintain a shallow water table. These areas will be immediately adjacent to shallow bedrock streams and along margins of larger rivers where low flows may support alluvial groundwater. Climatic change and drought in the northern Rockies region will affect all three GRYN parks. Vegetation that is dependent on supplemental water, such as riparian vegetation, may be more altered by these changing conditions than upland vegetation.

E. CUMULATIVE EFFECTS OF STRESSORS.

Riparian ecosystem condition reflects the cumulative effects of all activities that influence watershed hydrology and thus may be an important indicator of changing environmental conditions within the GRYN parks. Multiple resource uses on mountains and in valleys have modified the quantity and quality of water entering rivers. This is true for BICA, as the headwaters of the Big Horn River are used for many forms of resource extraction, ranching and agriculture often with release of stream contaminants. Sometimes the results of land use can be subtle, while in other cases, downstream impacts on riparian ecosystems can be dramatic. Timber harvest may result in larger and flashier floods which carry increased sediment. Leaving a buffer zone may help reduce sedimentation rates and provide for continued ecological interactions between streams and riparian vegetation (Kauffman, 1988).

Application to Greater Yellowstone Network Parks

Riverine and riparian systems within the three GRYN parks are influenced by many of the same stressors. The conceptual models illustrate the linkages between the many stressors (Figures 25-28). Although there may be many stressors that influence riverine and riparian systems in the parks, the conceptual model applies only a few that are known to potentially significantly alter these systems. As discussed above, stressors that influence riparian systems and that should be addressed in any inventory and monitoring program include (1) altered hydrology, (2) altered channel morphology, (3) climatic changes, especially droughts, (4) ungulate utilization of the riparian zone, (5) exotic plants, and (6) recreation. The discussion illustrates the importance of these stressors to each park but does not apply them specifically to park units. The importance to a park depends on extent and magnitude of a particular stressor. For example, altered hydrology is not a primary stressor in Yellowstone NP, but it plays and important role along the mainstem of the Snake River in Grand Teton NP, and is the primary stressor for the main water course and lake in BICA. Ungulates, on the other hand, may not be important in BICA along the river and lake, but are important locally in YNP and GTNP. BICA, on the other hand, may have ungulate herbivory issues in the uplands.

The conceptual model(s) show linkages among stressor and how they relate to dynamics of components of the riverine/riparian ecosystem. Following the flow of connected processes, it is possible to end up with a limited set of potential indicators that, if monitored, will offer evidence of changing watershed and river conditions within each park.

Each park has been geographically divided into watershed units (HUC units) for the purpose of addressing variability across the landscape of the parks. Within the GRYN parks there are several

riparian vegetation community types, some may occur in all parks while others may be specific to one or two parks, a consequence of geographic and environmental diversity. Table 1 presents riparian community types that occur within GRYN parks and identifies within HUC unit for each park those environmental threats or stressors that potentially may have an impact on long-term survival and condition of the riparian community. Eight different riparian vegetation community types are presented. Some of these relate to seral stages in riparian vegetation development and maturation, for example, gravel bar/river edge riparian communities up to mature cottonwood communities. Some riparian communities also relate to geographic locations, such as large river margins, lake shores, small mountain streams, or broad valley wetted-sediment deposits. The list of riparian community types is simplified for application to the whole GRYN. If expanded based on diversity within community type, the variability would create hundreds of types. For example, twenty four species of willow are found in the northern range of YNP and these produce a diverse set of willow communities based upon diverse environmental drivers (YNP 1997).

To allow comparisons across community types, a brief description follows:

A. Gravel bar/edge wetlands: this community type is found on point bars and the edges of rivers where flood disturbance is frequent. In most cases the vegetation cover includes herbaceous pioneer species, but young woody riparian species like *Salix exigua* and *Populus spp.* may also be present. In most cases the vegetation cover is sparse.

B. Herbaceous meadow: the community type may occur in broad alluvial valleys where the river is downcut and few woody plants are present. Herbaceous species are predominantly wetland sedge and grass species. Wetland forbs also may be present.

C. Willow/shrub: this is a diverse community because of the potential number of willows that may be present throughout the GRYN. The community is dominated by shrub willows and occurs on the edge of streams, adjacent floodplains, and wet alluvial flats and along seeps where groundwater is shallow. Some may be short willows (e.g., wolf willow), while some willow/shrub communities have tall willows (e.g., xxx). Other shrubs may be present with willows such as alder (*Alnus spp.*) in moist areas or shrubby cinquefoil (*Potentilla fruticosa*) in drier areas. In most cases, except where heavy browsing has reduced cover, aerial cover of this community is high.

D. Cottonwood: this community type, usually found in mid to lower elevations within the GRYN, is dominated by mature cottonwoods and may have some cottonwood recruitment under the canopy or in adjacent floodplain and point bar areas. There is little understory of other woody plants. This type of community may be found in areas with heavy browsing pressure, or in relatively sterile gravel or cobbled areas where cottonwood has established and has resisted scour when it occurs, but other woody plants either never established or were scoured away by high magnitude floods.

E. Cottonwood/willow/shrub: this community type found in mid to lower elevations in GRYN represents a mature cottonwood community with a well established understory of shrubs, often willows, and herbaceous ground cover. These usually are undisturbed sites with no deficiency of shallow groundwater.

F. Conifer/willow/shrub: this community type is more typically found along mid to higher elevation streams that have limited overbank scour. The conifer overstory represents mesic upland species growing near the stream, whereas willow and shrubs such as alder are more typically riparian and phreatophytic.

G. Lake shore: this community type could be represented by several of those above but also may include true wetlands where saturated sediment occurs along the lake margin. Willows may grow along stable lake shores whereas gravel bar type communities may be common along fluctuating lakes. Mid to higher elevation lakes may have conifer communities growing along the shoreline.

H. Riparian exotics (dominant): this community type occurs in highly disturbed areas or where hydrological controls are greatly altered from the norm. Nearly pure stands of tamarisk represent this type of community which often occurs in moist sediment upstream and at tributaries mouths of lakes with fluctuating levels. Altered downstream hydrology below dams also often creates riparian communities dominated by extensive stands of exotic species. Communities dominated by herbaceous exotic species (often noxious weeds) may occur on floodplain areas following a high magnitude, overbank, scouring flood.

Stressors that play an important part in each park differ, except perhaps for climate change and drought stress. Riparian communities in YNP, especially in the northern range, are greatly influenced by ungulate herbivory. GTNP has altered hydrology of the Snake River as a

major issue, but it also has herbivory problems along some streams within the park. Primary stressors of riparian condition in BICA are altered hydrology and invasion of non-native riparian species. Table 1 summarizes the similarities and differences among the parks and the HUC units within the parks. Because riverine/riparian systems are linear and cover only a small percentage of the landscape, comparisons by watershed units within each park may be difficult; however, different conditions within each watershed, especially if they are some distance apart, might allow identification of different responses of riparian communities to similar environmental stressors.

Potential Indicators

Several indicators related to riverine and riparian ecosystems can be identified from the conceptual model and the discussion above. Some indicators may be stressors or other non-"outcome" parameters, but the best may be an outcome parameter that functions as an integrator of several processes.

a. Riparian condition is one indicator, in actuality an index, that includes several riparian community parameters and channel geomorphic parameters. Riparian ecosystems are integrators of hydrogeomorphic conditions as well as local land use processes. Riparian condition includes metrics of horizontal and vertical vegetation structure, vegetation diversity and channel stability. The U.S. Forest Service and BLM have developed an index, Proper Functioning Condition (PFC), that attempts to address these parameters but it is subjective and includes little biological information. A modified version of PFC may be an appropriate index to use for "riparian condition".

b. Channel geomorphological metrics may also be a useful indicator of the condition of riverine and riparian systems. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is be changed from the "expected" geomorphic conditions.

c. Riparian avian community structure may be used as an indicator of riparian condition. Species diversity of riparian avian communities, including presence and/or absence of certain species that have been identified as species commonly found in "healthy" or "degraded" riparian vegetation, can be used as a surrogate of riparian condition, including linear connectivity of riparian patches along a river.

d. A biological stressor, exotic plants, may also be a useful indicator of riparian vegetation condition. Increasing presence of exotic plant species has greatly altered many riparian systems in the West. A degraded riparian community may be altered primarily because of the presence of exotic species. If a relationship between altered condition and abundance of exotic species can be established, cover and diversity of exotic plant species in the riparian zone may be a useful long-term indicator.

e. Aquatic biota, that is macroinvertebrates and/or fish populations, often indicate the geomorphology of a channel, the bedload materials, flow velocities at various stages as well as water quality. For general riverine and riparian conditions, aquatic biota may not be the best indicator, but if a combination of physical and chemical qualities need to be evaluated, aquatic biota may be a useful indicator. This indicator applies more to the river or lake systems of the GRYN parks and is discussed in more detail in that section.

Measurement of any of the above indicators would be done at randomly selected locations along reaches of rivers of interest. For lakes shores, randomly selected locations along a shore would be used in place of reach locations along a river. For the various parks, rivers of different sizes (orders) would be identified and long-term monitoring stations would be established.

8. ADDITIONAL INFORMATION ON POSSIBLE INDICATORS

Riparian ecosystems occur as the result of several environmental factors, hydrology being primary. However, new stressors such as heavy browsing, changes in beaver populations, introduction of exotic plants and recreation have become important in the health of overall distribution and condition of riparian communities. Because some of the "new" stressors have played a significant role in altering riparian communities, they may be important indicators, offering evidence of potential changes in the riparian communities of the GRYN area.

a. Riparian Condition.

Resource Monitored: Riparian vegetation structure and channel stability.

Justification: Riparian ecosystems, although a small part of the GRYN area landscape, support some of the greatest biodiversity. Changes in the health or condition of riparian communities will directly influence the assemblage of animal species found in the parks of the GRYN. Consequently, it is imperative that riparian condition (health) be included in a long-term monitoring program. Riparian condition is an indicator, in actuality an index, that includes sev-

eral riparian community parameters and channel geomorphic parameters. Riparian ecosystems are integrators of hydrogeomorphic conditions as well as local land use processes. They respond to changes in the watershed as well as the floodplain. They are very sensitive to climatic shifts that influence stream flows and groundwater levels. The woody vegetation in riparian areas is often the primary food source for wild and domestic ungulates during periods with forage shortages such as severe winters with deep snow, or summer drought.

Comment: Riparian condition includes metrics of horizontal and vertical vegetation structure, vegetation diversity and channel stability. The U.S. Forest Service and BLM have developed an index, Proper Functioning Condition (PFC), that attempts to address these parameters but it is subjective and includes little biological information. Other metrics of riparian condition include HGM (hydrogeomorphic methodology). This, however, is very comprehensive and would be difficult to apply to a large number of riparian areas.

Example of specific measurements for indicator: A modified version of PFC may be an appropriate index to use for "riparian condition".

b. Channel Dimensions

Resource Monitored: Variability and changes in channel cross section geometry and river length to floodplain length relationships.

Justification: Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems. Altered hydrological conditions and concomitant degraded riparian systems play a role in channel changes. For example, changing regional hydrology or influences of upstream flow regulators, e.g., dams will cause channels to adjust to new conditions and offer less or more habitat for riparian plant communities.

Comment: The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is being altered from "expected" geomorphic conditions. Decreasing width/depth ratios tend to indicate a degraded, incised channel; however, a greatly increasing width/depth ratio may result

TABLE 1 Riverine/Riparian Ecosystems. Environmental threats for each ecosystem type by HUC unit.

National Park	HUC Units	Gravel bar/ edge wetlands	Herbaceous meadow	Willow/shrub	Cottonwood	Cottonwood/ willow/shrub	Conifer/ willow/ shrub	Lake shore	Riparian exotics (dominant)
GRTE	Jackson Lake	1,2,3,4,5,6	3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6		1,4,5,6	
	Moran			3,4,5,6		??	3,4,5	1,4,5	
	Jenny Lake	3,4,5,6		3,4,5,6		3,4,5,6	3,4,5	4,5,6	
	Spread Creek	1,2,3,4,5,6	3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	3,4,5		
	Fall Creek	3,4,5		3,4,5		??	3,4,5	4,5,6	
BICA	Black Canyon	1,2,4,5,6		1,2,4,5,6				1,2,4,5,6	
	Layout	1,2,4,5,6			1,2,4,5	3,4,5		1,2,4,5,6	
	Fire Springs	1,2,3,4,5,6		1,2,3,4,5,6	1,2,4,5,6	1,2,3,4,5,6		1,2,4,5,6	1,2,3,4,5,6
YELL	Gallatin	4,5,6	5,6	3,5			3,5		
	Northern Range	4,5,6	3,4,5,6	3,5,6	3,5,6	3,5,6	3,5,6	3,5	
	Madison	4,5,6	3,4,5,6	3,5,6	?	?	3,5,6	3,5	
	Yellowstone	4,5,6	3,4,5,6	3,5,6			3,5,6	3,4,5,6	
	Henry's	4,5,6	3,4,5	3,4,5			3,5,6	3,5	
	Snake	4,5,6	5,6	3,5,6			3,5,6	3,4,5,6	

Environmental Threats (Stressors)

1 Altered hydrology
2 Altered channel
3 Herbivory
4 Invasive species
5 Climate change/Drought
6 Recreation

from excessive bank destabilization by ungulate use.

Example of specific measurements for indicator: Width-depth ratios at selected reach types along rivers of different sizes, along with geographic measurements of river sinuosity can be combined to offer an "index" metric for channel dimensions. Just the width-depth ratio on selected reaches may be satisfactory.

c. Riparian wildlife species.

Resource Monitored: Abundance of potential indicator wildlife/avian species.

Justification: Riparian avian community structure may be used as a wildlife species indicator of riparian condition. Species diversity of riparian avian communities, including presence and/or absence of certain species that have been identified as species commonly found in "healthy" or "degraded" riparian vegetation, can be used as a surrogate of riparian condition, including linear connectivity of riparian patches along a river.

Comment: Many studies have used presence and abundance of resident birds at select times of the year to demonstrate potential sources and sinks of avian populations. Riparian communities are usually the source of birds and thus any changes or loss of bird species and/or population composition may be an important indicator of riparian condition.

Example of specific measurements for indicator: Presence and abundance measurements taken within specific sized plots for 10 minutes at a number of sites along selected reaches of rivers of concern can be used as the metric for this indicator.

d. Exotic plants.

Resource Monitored: Exotic plant component of riparian plant community.

Justification: One of the biological stressors in the riparian conceptual model, exotic plants, may also be a useful indicator of riparian vegetation condition. Increasing presence of exotic plant species has greatly altered many riparian systems in the West. A degraded riparian community may be altered primarily because of the presence of exotic species. If a relationship between altered condition and abundance of exotic species can be established, cover and diversity of exotic plant species in the riparian zone may be a useful long-term indicator.

Comment: For this indicator to be useful, a relationship between riparian condition and exotic plant presence, especially for herbaceous species, needs to be established. Recent literature addresses increasing exotic plant presence in riparian areas, but a statistical connection between presence and riparian degradation is not well developed.

Example of specific measurements for indicator: The metric would be percentage cover of specific exotic species within riparian vegetation. This will only be useful if that percentage can be related to reduced function of the riparian area. This percentage should be determined by establishing permanent transects in selected representative riparian areas within the three GRYN parks. The transects will be used to sample woody vegetation, while small quadrats (e.g., 1x1 m plots) along the transects will be used to sample herbaceous vegetation.

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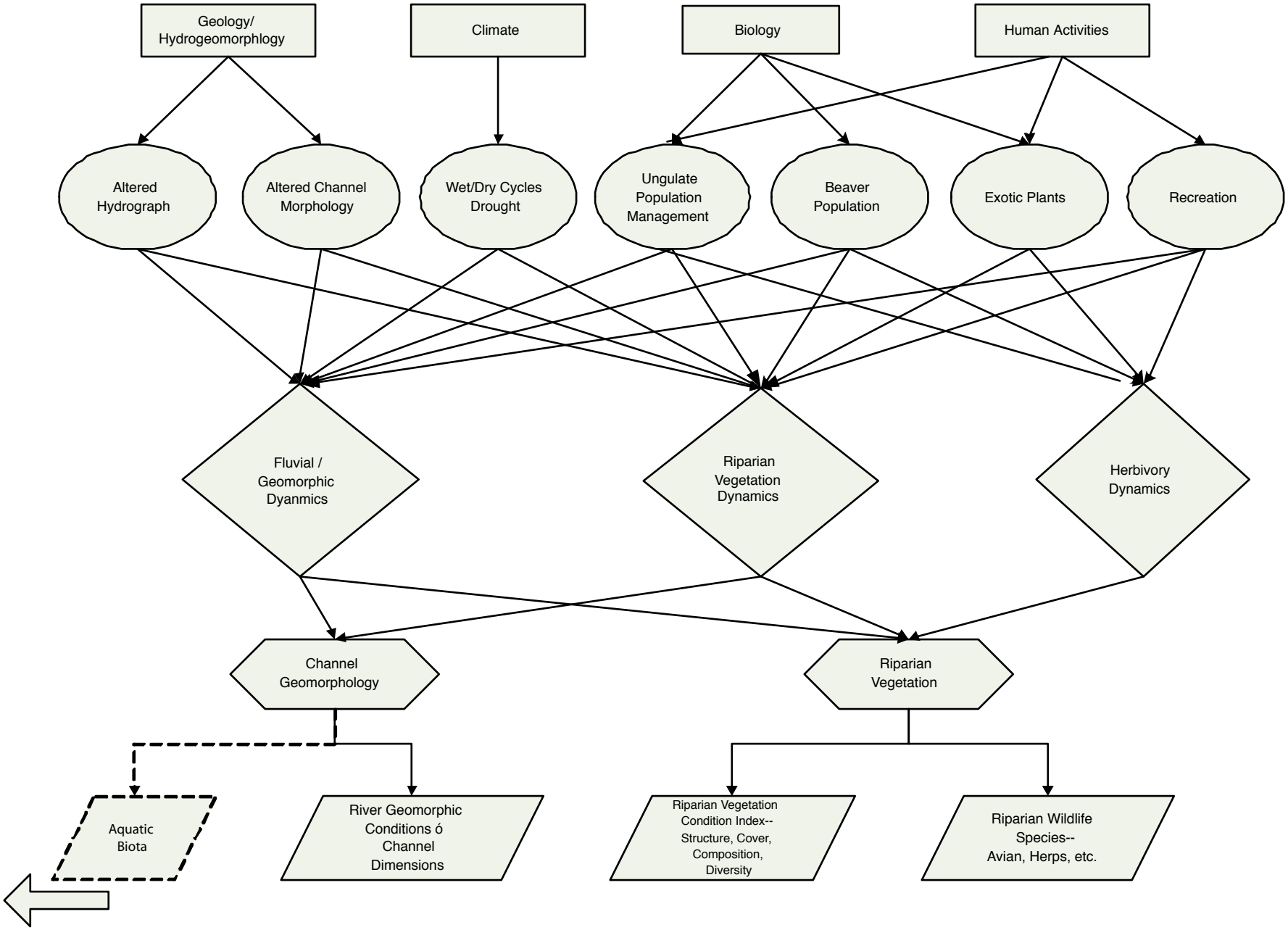

FIGURE 25 General riparian model.

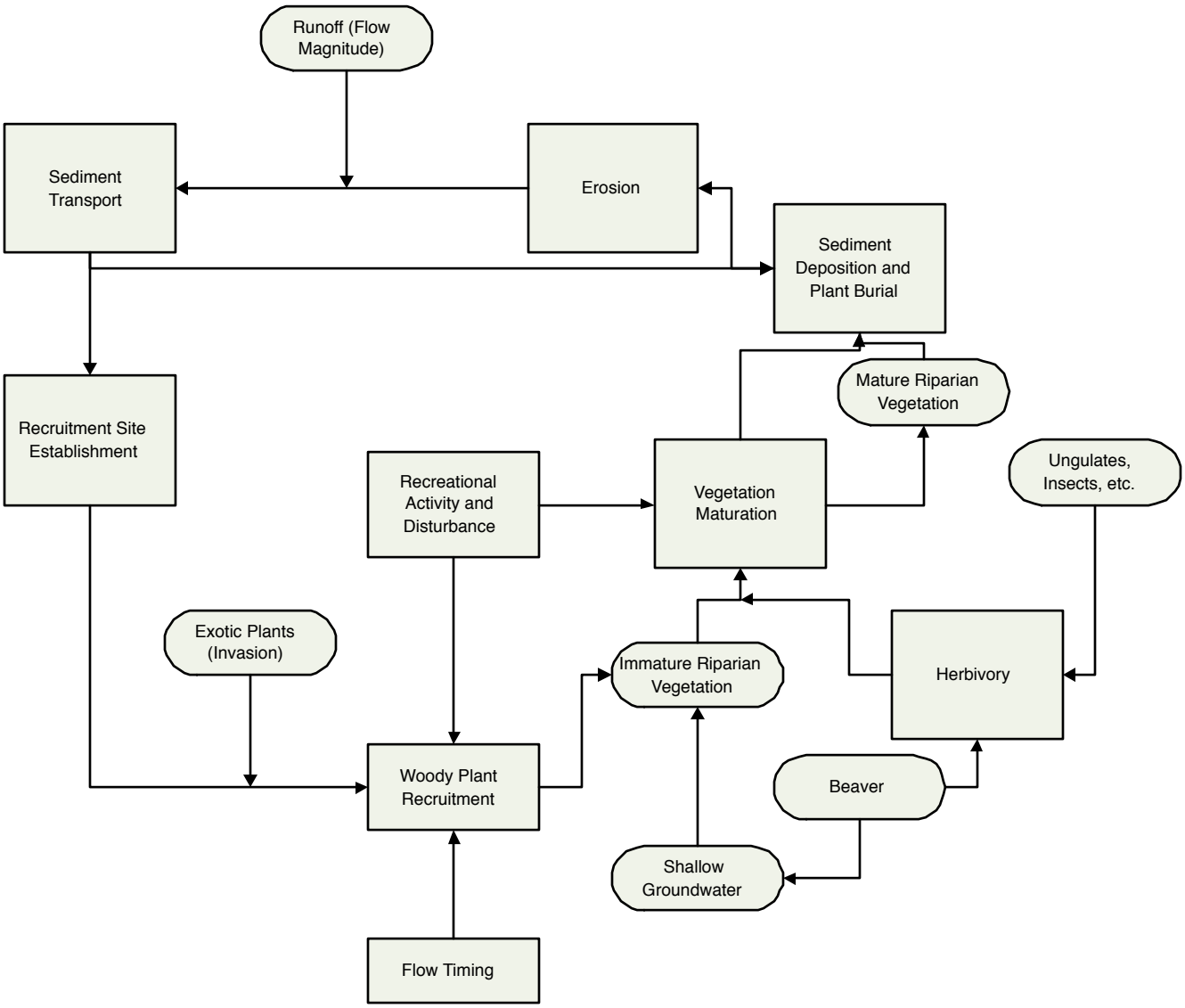

FIGURE 26 Riparian vegetation dynamics submodel.

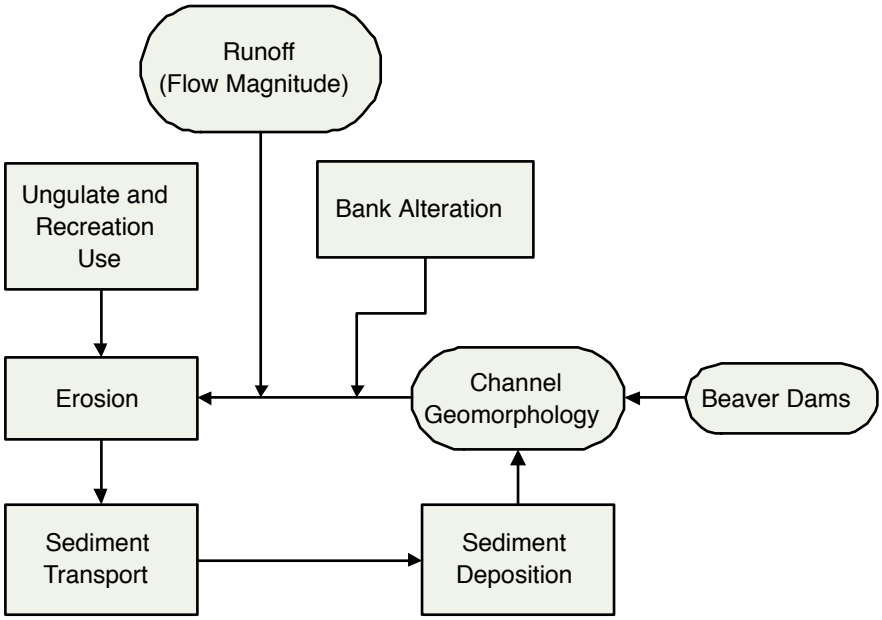

FIGURE 27 Riparian fluvial geomorphology dynamics submodel.

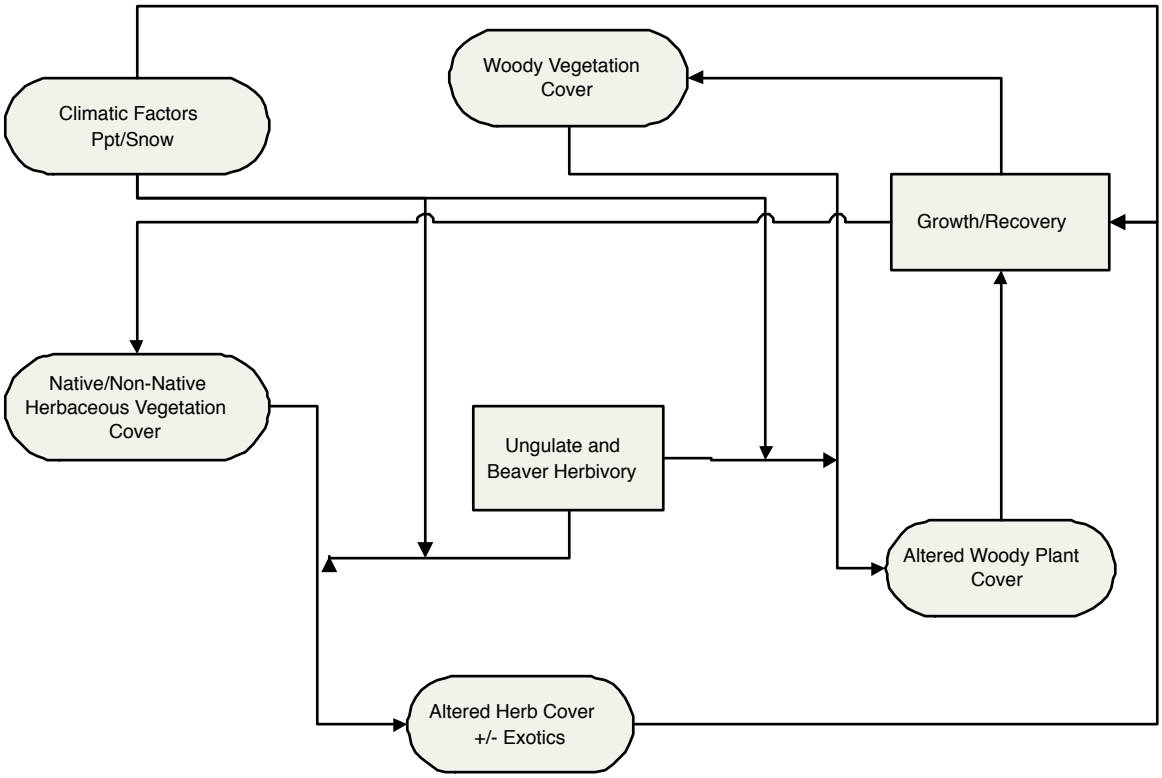

FIGURE 28 Riparian herbivory dynamics submodel.

WETLAND ECOSYSTEM NARRATIVE CONCEPTUAL MODEL

(author: Duncan Patten)

Wetlands are often a transition between aquatic and terrestrial ecosystems possessing some traits from both systems (Mitsch and Gosselink 2000). Wetlands are a primary source of biodiversity and this holds true for the GRYN area (Elliot and Hektner 2000). Wetlands play an important role in watershed hydrology, reducing flood peaks (Johnston 1994b), and improving stream water quality (Johnston 1991). Wetlands are highly variable and are found in many different conditions that have appropriate hydrology for wetland development. Most wetlands in the GRYN have been mapped by the USFWS in its NWI program. The more common wetland types (not necessarily based upon the NWI descriptions) within the GRYN area are, (a) depressional or pothole wetlands, (b) willow community wetlands, (c) spring or seep wetlands, (d) beaver dam wetlands, and (e) herbaceous wetlands or wet meadows. Although several ecosystem types such as riparian systems may resemble wetlands, they do not have all the appropriate characteristics for true wetland status (NRC 1995). Willow wetlands, however, may occur in riparian conditions. Chadde et al. (1988) defined 62 wetland communities in the northern range of YNP, some dominated by non-wetland plant species. The true wetland nature of some of these community types may be questionable based upon the definition presented below. The following definition of wetlands from a National Research Council report (NRC 1995) explains those features required for wetlands and mentions potential for alteration of those features, an issue discussed in this report.

"A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective or recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development" (NRC 1995).

Wetland Drivers

The general description of wetlands presented above points out the importance of hydrology as a primary controlling factor of wetland development, occurrence and maintenance (Mitsch and Gosselink 2000). Other factors that influence and/or alter hydrological events (i.e., inundation of wetlands) are also dominant drivers of wetland ecosystems. These external factors, for example climate and geomorphology, play an important role in general wetland occurrence and extent. Biological factors also play a role in wetland formation through feedback responses to hydrological processes (Mitsch and Gosselink 2000). Factors or stressors that influence the magnitude of climatic and geomorphic external factors, and also control vegetation and soil characteristics of wetland sites, are presented in Figure 29 ("Wetlands") as human and biotic drivers. These stressors, discussed in the following section, include: altered hydrology, introduction of exotic plants, occurrence and management of ungulates, beaver, and predators.

Stressors

a. **Upland Erosion:** Many wetlands are located in depressions, or in drainages that may be influenced by upslope erosional processes, often exacerbated by extreme wet climatic periods, and sometime by human activities, or natural processes such as fires, that destabilize slopes. Sediment (or alluvium) moving downslope will fill depressional wetlands and small drainages, thus reducing or eliminating the wetland.

b. **Wet/dry cycles:** Climate is highly variable, but when extremes of long-term wet or dry cycles occur they may alter the hydrology that controls wetland occurrence. Long-term droughts have caused many wetlands in the West to decline in size or dry up, thus eliminating many of the associated species commonly found in wetland communities. Contrarily, long-term wet periods may expand, or even create, wetlands. Longevity of these wetlands may be solely dependent on continued wet climatic cycles.

c. **Altered Hydrology:** The significance of hydrology in the formation and maintenance of wetlands becomes more obvious when the hydrology is altered through human activities. Three forms of hydrological alterations have been found to greatly modify wetlands. One is the prevention of inflows of water from natural sources which eventually may dry up the wetland. On the other hand, new or increased surface flows into low lying areas may form wetlands where they have not occurred. Groundwater withdrawal can lower the water table that supports wetland inundation, and/or maintenance of continually wetted soils re-

sulting in wetland losses. Groundwater decline is not always related to human activities as long-term droughts may result in decreased water percolation to groundwater and thus reduction of wetland ecosystems that are supported by a shallow water table or spring activity.

d. **Biological Stressors:** Plants and animals may modify wetland composition, structure and diversity.

e. **Exotic plants:** Throughout the country, exotic plants have been introduced into every kind of ecosystem. Wetland plants from other continents are found in wetlands in the U.S.A., and plants from other locations may also migrate by human means into areas where they are not native. Consequently, many of the wetlands within the GRYN region no longer have the pristine plant community composition from the past. Exotic plants may out-compete with native plants resulting in highly modified wetland communities.

f. **Ungulates:** Native ungulates may play a role in modification of wetlands. High density ungulate populations may alter vegetation composition or modify the geomorphic setting of wetlands. Management of ungulates plays a role in numbers and locations of ungulate herds.

g. **Beaver:** Beaver, once very common in the GRYN and then scarce, is making a comeback in some areas of GRYN. Beaver can alter flowing streams and create wetlands, especially on secondary channels of large rivers, and small creeks (Johnston 1994a). In many parts of the West, beaver once created strings of wetlands where rivers now occur. Reintroduction of beaver may eventually increase the extent of wetlands within the GRYN in the future.

h. **Predators:** Coyotes, wolves and other predators may indirectly play a role in wetland development and extent by controlling ungulates and beavers. Lack of predators becomes a wetland stressor because of their role in influencing the herbivores that modify wetlands.

Processes

The interaction of several stressors within the context of a functional wetland will result in a modified wetland as briefly discussed under "stressors". However, the ecological processes (diamonds) in Figure 29 ("Wetlands") that potentially lead to indicators may be a complex set of interactions which result in modifications to wetlands. None of the stressors act alone on existing wetlands, or in the creation of wetlands.

a. **Depressional Wetland Dynamics:** Probably the simplest of the submodels developed to show dynamics of interactions of stressors is that related to filling of depressional wetlands. Precipitation and erosional processes interact to create and reduce wetlands. Alluvium washed into depressional wetlands, in time, may reduce or eradicate wetlands in its path. Although depressional wetlands may not be the most common in the GRYN, they do occur and several studies have shown rates of sediment deposition in these (Ref.). These studies may be interpreted to illustrate the possible increase in deposition rates in the depressional wetlands (and ponds) in GRYN resulting from high rangeland utilization by ungulates in wetland watersheds and adjacent to depressional areas.

b. **Hydrological Dynamics:** As the primary driver of wetlands, hydrology and those factors that influence it, play an important role in extent of wetlands within the GRYN area. The amount of precipitation, a function of wet/dry cycles, is the primary controlling variable within the hydrological dynamics of the landscape that includes wetlands. The fate of precipitation, that is, what factors control its input to wetlands, becomes of prime importance in understanding wetland dynamics in GRYN. Figure 30 illustrates the complexity of the flow of water from precipitation to wetlands. Some water runs off into streams, lakes and human controlled or beaver created reservoirs. Some percolates into the ground and emerges as springs. Eventually, to form wetlands, these water sources must create standing water long enough to form hydric soils and allow wetland vegetation to establish.

c. **Wetland Vegetation Dynamics:** The presence of wetland vegetation is one of the three properties that define a wetland. The other two are duration of inundation and presence of hydric soils. If appropriate wetland physical conditions exist, wetland vegetation will establish. Altered hydrology may enhance wetland vegetation establishment if the hydrological changes create periods of inundation, or prevent wetland formation if the changes reduce or eliminate inundation periods. Wetland vegetation structure and cover may be altered by herbivory by ungulates, beaver and other wetland herbivores. Wetland plant species composition is being altered by presence of introduced, exotic plants throughout the country, the GRYN being no exception.

d. **Beaver Population Dynamics:** Beaver play a role as herbi-

vores, often altering the structure and cover of wetland plants (discussed above); however, the role of beaver may be more significant in the formation of physical conditions that form, and occasionally destroy, wetlands (Naiman 1988). Thus, the abundance and distribution of beaver in the GRYN area are important factors in presence (and demise) of wetlands. Beaver populations appear to be increasing in the GRYN area, some naturally and some through reintroduction. This increase, if not controlled by predators and humans, may eventually result in greater extent of wetlands.

Outcomes and Indicators

Within the GRYN area there are several wetland types that result from the interaction of natural hydrogeomorphic processes with stressors that control or alter features of the wetlands (i.e., hydrology, soils and vegetation). These wetland types, mentioned in wetland descriptions earlier in this discussion are (a) depressional or pothole wetlands, (b) willow community wetlands, , (c) spring or seep wetlands, (d) beaver dam wetlands, and (e) herbaceous wetlands or wet meadows. Each wetland type has its own unique set of characteristics, a consequence of all of the drivers and stressors creating it, however, some basic parameters or metrics are common to all. These include the fundamental structure and composition of the wetlands, and the associated species. Obviously, vegetation composition may be primarily woody or herbaceous, but metrics such as cover or species composition can be used as indicators for all wetland types.

Another set of wetland parameters that may also be used as indicators relates to the status of wetland associated species, such as birds and amphibians. Both of these species assemblages have been found to be useful indicators of wetland status.

1. Wetland Vegetation Parameters

Resource Monitored: Plant species composition, cover, abundance, or diversity for each wetland type (i.e., depression, willow, spring, beaver dam, and herbaceous wetlands).

Justification: The high biological diversity of wetlands is found in the plant community as well as associated animal communities and populations. The plant community is the foundation of the wetland ecosystem. It responds to the hydrological events that create inundation and hydric soils. Wetland plants, especially obligate wetland plants, are limited to wetland physical conditions. Consequently, plant associations in wetlands change in response to the magnitude of stressors that may alter the influence of hydrology or ability of the plants to establish and grow in wetland conditions. These changes, when determined in different types of wetlands will, over time, signal both short-term and long-term local and regional wetland changes.

Comment: Abundance is a term often applied to quantification of some ecosystem or community parameter. Because wetlands plant communities tend to be dense, estimates of cover of individual species may be the best metric to use. Cover classes (e.g., 1-5) may be appropriate. Sampling vegetation cover at representative wetlands of each type, when present, will produce data on increasing or decreasing cover of individual species and the whole community. This type of sampling will also produce data on community composition and species diversity.

Example of specific measurements for indicator: An example of a sampling scheme for determining species and total community cover, as well as species composition might be a series of random quadrats within a grid placed on the selected representative wetland, or stratified portion of the wetland if it is large. If the wetland has large woody species (e.g., willows), nested quadrats should be used (i.e., large (4x4 m) for woody and small (1x1 m) for herbaceous). The grid should be permanently marked to allow continued sampling of the same area of the wetland. Resampling (e.g., every 10 years) should be part of the long-term monitoring program.

2. Wetland associated species

Resource Monitored: Abundance of associated animal species (e.g., amphibians, birds, small mammals, etc.) in each wetland type (i.e., depression, willow, spring, beaver dam, and herbaceous wetlands).

Justification: Wetlands sustain a high diversity of associated species including, for example, birds, amphibians, small mammals, insects, etc. The abundance or presence of these species and/or the aggregate of these species (aka community) often act as surrogates for the condition or health of the wetland. Within a functional group, like birds, a change in composition of species from wetland specialists to generalists may indicate a change in food sources such as seeds and insects. In this way, the bird assemblage may be an easier metric to measure than comprehensive vegetation samples.

Comment: Avian (bird) species assemblages have been widely used

within the GRYN to determine the health of different ecosystems as well as avian source and sink vegetation communities. Riparian areas are a primary source and one could expect localized wetlands might also function in this capacity. Of the various associated species groups, the avian community probably is the easiest to sample, and long-term data sets for this group also exist for parts of the GRYN.

Example of specific measurements for indicator: Avian sampling includes regular (e.g., monthly) short-time (10 minute) visits to specific locations, in this case, specific wetland communities. The presence of every bird species within a pre-determined radius is recorded. The data can be organized into functional groups, such as resident, nesting migrants, neo-tropical migrants, etc. Sampling should be repeated on an annual or pre-determined time frame (e.g., every 1, 2 or 5 years) and this repeat sampling should be part of the long-term monitoring program.

3. Beaver populations

Resource Monitored: Presence of beaver activities (e.g., dams, mounds and/or bank burrows), and estimates of associated beaver numbers.

Justification: Beaver produce one kind of wetland within GRYN area that is associated with dams, ponds and elevated water tables. The presence or absence of beaver and these types of wetlands has reduced the diversity of wetlands and ecosystem types within the GRYN area. Consequently, biodiversity in valleys and along streams where beaver activity once occurred has declined. Beaver abundance tends to be cyclical, but some causes for these cycles may be related to human influence as well as changes in population of competitors for woody plants, predators and climate. There appears to be a resurgence of beaver in parts of the GRYN area. Although in many places with higher density human population the return of beaver is not welcome, within the natural areas of the GRYN region return of beaver is a sign of improving health of the landscape. For this reason, use of beaver population as an indicator (vital sign) may allow long-term evaluation of landscape health within those areas of the GRYN were beaver can occur and develop associated wetlands.

Comment: Within parts of the GRYN there has been some semblance of tracking beaver over the past few decades. A more systematic effort needs to be established that will not only determine where they are located and how many might inhabit each location, but also will determine the trends in beaver expansion or decline and the associated movements or migration of beaver families.

Example of specific measurements for indicator: All beaver locations within GRYN should be mapped (GIS recorded). This can be done by a combination of remote sensing and ground-truthing. A representative number of beaver sites should be visited to determine the population size at each site, if this type of data doesn't presently exist. These data sets, location and site population should be archived and regular (2-5 years) resampling of the GRYN region for beaver should become part of the long-term monitoring plan.

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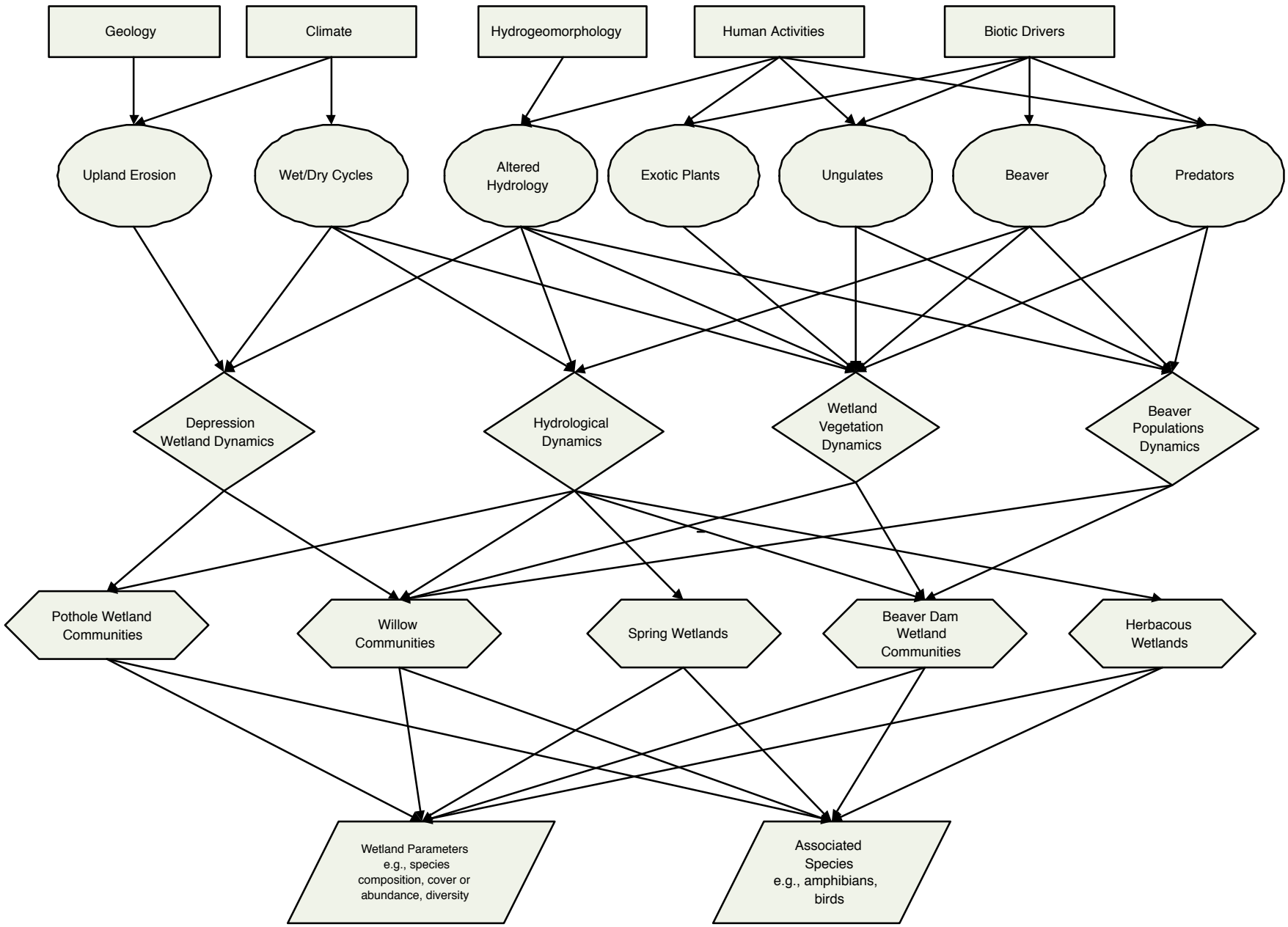

FIGURE 29 General wetland model.

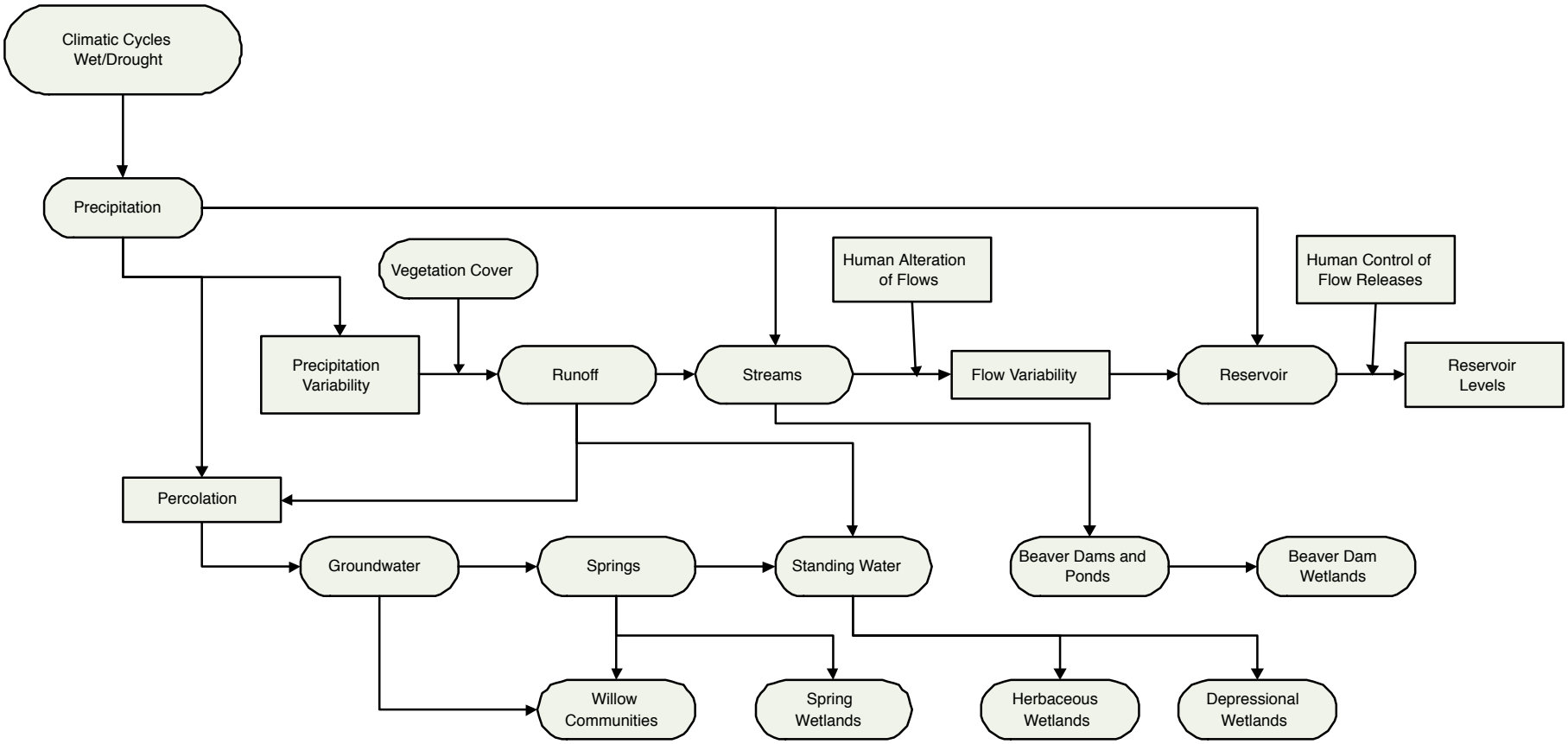

FIGURE 30 Wetland hydrology dynamics submodel.

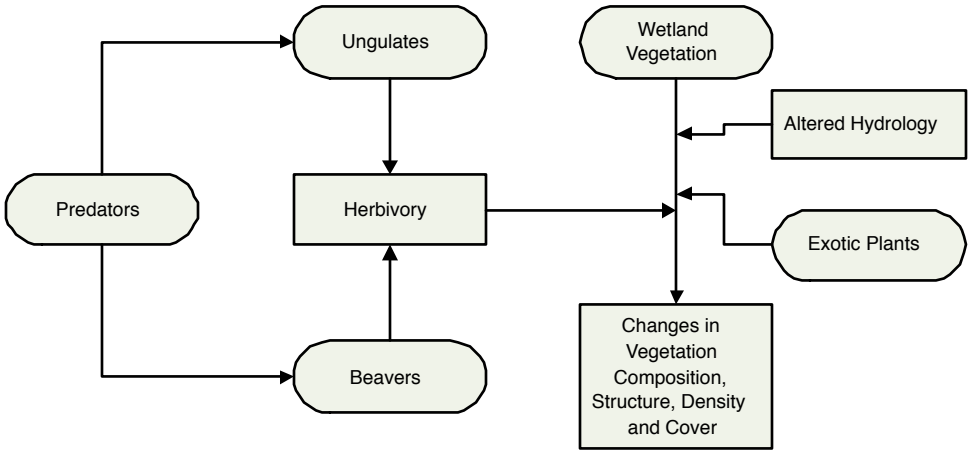

FIGURE 31 Wetland vegetation dynamics submodel.

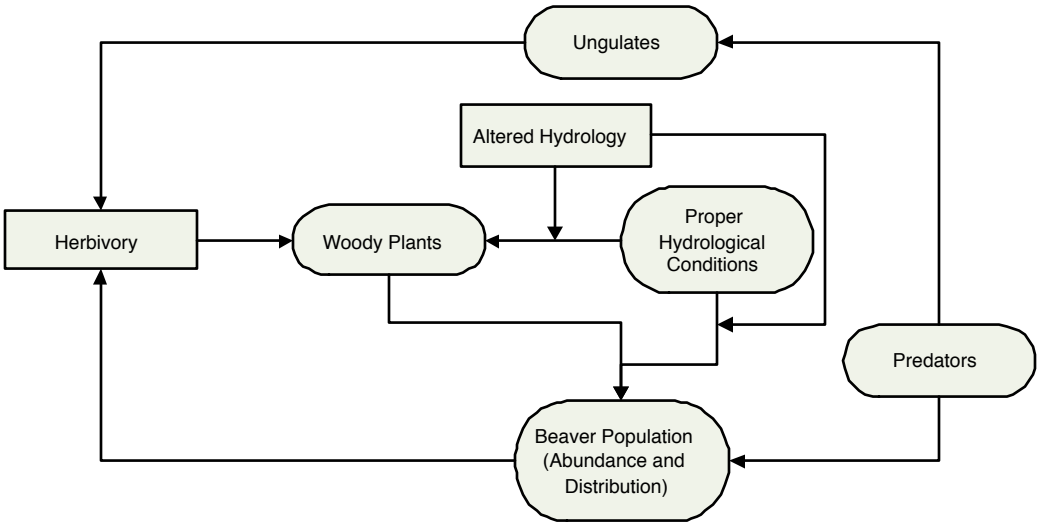

FIGURE 32 Wetland beaver population dynamics submodel.

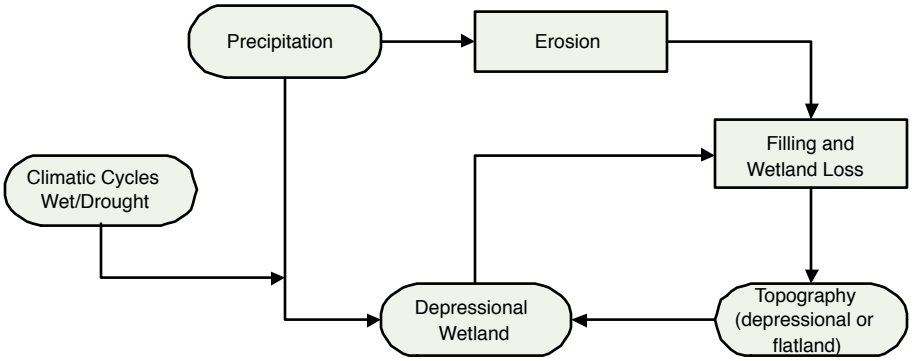

FIGURE 33 Depressional wetland dynamics submodel.

APPENDIX IV: DELPHI SURVEY—ROUND III

The following table contains a list of those indicators scored or nominated by the Delphi III survey participants. Scoring was based on a scale of 1 to 5, with 1 being unimportant and 5 being highly important. The scores were then averaged across all responses, yielding the score seen in the right-hand column of the table. Participants were also invited to add indicators they deemed important that did not appear on the original list to score. These responses have a score of 0.0.

Indicator	Score
AIR	
Loading chemical species in snowpacks	3.85
Atmospheric deposition of sulfur	3.78
Acid neutralizing capacity in headwater lakes	3.54
Accumulation of toxic air contaminants in biota	3.52
Change in visibility deciviews	3.52
Atmospheric deposition on nitrogenv	3.46
Loss of forest productivity	3.46
Ozone exposure index--W126	3.14
Nitrogen concentration in streams during spring snowmelt	3.00
Number of days with smoke	2.48
Human health-related air quality	0.00
Emission rates of key gases to the atmosphere over Yellowstone NP.	0.00
Environmental contaminants	0.00
AQUATIC	
Aquatic species at risk	4.16
Native fish community structure, composition, stability	4.14
Native aquatic macroinvertebrate diversity/richness	4.14
Aquatic habitat loss and degradation	4.00
Exotic fish community structure, composition, stability	3.72
Lake phytoplankton & zooplankton community assemblages	3.60
Exotic aquatic macroinvertebrate diversity/richness	3.50
Aquatic disease & pathogen prevalence, contagion, vulnerability	3.40
Stream periphyton and zoobenthos community assemblages	3.30
Spawning fish vital rates	3.25
Critical food abundance, distribution and stability in aquatic habitats	3.00
Aquatic/terrestrial trophic relationships	0.00
Wetland birds	0.00
Hot spring microorganism	0.00
Genetic integrity of native fishes	0.00
Aquatic sediment fossil records of all types.	0.00
Fish (native & alien) population abundance, distribution, and vital rates	0.00
Wetland vegetation communities	0.00
CLIMATE	
Total precipitation	4.29
Stream flow patterns	3.61
Plant phenology	3.50
Extreme hydrologic events	3.43
Snow water equivalence of snowpack	3.41
Number of days ground is snow-covered	3.40
Maximum air temperature	3.38
Date of "spring green-up"	3.32
Alpine/subalpine climatic conditions & micro-environment	3.29
Minimum air temperature	3.29
Snow covered area	3.24
Soil moisture	3.13
Period of lake ice cover	3.10
Extent of frozen ground	3.00

Indicator	Score
Surface UV	2.96
Date of lake overturn	2.95
Soil temperature	2.77
Number of severe storms	2.65
Photosynethically active radiation (PAR)	2.61
Number of rain-on-snow events	2.52
Number of cloudy days	2.50
GEOLOGY & GEOTHERMAL	
Earthquake activity	4.23
Geothermal water chemistry & temperature	4.13
Geothermal water flow rate	3.91
Geothermal feature abundance & distribution	3.78
Volcanic unrest	3.75
Contamination of thermal microbial populations	3.73
Active geological processes (e.g. slope failure, etc)	3.55
Thermal heat transfer	3.45
Geyser eruption volume & rate	3.24
Native microbial populations	0.00
Paleontological Resources	0.00
Fumarole degassing	0.00
Annual sinter layering	0.00
Streamflow; stream channel morphology	0.00
HUMAN	
Landscape heterogeneity & habitat fragmentation	3.96
Winter use activities (snowmobiles, skiers, other winter recreationists)	3.93
Land use--land cover	3.62
Secure wildlife habitat	3.61
Human-wildlife interaction (habituation)	3.54
Hydrologic modification (dams, diversions, return flow)	3.54
Sound quality	3.52
Visitor experience and satisfaction	3.36
Backcountry overnight use (people, stock, & boat use nights)	3.32
Backcountry day use (hikers, stock users, boaters, anglers, etc.)	3.16
Bio-prospecting	3.00
Road-killed wildlife	2.88
road corridor impacts	0.00
Night Sky Pollution	0.00
Urban develop near park and in wildlife corridors	0.00

Indicator	Score
INVERTEBRATES	
Critical habitat abundance, distribution & stability	3.68
Insect biodiversity	3.64
Insect herbivory	3.08
Insect biomass	2.88
Disease in terrestrial invertebrate communities	2.64
links between vertebrates and invertebrates and the changes in the landscape	0.00
Exotic insects	0.00
Insect species distribution	0.00
Invertebrate (all groups) diversity and distribution	0.00
SOIL	
Below-ground biomass	3.83
Hydrothermal soil chemistry	3.75
Soil chemistry (nitrogen, organic matter)	3.25
Soil structure and stability	3.25
Soil biodiversity	3.23
Cryptobiotic crust integrity	3.08
Soil and sediment erosion	2.92
VEGETATION	
Exotic terrestrial plant species diversity/richness	4.30
Whitebark pine ecology, distribution, mortality, recruitment	4.03
Native terrestrial plant species diversity/richness	4.00
Wetland vegetation community structure & composition	3.82
Aspen distribution, growth & recruitment	3.69
Grassland & shrub steppe community structure & composition	3.66
Willow – cottonwood community structure & composition	3.63
Alpine/ subalpine community structure & composition	3.58
Wetland species at risk	3.53
Vegetation chemistry	3.46
Forest community structure & composition	3.41
Fire and fuel loading	3.38
Quality and diversity of sagebrush habitat	3.28
Riparian vegetation community structure & composition	3.21
Taxonomy & distribution of aquatic vegetation	3.11
Browse community structure & composition	3.10
Net primary productivity	3.09
Beaver dam wetland community structure & composition	3.09

Indicator	Score
Desert shrub community structure and composition	3.00
Stream bank stability	2.97
Tree line elevation	2.92
Floodplain development	2.90
Sediment deposition in depressional wetlands	2.58
Juniper community structure & composition	2.56
Impacts of livestock grazing	0.00
Bryophytes	0.00
Distribution of exotic plant diseases	0.00
Bark beetle trends	0.00
Impacts of browsing by ungulates	0.00
Demographics of selected plants	0.00
Cushion plant community species richness and diversity	0.00
Lichen abundance and distribution	0.00
Area occupied by rare or declining plant community types	0.00
Plant disease trends	0.00

APPENDIX V: VITAL SIGNS MONITORING WORKSHOP REPORT

REPORT OF

THE NATIONAL PARK SERVICE
GREATER YELLOWSTONE INVENTORY AND MONITORING NETWORK: VITAL SIGNS MONITORING WORKSHOP

MAY 6-8, 2003

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Bozeman, Montana

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EXECUTIVE SUMMARY

This report summarizes the events of the *Vital Signs Monitoring Workshop* hosted by the Greater Yellowstone Inventory and Monitoring Network (GRYN) May 6-8, 2003 at the Strand Union Building on the campus of Montana State University, Bozeman, Montana. This workshop is part of the extensive process used to select vital signs to be included in the GRYN Vital Signs Monitoring Plan. The overall goal of the meeting was to apply priority setting to a list of proposed candidate vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the GRYN. Throughout the workshop, participants also undertook the task of peer review of the ecosystem conceptual models and the decision support system created by the GRYN workshop planning team. (Please see Appendix A for the complete workshop agenda.)

The first day of the workshop was designed to create a shared knowledge and understanding of the National Inventory and Monitoring (I&M) Program, the GRYN and the process by which the workshop planning team developed the list of proposed candidate vital signs used throughout the *Vital Signs Monitoring Workshop*. The goals of the National I&M Program were explained to the participants, as was the need to create a comprehensive and integrative program. Because of time and budgetary constraints, prioritization of vital signs is fundamental, and the primary objective of this workshop was to use experts' knowledge to undertake one step of the prioritization process. Participants were informed that choices they made during this workshop did not constitute a final list of vital signs to be monitored by the GRYN, but that their decisions would be used by the GRYN staff and Technical Planning Committee to make recommendations to the Board of Directors for final approval in August 2003.

During the second day of the workshop, participants were divided into resource-based breakout groups as follows: air quality and climate (joint group), geology and geothermal (joint group), aquatics and water quality (joint group), human use, invertebrates, terrestrial vegetation, terrestrial vertebrates. Using a list of proposed candidate vital signs and information such as the justification given through the conceptual model process or the Delphi survey process and proposed metrics, the breakout groups used a worksheet to evaluate each candidate vital sign using a predetermined set of desirable characteristics. The completion of these worksheets required current knowledge about the ecological relevance, response variability, management relevance, feasibility of implementation, interpretation and utility of the proposed vital sign. (Please see Appendix B for the complete set of selection criteria.) These data were given to the workshop data manager and entered into the decision support system Access database in real time to produce a ranked list of candidate vital signs. (Please see Appendix I for the ranked list of candidate vital signs.)

On the third day of the workshop, participants were given the opportunity to evaluate the ranked list of candidate vital signs and give overall comments. Comments are given in more detail in the body of this report. Participants then engaged in an exercise to determine the spatial and temporal scales within which data about each candidate vital sign could be collected or evaluated. The results of this exercise will be used to evaluate the utility of the vital signs throughout various spatial and temporal scales. This information will be used to summarize the spatial sampling design for the parks.

OVERVIEW OF THE GRYN

GRYN Background Information

The Mission of the National Park Service (NPS) is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations". To uphold this goal, the NPS created the Natural Resource Challenge in 2000 to encourage National Parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring and management. This Challenge was legally guided by the *National Parks Omnibus Management Act of 1998*. Through the Natural Resource Challenge, the 265 parks of the NPS were placed into seven regions and, subsequently, organized into thirty-two Inventory and Monitoring Networks, based on geographic and ecological similarities. The overarching goal of the Networks can be summarized by the following quote from the NPS Advisory Board in July 2001: "A sophisticated knowledge of resources and their condition is essential. The Service must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public. For it is the broader public that will decide the fate of these resources". The goals of the Networks are:

- To inventory the natural resources and park ecosystems under NPS stewardship;
- To determine their nature and status;
- To monitor park ecosystems to better understand their dynamic nature and condition;
- To provide reference points for comparisons with other altered environments;
- To integrate natural resources inventory and monitoring information into NPS planning, management and decision-making.

The Greater Yellowstone Area (GYA) encompasses 18 million acres in three states—Montana, Wyoming and Idaho. Six National Forests and three National Wildlife Refuges lie within this area. Known as one of the largest intact natural areas in the contiguous United States, it has an enormous variety of vegetative communities that boast stable grizzly bear populations, trumpeter swan wintering grounds, free-ranging bison and the largest elk herd in North America. However, because of its wild nature, the GYA is attracting widespread development, in turn creating new disturbances to flora and fauna. The GRYN encompasses the GYA, which consists of four National Park Service protected areas: Bighorn Canyon National Recreation Area (BICA), Grand Teton National Park (GRTE), John D. Rockefeller Memorial Parkway (JODR) and Yellowstone National Park (YELL).

The GRYN was approved by a charter in 2001 and consists of a Board of Directors, Technical Planning Committee, Science Committee and GRYN staff. The Board of Directors (BOD) is comprised of the park superintendents (or his/her appointee) from each of the three GRYN parks and the Research Coordinator for the Rocky Mountains-Cooperative Ecosystems Studies Unit. The BOD directs the GRYN and provides oversight, as well as approving budgets, work plans and the final monitoring plan. The Technical Planning Committee (TPC) is responsible for strategic decisions, such as writing work plans, identifying subject experts as scientific advisors and providing the GRYN with current data and methodologies being used by the parks. A representative from each park sits on the TPC, as well as the Inventory and Monitoring (I&M) Program Manager and the Research Coordinator for the Rocky Mountains-Cooperative

Ecosystems Studies Unit. Members of the Science Committee (SC) are chosen from regional universities and other scientific agencies. The role of the SC is to provide scientific background, suggestions and review that will be used to choose vital signs and to assist in the creation of sampling designs and protocols. The GRYN staff consists of a Program Manager, Cartographic Technician, Communications Director and Writer/Editor, all of whom are based at the Forestry Sciences Lab at Montana State University in Bozeman, Montana and are hosted by the USGS-Northern Rocky Mountain Science Center. In addition, Bighorn Canyon National Recreation Area houses a GRYN ecologist and Grand Teton National Park hosts a GRYN hydrologist. The positions of Data Manager and Quantitative Ecologist, both to be based in Bozeman, will be filled in 2003.

The GRYN is focusing its efforts in three primary areas: data management, inventories and long-term monitoring. Because monitoring vital signs is one of the primary goals of the GRYN, the selection of these vital signs and how best to measure them is an integral part of the success of the program. In order to assure a secure scientific backing, the GRYN formed partnerships with universities, non-profits and park personnel. In 2001 the GRYN joined with the University of Idaho-College of Natural Resources to conduct an internet-based survey of park personnel, university faculty, environmental groups and other agencies. This "Delphi" survey process consisted of three rounds of questioning meant to identify and rank the most important ecosystem components, conditions and processes. Over 100 individuals responded to this survey.

In addition to the Delphi surveys, the GRYN took on the task of developing conceptual ecosystem models to understand the complex nature of the interactions between ecosystem components. These conceptual models are being used to better understand the ecosystems under study and provide solid scientific information based in literature as well as to help guide those who will choose the vital signs for monitoring. The models show drivers, stressors, ecological responses, outcomes and indicators that will warn managers of ecosystem changes.

Along with the Delphi survey and conceptual models, the GRYN has completed a literature review and park-specific workshops. The literature review allows the GRYN quick access to a variety of pertinent scientific studies that have been performed in the GYA and, specifically, in the GRYN parks. The GRYN also hosted park-specific workshops, preceding the *Vital Signs Monitoring Workshop*, where park managers were given the opportunity to peer review the conceptual models and selection criteria used by the GRYN during the *Vital Signs Monitoring Workshop*. (Workshop reports from the park-specific workshops are available upon request.)

Purpose of the *Vital Signs Monitoring Workshop*

The list of vital signs to be monitored by the GRYN will be approved by the Board of Directors in August 2003. In order to narrow down an extensive list of possible indicators to a manageable few that will become the final list, the GRYN, under guidance from the National I&M Program, hosted the *Vital Signs Monitoring Workshop*. The goal of this workshop was to assemble subject-area experts to give guidance on which proposed candidate vital signs they believed were most beneficial to the GRYN in keeping with the Service-wide Network goals set forth by the NPS. In order to complete these tasks, the workshop planning team created a list of thirteen

selection criteria—a set of yes/no questions to be answered by workshop participants, with space provided for helpful comments corresponding to the criteria. (Please see Appendix H for the complete table of comments.) The selection criteria were developed to determine which of the candidate vital signs contained those desirable characteristics that were deemed important through a literature review and peer review during the park-specific workshops prior to the *Vital Signs Monitoring Workshop*. The selection criteria worksheets were completed by the participants and then entered into the decision support system Access database the afternoon and evening of the second day of the workshop. This allowed the workshop planning team to present the results to the participants during the third day of the workshop, allowing for comment by the participants on both the process and results.

Approximately 150 individuals were invited from a variety of government, non-government, academic and non-profit organizations, with fifty-six attending. Organizations represented include: Yellowstone National Park, Grand Teton National Park, Bighorn Canyon National Recreation Area, Rocky Mountains-Cooperative Ecosystems Studies Unit, National Park Service-Air Resources Division, U.S. Geological Survey-Water Resources Division, U.S. Geological Survey-Northern Rocky Mountain Science Center, Environmental Protection Agency, Greater Yellowstone Coordinating Committee, U.S. Forest Service, Wyoming Game and Fish, Snowcap Hydrology, Yellowstone Ecological Research Center, Montana Natural Heritage Program, Montana State University, Montana State University-Big Sky Institute, Idaho State University, Iowa State University, University of Oregon, University of Montana, University of Wyoming and the Wyoming Natural Diversity Database. For a complete list of participants and contact information, please see Appendix C.

Workshop Planning Team

The workshop planning team consisted of a group of individuals who helped create the concept behind the *Vital Signs Monitoring Workshop*, establish workshop goals, generate useful selection criteria and produce a decision support system database. Cathie Jean, Program Manager for the GRYN, was the leader of workshop planning and implementation. Tom Olliff, Chief of Resources at Yellowstone National Park and a member of the TPC, was an integral part of the vital signs selection process and provided helpful critique. Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was the author of the selection criteria, ranking process and development of narrative and schematic conceptual models. Ann Rodman, Supervisory GIS Specialist at Yellowstone National Park and a member of the TPC, created the version of the decision support system Access database used during the workshop and provided oversight during data entry and analysis. Duncan Patten, Research Professor at Montana State University, was instrumental in the conceptual model design, as well as author of many individual models and narratives. Bob Hall, Assistant Professor at the University of Wyoming, was the aquatics conceptual model author. Dan Tinker, Assistant Professor at the University of Wyoming, authored many of the terrestrial vegetation conceptual models. Anne Schrag, Communications Director for the GRYN, provided logistical support during the workshop and prepared this workshop report.

The Future: Where do we go from here?

After completion of the *Vital Signs Monitoring Workshop*, the GRYN will work closely with the TPC to choose and recommend vital signs for BOD approval. The GRYN will begin this process by hosting the Technical Planning Committee Vital Signs Selection Meeting at Mammoth Hot Springs, Yellowstone National Park, in June 2003. During this meeting, the GRYN staff and Technical Planning Committee members will choose candidate vital signs to submit to the Board of Directors for approval. In order to select the appropriate vital signs for monitoring, they will have at their disposal a conceptual framework for the proposed vital signs, the ranked list of vital signs from the *Vital Signs Monitoring Workshop* and technical notes on highly ranked vital signs from all resource areas. After the vital signs selection has occurred, the Board of Directors will have final approval during an August 2003 meeting at Lake, Yellowstone National Park. Following this meeting, the GRYN will submit its Phase II Report in September 2003, outlining the process it took to choose the selected vital signs, including literature review, the Delphi survey, conceptual models and the workshop series. During the following year, 2004, the GRYN will undertake extensive research efforts to develop monitoring objectives and protocols that will be included in the Phase III Report, to be submitted in December 2004, along with the Draft Vital Signs Monitoring Plan for peer review. The final Vital Signs Monitoring Plan will be submitted in December 2005.

VITAL SIGNS MONITORING WORKSHOP-DAY 1

Objectives

The objectives of the first day of the *Vital Signs Monitoring Workshop* were as follows:

- To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
- To inform participants of the process used to identify candidate vital signs
- To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

Presentations

In order to accomplish these objectives, several presenters were asked to share information about the part of the workshop planning process with which they were involved. To open the meeting, Tom Olliff, Chief of Resources at Yellowstone National Park, shared the sentiment that this is a historic time in the life of the NPS with respect to a shift in focus from scenery management to natural resources management.

Introduction to the National Park Service Inventory & Monitoring Program

Steve Fancy, National I&M Program Coordinator

This introduction was followed by a presentation by Steve Fancy, National I&M Coordinator, about the national program perspective. He referred to the Natural Resource Challenge, which provides the funding for the I&M Program, as a "wave of change", giving true meaning to the phrase "science for parks, parks for science". The Challenge doubles the natural resource staff in the NPS. According to Fancy, goals of long-term monitoring include providing an early warning of change in order to eliminate non-action due to a lack of knowledge and resources. In addition, the I&M Networks are tasked with identifying what kinds of changes are acceptable, meanwhile focusing on the most significant ecological indicators because of time and money constraints. Fancy also focused on the need for partnerships between Networks and universities and other agencies, all the while keeping the information obtained through inventories and monitoring useful for many different divisions within the parks. The creation of Networks will allow for professional staff to design, implement and communicate the results of the I&M program throughout the Network parks.

GRYN Vital Signs Monitoring Plan

Cathie Jean, GRYN Program Manager

Cathie Jean, Program Manager for the GRYN, gave an overview of the GRYN, including the GRYN parks, operating procedures and budget estimates. Jean gave an overview of the process leading to the list of proposed candidate vital signs. The Delphi Internet survey consisted of

three rounds of questions, with the third round including a ranking of indicator importance. One value of such a survey was the independent thinking that took place because participants were dispersed through time and space. However, this process also lacks statistical power. Ecosystem conceptual models were then created to show the most important components and linkages in key ecosystems throughout the parks of the GRYN and are backed by scientific literature. Jean then emphasized the importance of the process the participants would undergo during day two, and encouraged recording any comments that classify or justify answers given on the selection criteria worksheets.

Variability in Natural Systems and Monitoring Considerations

Duncan Patten, Research Professor, Montana State University

The focus of Duncan Patten's presentation was the application of historic range of variability to ecosystem management and monitoring. This presentation was requested, in part, to give participants a frame of reference for some of the selection criteria that dealt with the natural range of variability of certain proposed candidate vital signs. According to Patten, the historic range of variability helps in understanding the dynamic nature of ecosystems. In order to consider past conditions, one must include both natural and human-induced impacts, such as climate change, invasive species, etc. One method of evaluating the historic range of variability is through repeat photography, which gives a good representation of historic changes, as well as showing temporal and spatial variability, but also requires interpretation. Patten left participants with the question of whether the historic range of variability is a useful tool for monitoring at a variety of scales, as well as the question of "what do we do?" when the desired future condition does not match the historic range of variability or the present condition does match the historic range of variability.

The Role of Conceptual Models in Choosing Vital Signs

Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
Duncan Patten, Research Professor, Montana State University
Dan Tinker, Assistant Professor, University of Wyoming
Bob Hall, Assistant Professor, University of Wyoming

Glenn Plumb, Supervisory Wildlife Biologist at Yellowstone National Park, was on detail with the GRYN during the winter of 2002-2003 with the specific task of helping to create a defensible vital signs selection process. Plumb went about this task by using graphic conceptual models as "problem solving vehicles" that illustrate the linkages among key environmental drivers, stressors, ecological effects, outcomes and measurable parameters that serve as ecological response signals. According to Plumb, the GRYN conceptual model formula was based off of work done in the Everglades, wherein eight steps were taken to create useful conceptual models that lead the GRYN to a list of vital signs to monitor. These steps include: 1) considering the spatial, temporal and ecological scales and boundaries; 2) identifying important elements of ecosystem structure and function; 3) identifying sources of anthropogenic or natural stressors of concern; 4) describing stressor mechanisms and routes of exposure or linkage; 5) identifying ecological receptors and at-risk components; 6) identifying ecological endpoints; 7) developing

stress-effects causal pathways; and 8) identifying a particular structural framework for the graphics. Plumb stressed that the conceptual models designed for the GRYN were not meant to be complete ecosystems, rather to identify components of the systems that are often not considered, but are more informative than many other parts of the system that are easily recognized and used.

Following this presentation, Duncan Patten, Dan Tinker and Bob Hall, three of the five conceptual model authors for the GRYN, gave brief presentations on chosen models, in order to guide participants through this part of the process used to identify proposed candidate vital signs. A complete set of draft conceptual models presented at the workshop can be found in Appendix D.

Evening Conceptual Model Social Hour

On the evening of day one of the workshop, participants were invited to a social in which the draft conceptual models were displayed for peer review. Conceptual model authors contributed fifteen total models focusing on the following systems: lake, river, dry woodland, lodgepole pine, ponderosa pine, whitebark pine, mixed conifer, aspen, alpine and timberline (joint), riparian, wetland, shrubland, grassland, geothermal and Yellowstone National Park. These models were reproduced in 36”x 42” poster size at the social and participants were encouraged to discuss questions, concerns and comments with the authors and to “mark up” the posters with changes they believed would make the posters more informative or inclusive of important ecosystem processes. Dan Tinker, terrestrial systems model author, received many excellent and helpful comments during this time and thought that the social atmosphere was helpful. According to Bob Hall, aquatics conceptual model author, the peer review received during this social hour was very helpful, especially since the social occurred almost directly after the presentation of the models. Therefore, many participants came with questions or ideas already formulated and ready for discussion.

VITAL SIGNS MONITORING WORKSHOP-DAY 2

Objectives

The objectives for the second day of the *Vital Signs Monitoring Workshop* were as follows:

- To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
- To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

Breakout Group Sessions

Participants were directed to breakout rooms (one group per room, except for very small groups) and given the task of completing the selection criteria worksheet(s) for each vital sign assigned to that group. The number of assigned candidate vital signs ranged widely, from fifty-four in the terrestrial vegetation group to seven in the invertebrate group. However, the number of experts in each group also varied, from thirteen in the terrestrial vegetation group to three in both the invertebrate and human-use groups. In fact, the terrestrial vegetation group proved to be too large and, thus, was split into two groups after the lunch break in order to facilitate the scoring process. Although the terrestrial vertebrate group was also quite large, the group members had fewer candidate vital signs to score than the vegetation group. In addition, the vertebrate group found it helpful to designate threshold values from the beginning of the process in order to answer the criteria as efficiently as possible. The complete list of breakout group members can be found in Appendix E.

Each group was assigned a group moderator—usually the author of the conceptual model(s) that best applied to that breakout group. In addition, two professional facilitators were on hand throughout the three-day conference to answer questions about the consensus process and to guide groups whose assignments proved difficult. The groups were to use the following process to complete the selection criteria worksheets (please see Appendix F for a complete list of proposed candidate vital signs and Appendix B as a reference for the selection criteria worksheets):

- Decide on the appropriate name for the proposed candidate vital sign. The group could choose to:
    - keep the current candidate vital sign name
    - change the candidate vital sign name to be more informative
    - lump the candidate vital sign with another vital sign
    - split the candidate vital sign into multiple (two or more) new vital signs
- Choose the parks in which the candidate vital sign occurs or applies
- Answer each selection criteria by filling in the “yes” or “no” bubble on the worksheet
- Add comments that refer to one of the following:
    - the specific selection criteria statements
    - the broad topic group of selection criteria (i.e. “management relevance”)
    - the vital sign as a whole

To aid the groups in using the selection criteria, the workshop planning team composed a short, descriptive phrase to better explain each of the statements. These explanations, along with the vital signs information, the schematic conceptual models, the narrative conceptual models and some appendices offering information specific to the selection criteria were included in breakout group notebooks. One notebook was given to each group. The vital signs information contained in this notebook was extremely lengthy and, therefore, is not included in full in this report. An example follows and the entire report is available upon request:

Channel dimensions Unique ID: AqHa_123

Primary Resource: Aquatic Habitats Secondary: Rivers and Streams

Why is this an important Vital Sign?

Riparian vegetation not only responds to changing channel geomorphology but plays a role in its formation. Any change in channel geomorphology will consequently alter the amount and distribution of the riparian community. Thus, channel geomorphological metrics may be a useful indicator of the condition of riverine and riparian systems. Altered hydrological conditions and concomitant degraded riparian systems play a role in channel changes. For example, changing regional hydrology or influences of upstream flow regulators, e.g., dams, will cause channels to adjust to new conditions and offer less or more habitat for riparian plant communities. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is being altered from expected geomorphic conditions. Decreasing width/depth ratios tend to indicate a degraded, incised channel; however, a greatly increasing width/depth ratio may result from excessive bank destabilization by ungulate use.

Metrics:

Variability and changes in channel cross section geometry and river length to floodplain length relationships.

The expanded explanations of the selection criteria and the appendices can be found in Appendix G of this report.

In order to decide on an appropriate name for the proposed candidate vital sign, the group generally went through much discussion. Many of the original candidate vital sign names did not seem as informative as possible to group members. This process occurred simultaneously with the lumping and splitting of vital signs. Obviously, the freedom to create new vital signs from those given was important for participants. This liberty also allowed the participants to feel more comfortable with the candidate vital sign name than if they had been limited to using those provided through the Delphi survey and conceptual models. However, one overall problem with the candidate vital sign names occurred when participants noted that some candidate vital signs were very specific (i.e. specific taxa), while others were broad (i.e. group of taxa, such as small-bodied mammals). Many times a potential vital sign would be a better indicator if its name were more descriptive (i.e. specific butterfly species instead of overall insect biodiversity). As was seen in earlier park-specific workshops, vital signs about which people know little or are perplexed tend to rank in the middle, whereas those vital signs about which people know a lot (possibly because they are more specific) tend to rank either very high or very low, depending on the circumstance.

The next step in the worksheet process was to choose in which parks the candidate vital sign occurs or applies. Many times the candidate vital sign applied to all three parks. However,

occasionally the candidate vital sign would not apply in one or two parks. This occurred more often with Bighorn Canyon in the area of geothermal features and terrestrial vegetation. However, often Bighorn Canyon had candidate vital signs in which it was the only park that a species or community occurs or specific measurement applies. This outcome was expected by the workshop planning team.

The workshop planning team put much thought into the structure of the selection criteria and the possible ways of quantifying a response that is, in actuality, qualitative by nature. Originally designed as a coarse and fine filter criteria wherein participants would choose how many statements they agreed with (thus giving a specific "score" such as low, medium or high that corresponded with a number), the selection criteria evolved to become a set of thirteen "yes/no" questions based upon extensive literature review and National I&M Program guidance as to what makes a "good" ecological indicator. These thirteen questions were placed into five broader categories, including ecological relevance, response variability, management relevance, feasibility of implementation and interpretation and utility. By making the answers to these questions binary in nature, the workshop planning team believed that they would provide a way in which participants could complete the task on time and eliminate debates about semantics. As the "yes/no" answers were entered into the Access database, the database was programmed to convert and calculate the scores as follows:

- For those broad topic areas that contained only two questions (i.e. ecological relevance):
    - two "yes" answers=1.0 score
    - one "yes" answer and one "no" answer=0.5 score
    - two "no" answers=0 score
- For those broad topic areas that contained three questions (i.e. response variability):
    - three "yes" answers=1.0 score
    - two "yes" answers and one "no" answer=0.6 score
    - one "yes" answer and two "no" answers=0.3 score
    - three "no" answers=0 score

In addition to this scoring method, the workshop planning team decided on a weighting scheme for the broad topic areas. The scheme was decided upon after input from the park-specific workshops on which broad topic areas participants felt were most important in creating a useful indicator of ecosystem health. These weights were then multiplied by the broad topic area scores (explained above) to create the final score. The weights chosen were as follows:

- Ecological relevance=25%
- Response variability=25%
- Management relevance=20%
- Feasibility of implementation=15%
- Interpretation and utility=15%

Another aspect of the decision of which candidate vital signs to monitor includes the responsibility of National Parks to monitor those resources whose protection is required by law. Therefore, information on the legal relevance is included in the Access database in the form of which piece of legislation requires the protection of specific resources. After much debate

throughout the park-specific workshops, the workshop planning team decided to omit this criteria as a decision to be made by the expert participants who attended the workshop.

Although the workshop planning team made every effort to insure that sufficient explanations of the selection criteria and background information were provided to the participants, the process of ranking the candidate vital signs still produced questions and concerns. Because many comments were shared between group members and not formally recorded, what follows is a rough summary of major topic areas of discussion.

Overall comments about the process and/or selection criteria

- Many individuals felt that there was a need to separate the drivers and stressors from the response variables in order to fairly evaluate them as candidate vital signs. Also, there was much discussion about incorporating both types of candidate vital signs to create a comprehensive monitoring plan.
- One conceptual model author noted that, while lumping and splitting certainly was helpful in some circumstances, occasionally, when a vital sign was split, it lost its relevance with respect to why it was originally nominated. For example, when "riparian associated animal species" is split into specific taxa vital signs, the importance of the community structure that made it a good indicator of riparian ecosystem health is lost.
- One participant felt that narratives accompanying the conceptual models would have proven helpful. Although the narratives contributed by the conceptual model authors were provided in the notebooks, along with the vital signs justification statements, the workshop planning team did not set aside specific time to review them or notify the participants of their existence. Sending these materials ahead of time would have allowed participants to review their contents and come with any prepared questions.
- Many participants felt it would have been helpful to do a "trial run" of a few vital signs in order to alert them of potential difficulties with the selection criteria. This did occur, to some extent, at the park-specific workshops, wherein participants were given the opportunity to progress step-wise through the selection criteria, alerting the workshop planning team of potential difficulties. These suggestions were then incorporated into the final selection criteria presented to the *Vital Signs Monitoring Workshop* participants.
- One participant observed that a particular candidate vital sign could be both affected by some driver or stressor and also be a driver or stressor for another vital sign.
- A moderator noted that the overall response to the list of proposed candidate vital signs was very positive.

Specific comments about the process and/or selection criteria

- The terrestrial vertebrates group mentioned that vertebrate and invertebrate monitoring should be stratified by habitat. In addition, this group added that the candidate vital sign "native species richness" caused more discussion and differences of opinion than any other candidate vital sign and, therefore, they feel it should be re-evaluated.

- One individual felt that the sagebrush community that constitutes an important part of Grand Teton National Park was overlooked.

Concerns with the interpretation of the selection criteria

- Many groups created a "threshold level" for agreement with a specific selection criterion. In some cases, this threshold level was inconsistent among candidate vital signs.
- Many of the groups felt that particular criteria were not specific enough in their original wording to be assigned a "yes" or "no" answer definitively. Therefore, groups had to go through a decision process in order to define what "yes" or "no" meant in these cases. Hopefully, in addition, the groups also recorded this reasoning in the comment section of the worksheet.
- Although the workshop planning team made a best effort to include park managers in each of the breakout groups, many groups still did not feel comfortable answering the management relevance criteria without further assistance. Many groups felt that someone with complete knowledge of the business plan standards, enabling legislation, GPRA goals, etc. should go through their answers and check them against these management standards.
- There was much disagreement about how long a "long-term dataset" had to be. Groups obviously defined "long-term" differently depending upon what types of data they were evaluating.
- Although participants were asked not to take into account whether or not another agency is currently monitoring a specific proposed candidate vital sign, one group chose to rank highly those candidate vital signs that are already being monitored. This group also had the task of evaluating many stressors to the environment; thus, changing the application of the selection criteria. The effects of this ranking method are not yet fully understood, but will certainly be taken into account by those making the final decisions about which vital signs should be monitored. This also brings up the fact that this ranking is not the sole determinant of which vital signs will be monitored by the GRYN. Many other factors will be evaluated.
- Some groups also mentioned that whether or not a candidate vital sign was "cost prohibitive" was not specific and, therefore, required the use of intuition in the ranking process.
- The air quality/climate group moderator noted that it is virtually impossible to distinguish between natural variation and human-induced variation, which was one of the selection criteria.
- The natural versus human-induced criterion also raised questions because of the circular relationship between human and natural drivers.

Concerns with the wording of the selection criteria

- The aquatics group moderator felt that the criterion concerning the candidate vital sign's helpfulness in identifying the causal mechanism of an ecological response was difficult to interpret. In addition, he noted that the criterion concerning low statistical power and variability was complicated because these two things were not thought to be the same and that it overlapped with the question concerning natural versus human-induced variation.

- There was some confusion as to the meaning of scales with respect to ecological organization. One participant felt that the use of levels would have been more clear.
- Adjectives used in the selection criteria to qualify statements (such as "helpful") were often difficult for participants to interpret.
- Some groups had difficulty with the definition of "high" and "low" with respect to natural variability and, therefore, this definition was generally used inconsistently within and among breakout groups.

Comments recorded by breakout groups regarding the selection criteria

The breakout groups were asked to record any comments that qualified their answer to a specific statement and/or a set of statements, such as "management relevance". These comments usually concerned why a certain park was not included in the applicable parks section or why the candidate vital sign was difficult to evaluate, given the selection criteria. Because many comments were recorded, resulting in a multiple-page report, a complete list of these comments is contained in Appendix H instead of in the body of this report.

VITAL SIGNS MONITORING WORKSHOP-DAY 3

Objectives

The objectives of the third day of the *Vital Signs Monitoring Workshop* were as follows:

- To present the results of the breakout groups' decisions on ranked list of vital signs
- To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
- Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the GRYN

Presentations, Breakout Group Exercises and Comments

Each participant was given a copy of the entire ranked list of candidate vital signs by score. Although many different kinds of reports could be produced and were discussed by the workshop planning team beforehand, an executive decision was made to distribute the ranked list by overall score. Many participants immediately voiced frustration with those candidate vital signs that ranked high and wanted to see the ranked list by resource area. This outcome was somewhat expected by the workshop planning team. A report listing the candidate vital signs by park and then by resource area was quickly produced and distributed. The distribution of this list was followed by a short presentation and comment section before participants were asked to participate in a breakout group exercise.

Presentation of the ranked list of vital signs

Cathie Jean, GRYN Program Manager

Cathie Jean congratulated the group on a job well done and commented on how nice it would have been to have one person contribute that one indicator that could tell us everything. Jean mentioned that the group did an excellent job of "cleaning up" the original list of proposed candidate vital signs by subsuming ninety candidate vital signs and adding twenty-one. Jean pointed out that nineteen vital signs received a "perfect" score, meaning that they met all of the selection criteria. She also pointed out that some groups interpreted the selection criteria differently and that this would be taken into consideration when choosing the final vital signs list. She reminded the participants that this ranked list was not the final list of vital signs to be monitored by the GRYN, but rather a tool to use in choosing the final vital signs. A complete ranked list of the candidate vital signs can be found in Appendix I of this report.

Comments

Many participants felt the need to share comments about the ranked list with the group as a whole. These comments were valuable in understanding the limitations of this exercise. The comments are summarized below:

- Participants felt that the candidate vital signs needed to be ranked relative to the other candidate vital signs in their resource areas. Participants were concerned that the GRYN would choose to monitor only those highly ranked vital signs without consideration of choosing a broad suite from many different resource areas.
- Participants felt it may be useful to have time to reconsider the candidate vital signs from their breakout group, as some believed that the scoring changed throughout the day and, thus, affected the overall result. Many groups who were rushed to finish by 5pm believed that those candidate vital signs scored later in the day could possibly have received better scores than they normally would have and believed that time for recalibration could have helped.
- Participants once again recognized the unevenness in specificity of the candidate vital signs. According to many experts, this caused an unevenness in scoring as well.
- Some participants included comments of papers that could be important and helpful in choosing vital signs. These included papers by Tom Hoeskstra of the Inventory and Monitoring Institute and the EPA's EMAP website.
- Concerns arose about the difference between vital signs that are drivers and those that are response variables.
- A comment was made that the vertebrate group did not look at specific habitat types, while the vegetation group did. This comment also follows that statement given by the vertebrate group on day two that vertebrate monitoring should be stratified by habitat.
- A participant brought up the fact that many of the highly ranked vital signs overlap, while also impacting other candidate vital signs.
- Someone also mentioned that there are many long-term datasets available, and a monitoring program should focus on what data can be used from these long-term datasets, even though they were not originally created to monitor the chosen candidate vital signs.
- Integration was a key component of many comments. Most participants felt that in order to have a comprehensive program, the GRYN must concentrate on integration both with other agencies as well as integrating the chosen vital signs into a coherent whole, including knowledge of the basic drivers of the systems.

Breakout group exercise

Options for organizing highly ranked vital signs into a coherent monitoring program

In order to bring some closure to the meeting, the workshop planning team devised a short exercise focusing on the creation of a conceptual framework that explains the spatial and temporal scales on which the candidate vital signs operate. To do this, the participants were asked to form into the same breakout groups that they had used during day two and were given overheads with a blank template of spatial and temporal scales. Participants were given the opportunity to draw the spatial and temporal scale of the candidate vital signs that they had ranked highly during day two on the overhead and to watch for aggregations of candidate vital signs along these given scales. Reproductions of the results of this exercise are contained in Appendix J of this report. Overall comments about the exercise follow.

Comments

- While some candidate vital signs may be sampled at a small scale, the effects of the results of this sampling can be amplified; thus, the candidate vital sign will have a wider applicability.
- The geology/geothermal group had to rescale the axes, as they were given a template made for ecological processes.
- The aquatics group also rescaled the axes to make the template more useful. A question was posed to the aquatics group about whether or not yearly changes in algal production is a reasonable way to assess nitrogen inputs. The answer given was that changes in diatom populations can be detected in time scales even shorter than one year.
- The air quality/climate group qualified the answers given by commenting that they focused on the measurement period and that the effects would be seen throughout the range of spatial and temporal scales given.
- One comment was made that the U.S. Forest Service starts monitoring with aerial detection and then "fills in" with groundwork.
- A participant commented that some vital signs will be good at detecting small-scale changes rather quickly, while others will be better at detecting changes across multiple scales. A mixture of these types of vital signs could produce the desired result of a comprehensive monitoring program.
- Someone also commented on the difficulty in integrating human-caused change with the vast array of natural variation one finds within ecosystems. The question was posed as to whether the monitoring program should be looking at human impacts or having the ecosystems unimpaired for future generations. In order to accomplish this, goals and objectives need to be set; then, the monitoring objectives that the GRYN establishes can define a meaningful level of change and how best to detect such a change.

CONCLUSIONS

In conclusion, the *Vital Signs Monitoring Workshop* hosted by the GRYN was a success. Although participants had concerns with the wording and interpretation of the selection criteria, as well as the ranked list of candidate vital signs, the workshop planning team agreed that creating a framework that allowed a large group of experts to come together and offer knowledge and insight into the proposed list of vital signs was extremely useful and productive. The participants successfully applied an objective set of criteria to a long list of proposed candidate vital signs. The criteria used were a balance of complex ideas and a simplified ranking system. Because of among-group variations in interpretation of the criteria, the results are best reviewed within groups.

In order to aid future Networks with their vital signs scoping workshops, the GRYN has developed a short list of lessons learned from the *Vital Signs Monitoring Workshop*:

- Doing a "trial run" of the selection criteria and a proposed candidate vital sign will help everyone involved to understand the depth of knowledge and consideration that is needed to answer the given questions
- Sending out information that will be used during the workshop would be helpful to those who have time for preparatory work
- Spending time deciding on the level of specificity for the candidate vital signs names and tailoring the names to this level before the workshop could eliminate some of the confusion seen at the GRYN workshop
- Making sure that participants are given a chance to review the schematic and narrative conceptual models beforehand would allow for a greater understanding of the process as well as give participants a chance to express concerns with the results of these processes with the model authors
- The first and second weeks of May are generally poor times to invite academic and agency scientists to travel for a meeting
- Given more time, many of these concerns would probably have been addressed by the GRYN.

Despite the set-backs, the GRYN now has a defensible list of candidate vital signs based on sound scientific advise from experts in many different fields from which it can take on the task of creating a comprehensive and integrative monitoring program. By all accounts, the participants who took part in this process, although frustrated at times, were always forthcoming with helpful comments about the process and the specific candidate vital signs, as well as having a high level of respect and praise for their colleagues in this exercise. The outcome of this meeting will be of particular interest to those Networks that are just beginning this process. The workshop planning team and the staff of the GRYN expresses a wealth of gratitude toward all who participated and hopes that everyone will stay tuned for our next steps!

ACKNOWLEDGEMENTS

The Greater Yellowstone Inventory and Monitoring Network wishes to extend a sincere thank you to those who made this workshop possible. The USGS-Northern Rocky Mountain Science Center is the campus host for the GRYN and, therefore, serves a central role in the GRYN's ability to use campus resources. A partnership through the Big Sky Institute at Montana State University allowed us to provide refreshments for guests through MSU Catering. We would like to thank the MSU Foundation for allowing us the use of their Great Room for our evening social. We would like to express our gratitude for the facilitation services provided by Michele Tae (throughout the workshop series) and Nancy Budge (for this workshop). Peggy Herzog was the scribe for the workshop series. A big thanks goes out to Chad Jacobson, Cartographic Technician for the GRYN, who became the interim data manager for the duration of the conference. Finally, many thanks to the GRYN's student employee, Sarah Stehn, who was extremely helpful in the days before the workshop, as well as aiding Chad with the data entry during the evening on day two of the workshop.

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APPENDIX A-WORKSHOP AGENDA

Greater Yellowstone Network Vital Signs Monitoring Workshop

Agenda

May 6-8, 2003
Ballroom C, Strand Union Building
Montana State University

Overall Workshop Objective:
To apply priority setting to a list of vital signs to be monitored as a means for determining the long-term ecosystem health of the parks of the Greater Yellowstone Network

May 6

Day 1 Objectives:

1. To create a shared understanding of the NPS I&M Program and the Greater Yellowstone Network
2. To inform participants of the process used to identify candidate vital signs
3. To create an informal, open-forum discussion of the posted conceptual models as part of an evening social hour

12:30 **Participants Arrive, Joseph May Ballroom C, Strand Union Building**
Sign-in/registration

1:00 **Welcome, Opening Comments**
Tom Olliff, Chief of Resources, Yellowstone National Park

1:10 **Statement of Meeting Goals and Agenda Review**
Cathie Jean, Program Manager, Greater Yellowstone Network

1:25 **Introduction to the National Park Service Inventory & Monitoring Program**
Steve Fancy, National I&M Program Coordinator

Greater Yellowstone Network Vital Signs Monitoring Plan
Cathie Jean, Program Manager, Greater Yellowstone I&M Network

2:00 **Variability in Natural Systems and Monitoring Considerations**
Duncan Patten, Research Professor, Montana State University

2:30 **Break**

2:45 **The Role of Conceptual Models in Choosing Vital Signs**

- Overview of Conceptual Models, Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park
- Riparian and Wetland Ecosystem Model, Duncan Patten, Research Professor, Montana State University
- Terrestrial Ecosystem Model, Dan Tinker, Assistant Professor, University of Wyoming
- Aquatic Ecosystem Model, Bob Hall, Assistant Professor, University of Wyoming

3:45 **Workshop Objectives and Instructions**
Michele Tae, facilitator
- Breakout group objectives
- Explanation of Selection Criteria
- Roles of Moderators, Facilitators and Participants
- Participant Assignments and Meeting Locations

5:00 **Adjourn**

6:30 ****Social Hour**, MSU Alumni Foundation, 1501 S. 11th Ave.**
******Participants are encouraged to critique the conceptual models and discuss candidate vital signs with the authors of the conceptual models.

May 7

Day 2 Objectives:

1. To apply the selection criteria from the decision support system to each candidate vital sign in the topic area and provide results to the decision support system manager by 5:00 pm
2. To document comments related to the scoring decisions that will be incorporated into a report for the Technical Committee and Science Committee

8:00 **Groups Convene**
*Please use the attached map of the Strand Union Building and breakout group room assignments to find your breakout room for the day.

12:00 **Luncheon, Joseph May Ballroom C, Strand Union Building**

5:00 **Adjourn**

May 8

Day 3 Objectives:

1. To present the results of the breakout groups' decisions on ranked list of vital signs
2. To discuss options for organizing, into logical groups, vital signs whose data are generally collected simultaneously or, when combined, are more useful for interpreting results.
3. Using a full suite of vital signs, to build a conceptual framework that integrates the diversity of spatial and temporal scales across the network.

8:00 **Groups Convene, Joseph May Ballroom C, Strand Union Building**
Welcome and Comments
Michele Tae, facilitator

8:15 **Presentation of the Ranked List of Vital Signs**
Cathie Jean, Program Manager

8:30 **Part 1 Integration Exercise: Options for Organizing Highly Ranked Vital Signs into Logical Groups**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

9:45 **Break**
** For those participants whose flights depart around noon or 1pm, a shuttle will be leaving from the Strand Union Building to take you to the airport following break.

10:00 **Part 2 Integration Exercise: Building a Conceptual Framework that Integrates a Full Suite of Vital Signs**

11:15 **Results of Conceptual Framework Exercise:**
Michele Tae, facilitator
Glenn Plumb, Supervisory Wildlife Biologist, Yellowstone National Park

11:45 **Wrap-up and adjournment**
** For those participants with flights later in the afternoon, a shuttle will be leaving from the Strand Union Building to take you to the airport at noon.

APPENDIX B-SELECTION CRITERIA WORKSHEET

VITAL SIGN:
PRIMARY RESOURCE:
Secondary Resource:

Parks that this Vital Sign applies to:

YELL GRTE BICA

VITAL SIGN CRITERIA	Yes	No	Comments
Ecological Relevance			
• The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature	❍	❍	
• The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization	❍	❍	
Response Variability			
• The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power	❍	❍	
• The candidate vital sign is anticipatory and is sensitive enough to stressors to provide an early warning of change	❍	❍	
• The candidate vital sign has low natural variability and has high signal-to-noise ratio (e.g. low error)	❍	❍	
Management Relevance			
▪ The candidate vital sign is stated in specific park management goals, GPRA goals, or Business Plan standards.	❍	❍	
▪ There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions or for evaluating past management decisions	❍	❍	
Feasibility of Implementation			
• The candidate vital sign's cost of measurement is not prohibitive	❍	❍	
• Impacts of measuring the candidate vital sign meet NPS standards	❍	❍	
• The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel	❍	❍	
Interpretation and Utility			
• The response of the candidate vital sign can be distinguished between natural variation and anthropogenic impact-induced variation	❍	❍	
• The candidate vital sign is helpful in identifying the causal mechanism of an ecological response	❍	❍	
• Historic databases and baseline conditions for the candidate vital sign are already known	❍	❍	

APPENDIX C-WORKSHOP PARTICIPANT LIST

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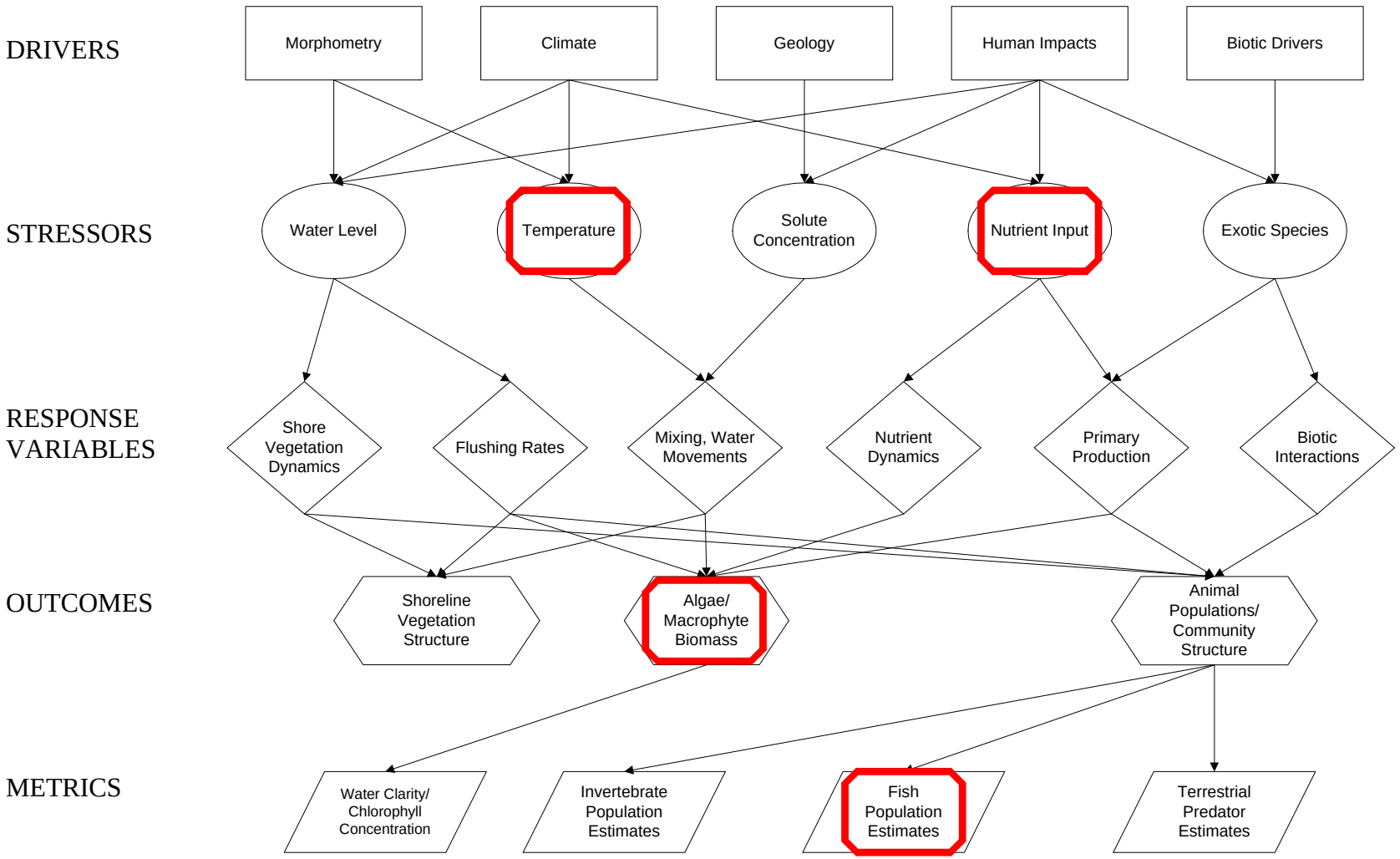
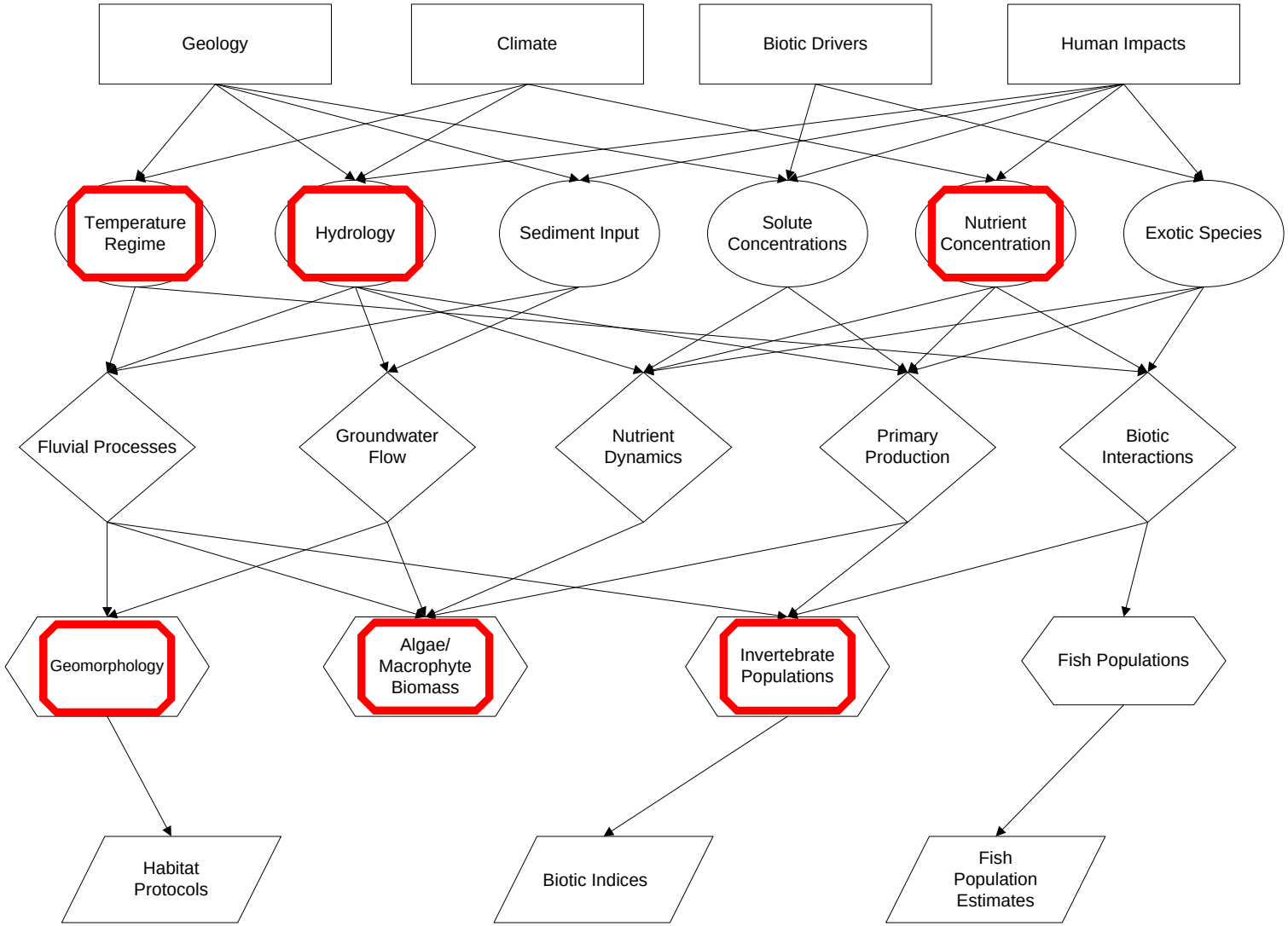
APPENDIX D-SCHEMATIC ECOSYSTEM CONCEPTUAL MODELS

**Please note: those polygons highlighted in red represent proposed candidate vital signs chosen by the authors.

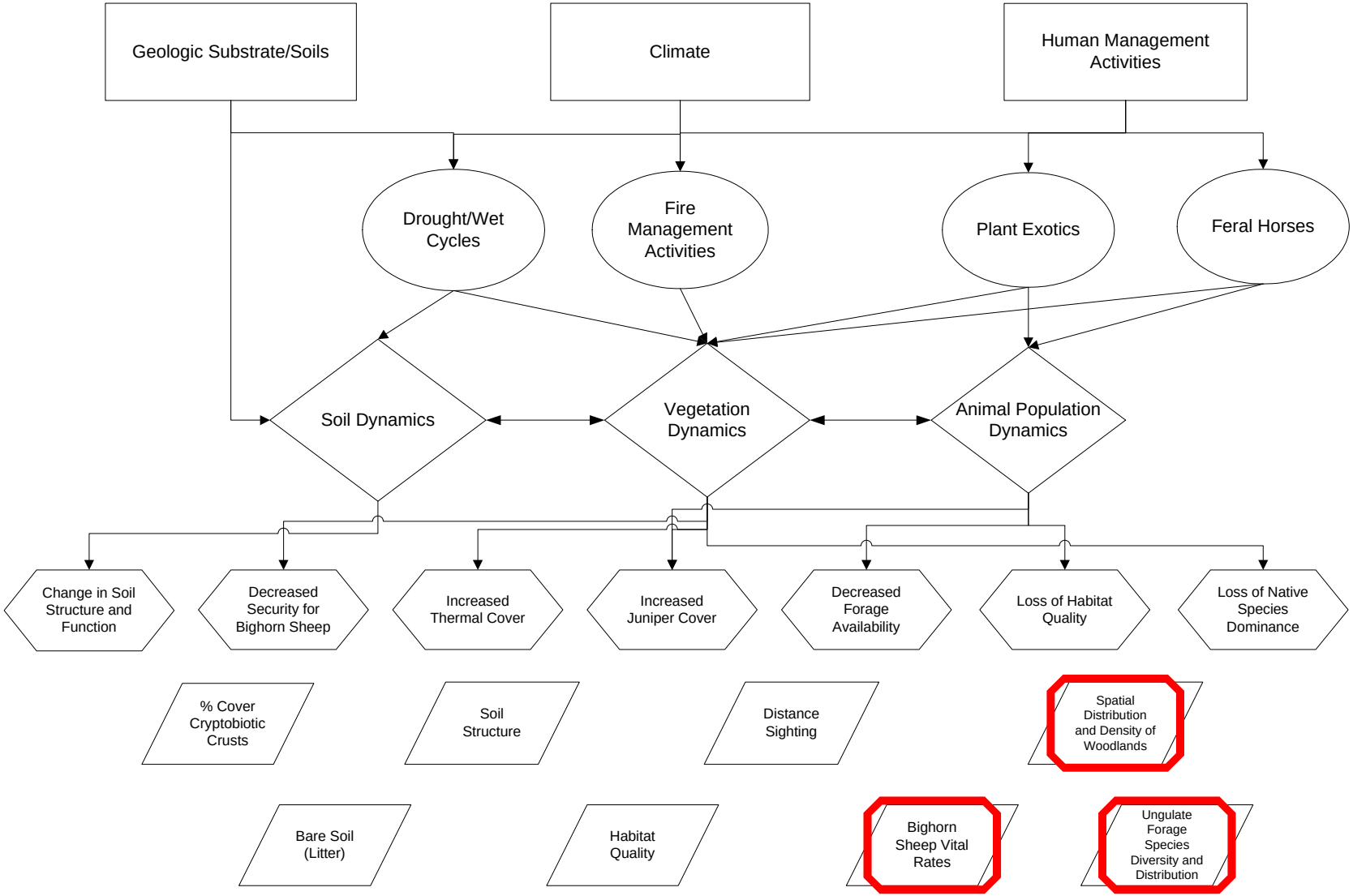
Lake Model-Bob Hall



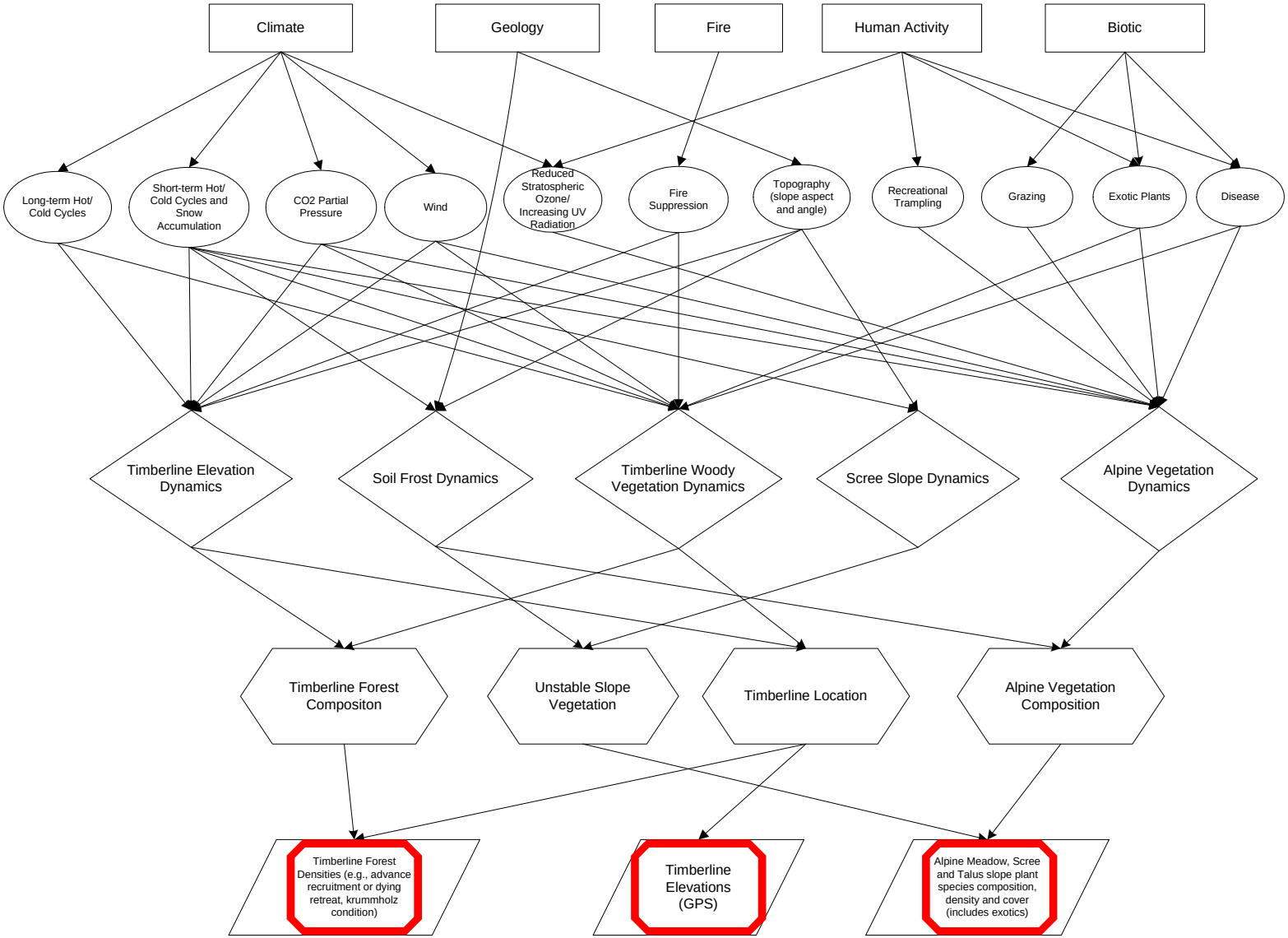
River Model-Bob Hall



Dry Woodland Model-Cathie Jean

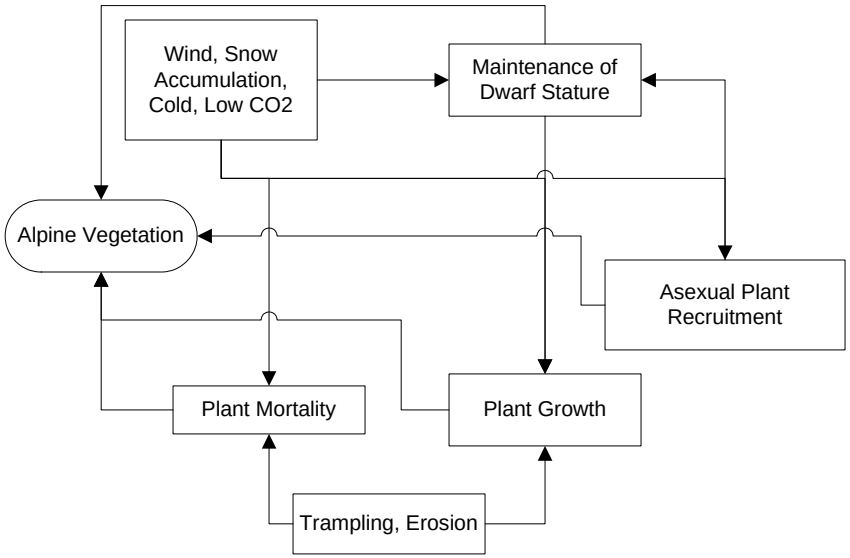


Alpine and Timberline Model-Duncan Patten

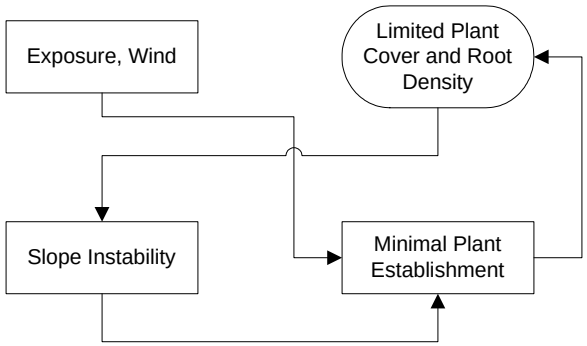


Alpine and Timberline Submodels-Duncan Patten

Alpine Vegetation

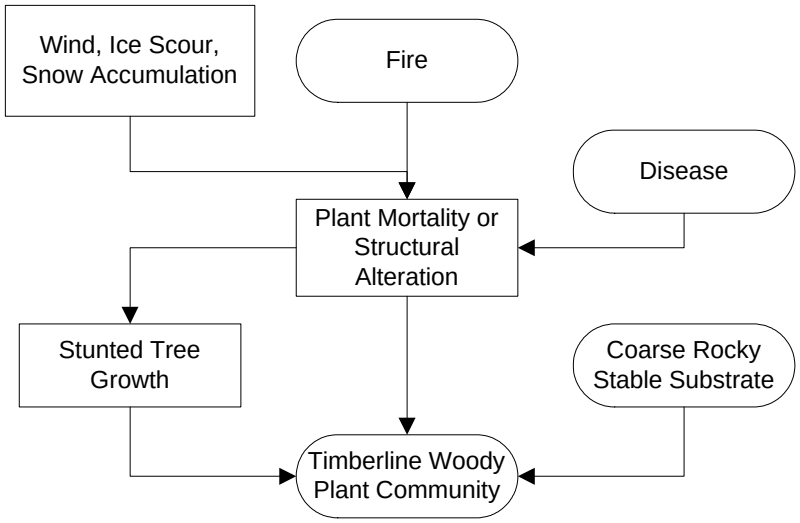


Scree Slope Dynamics

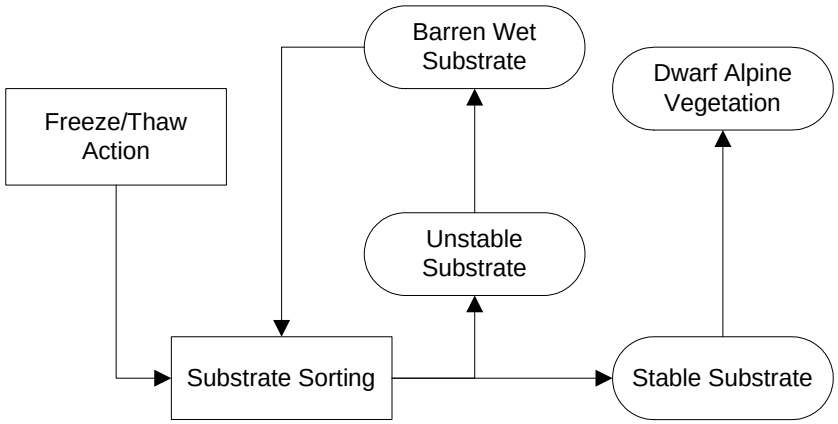


Alpine and Timberline Submodel (continued)-Duncan Patten

Timberline Woody Vegetation

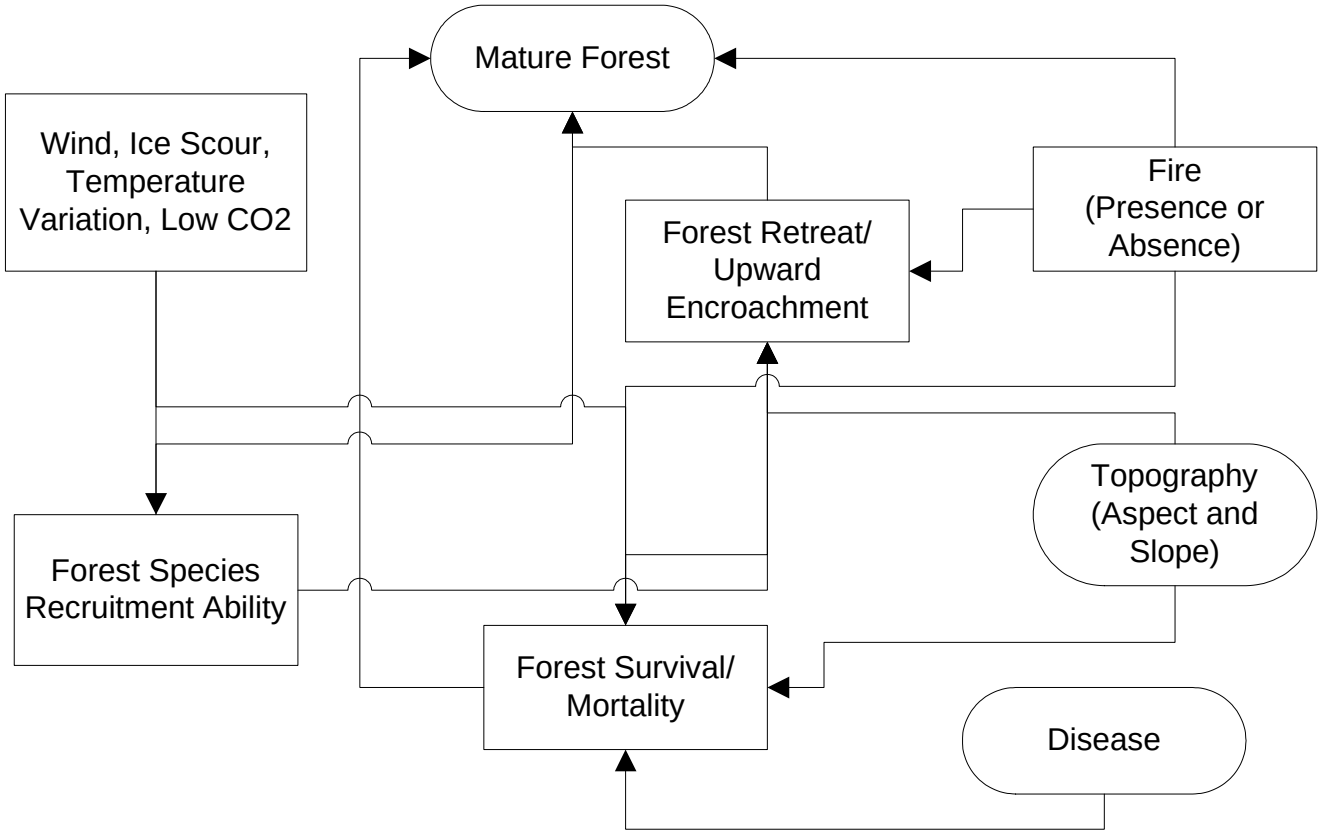


Soil Frost Dynamics

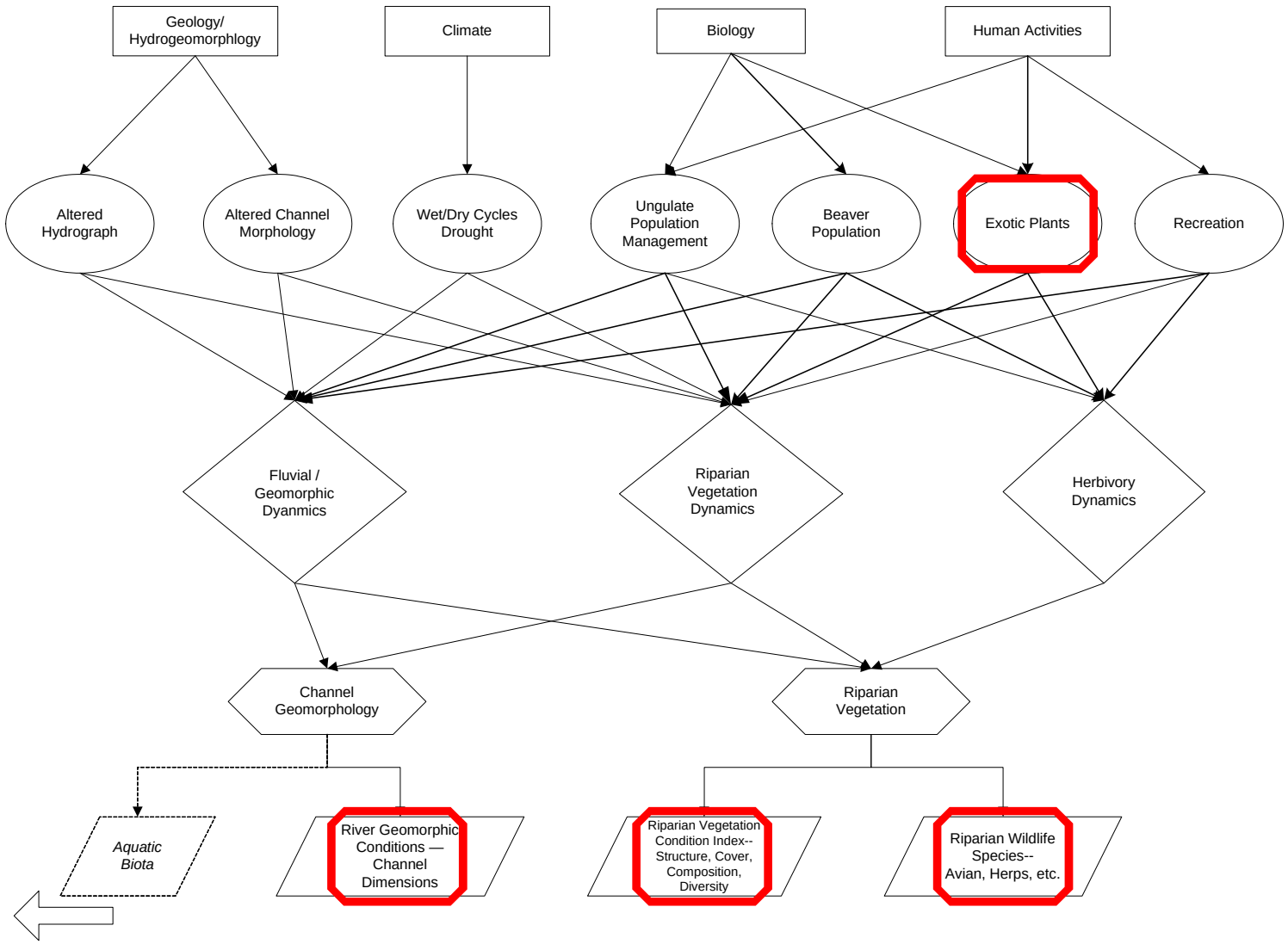


Alpine and Timberline Submodels (continued)-Duncan Patten

Timberline Elevation

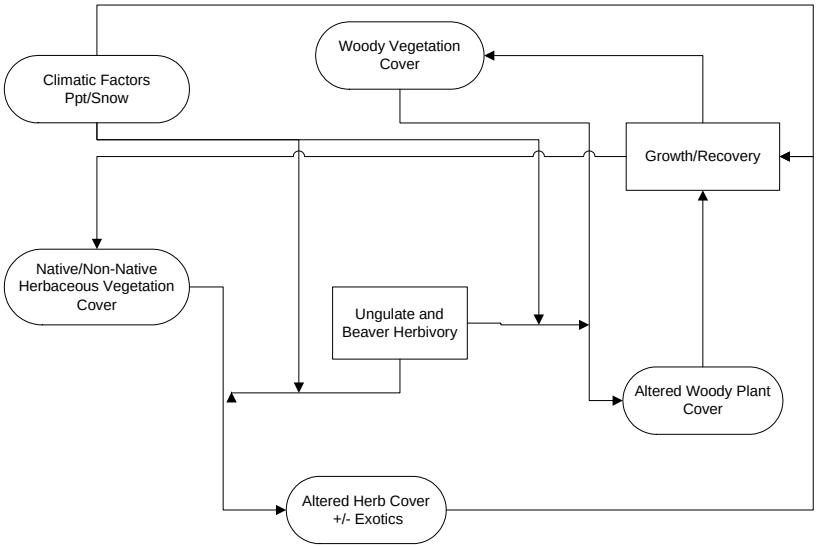


Riparian Model-Duncan Patten

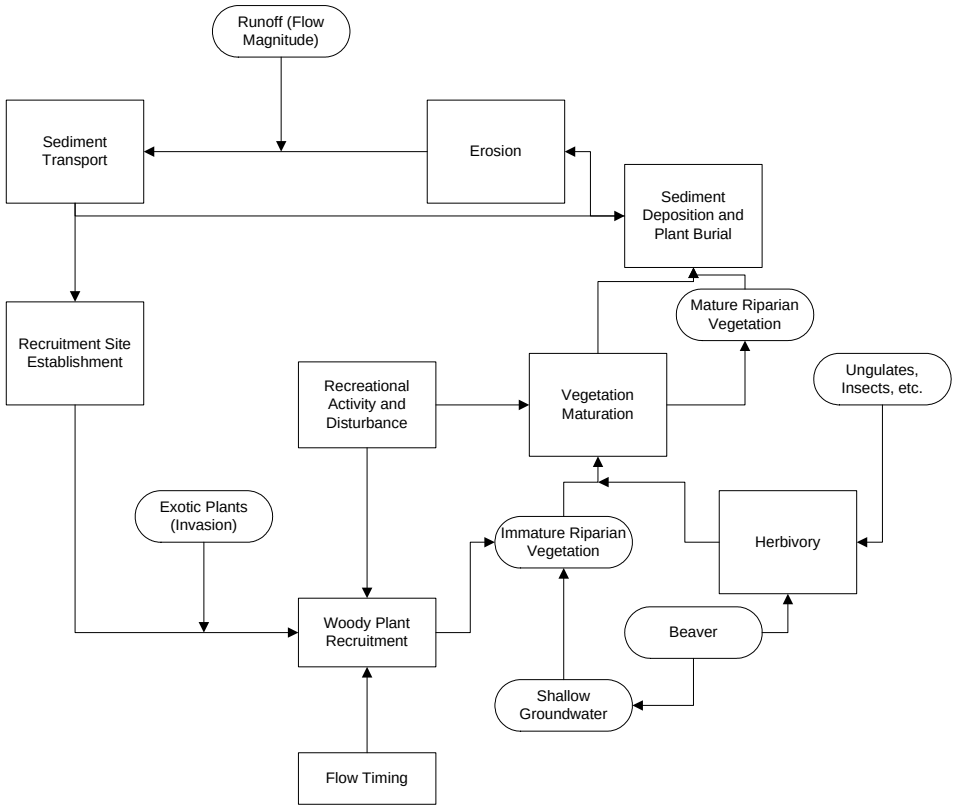


Riparian Submodels-Duncan Patten

Herbivory Dynamics

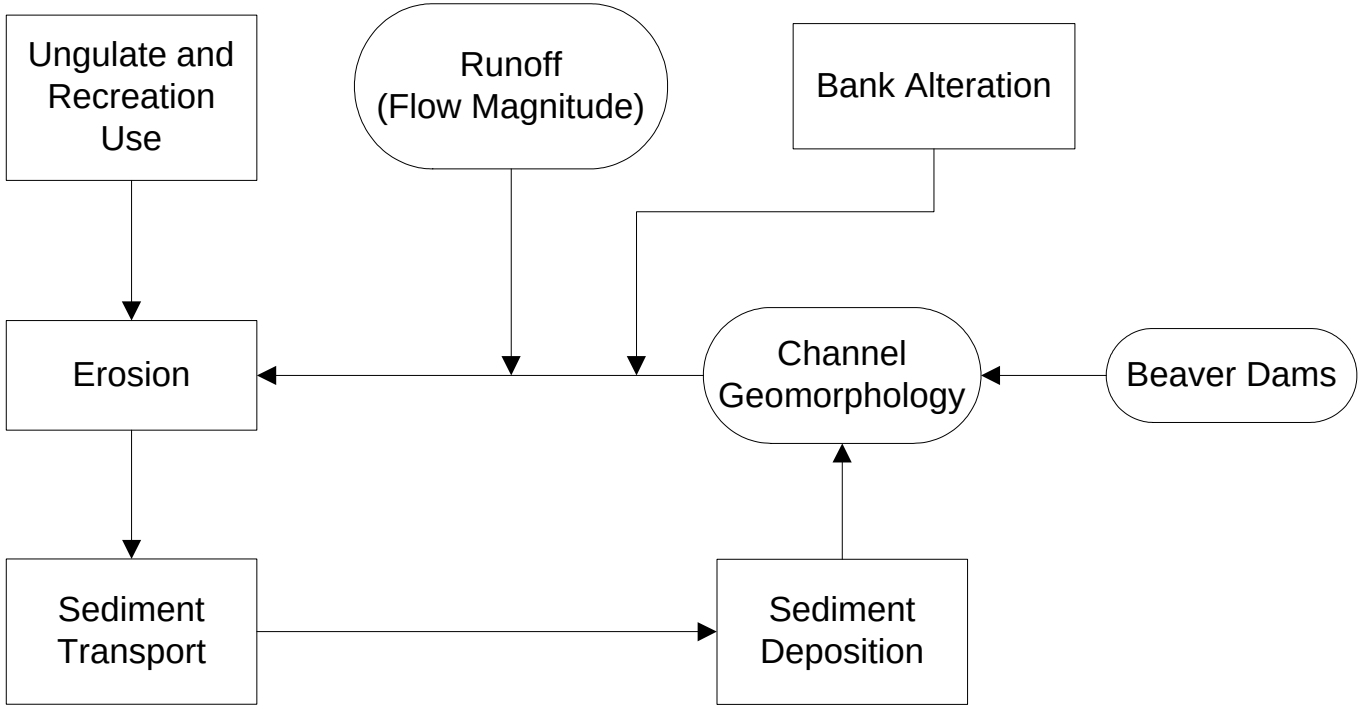


Riparian Vegetation Dynamics

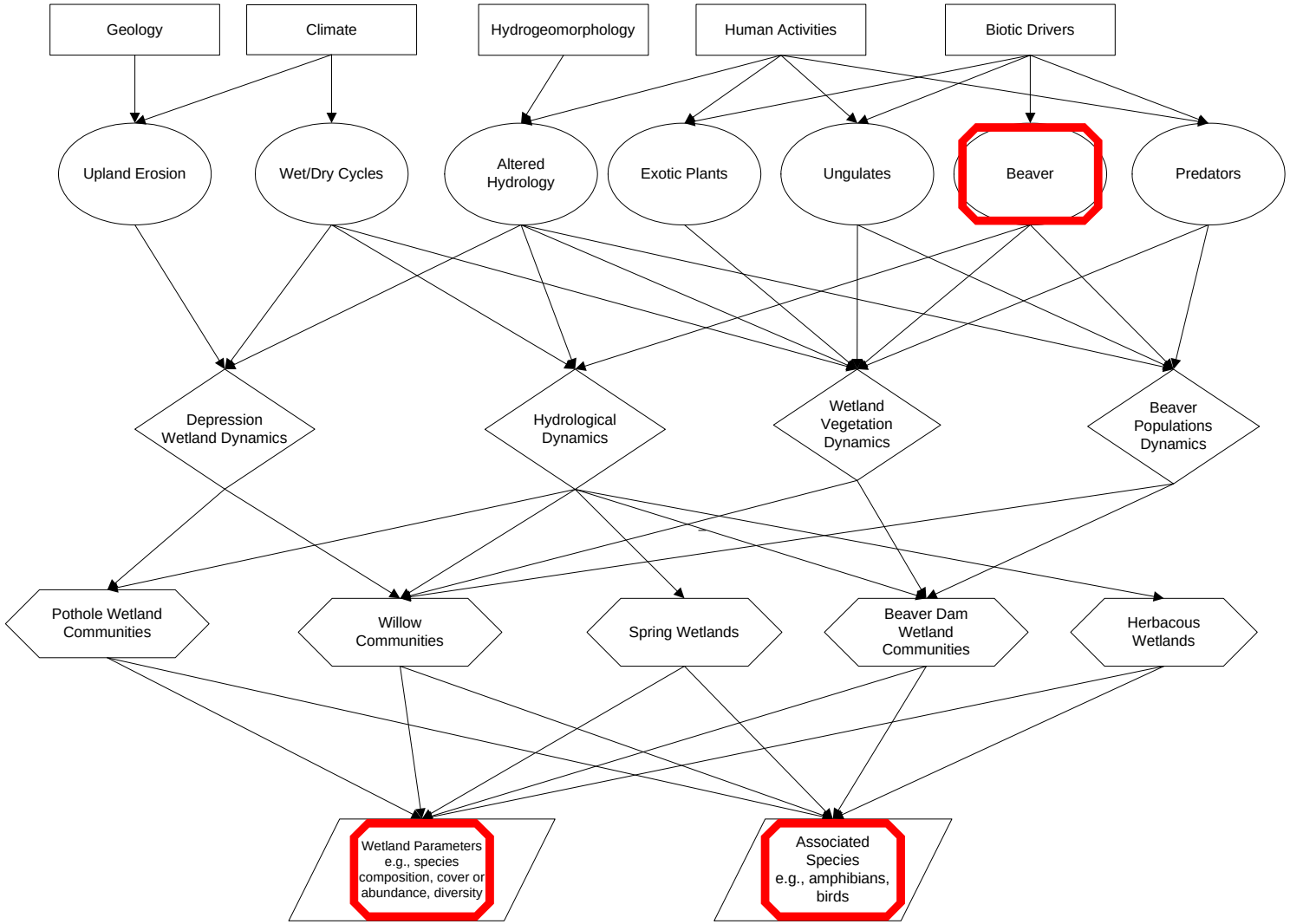


Riparian Submodels (continued)-Duncan Patten

Fluvial Geomorphology Dynamics

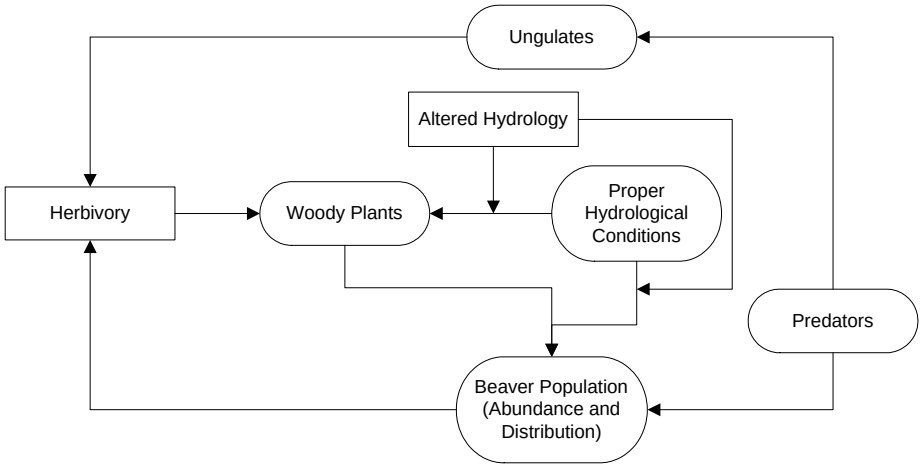


Wetland Model-Duncan Patten

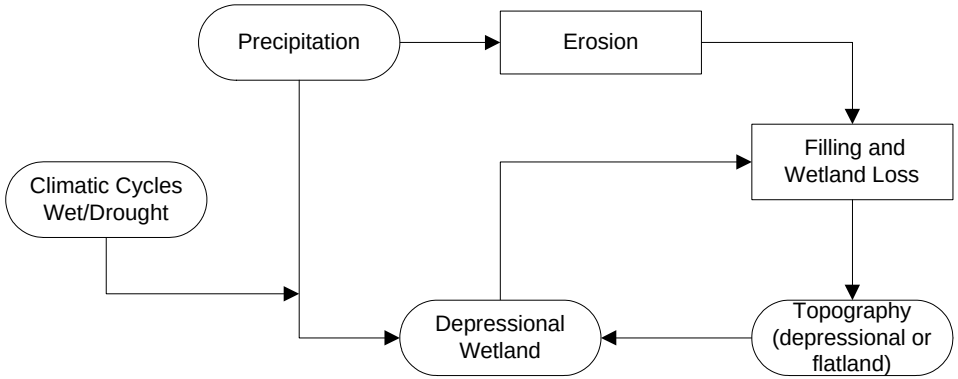


Wetland Submodels-Duncan Patten

Beaver Population Dynamics

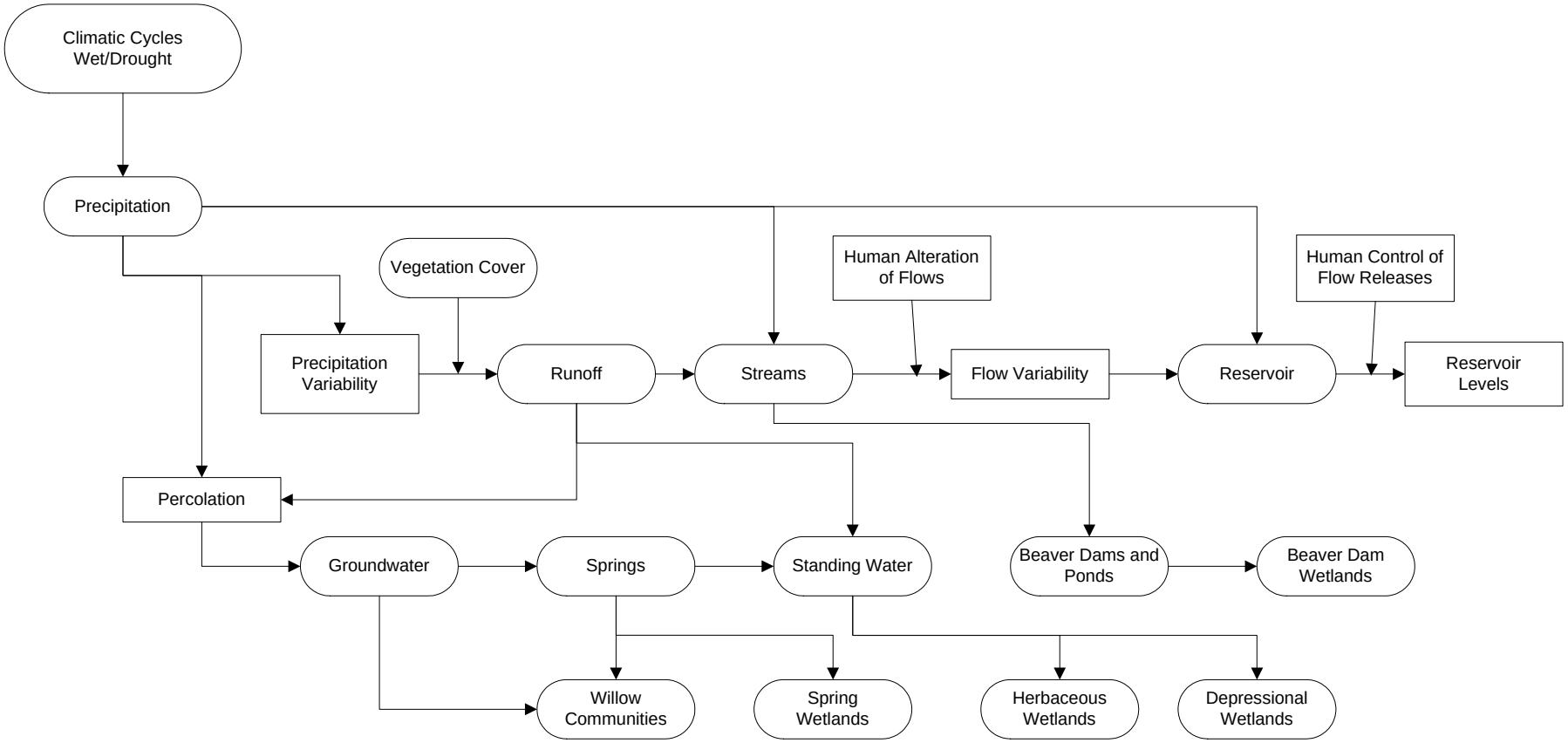


Depressional Wetland Dynamics



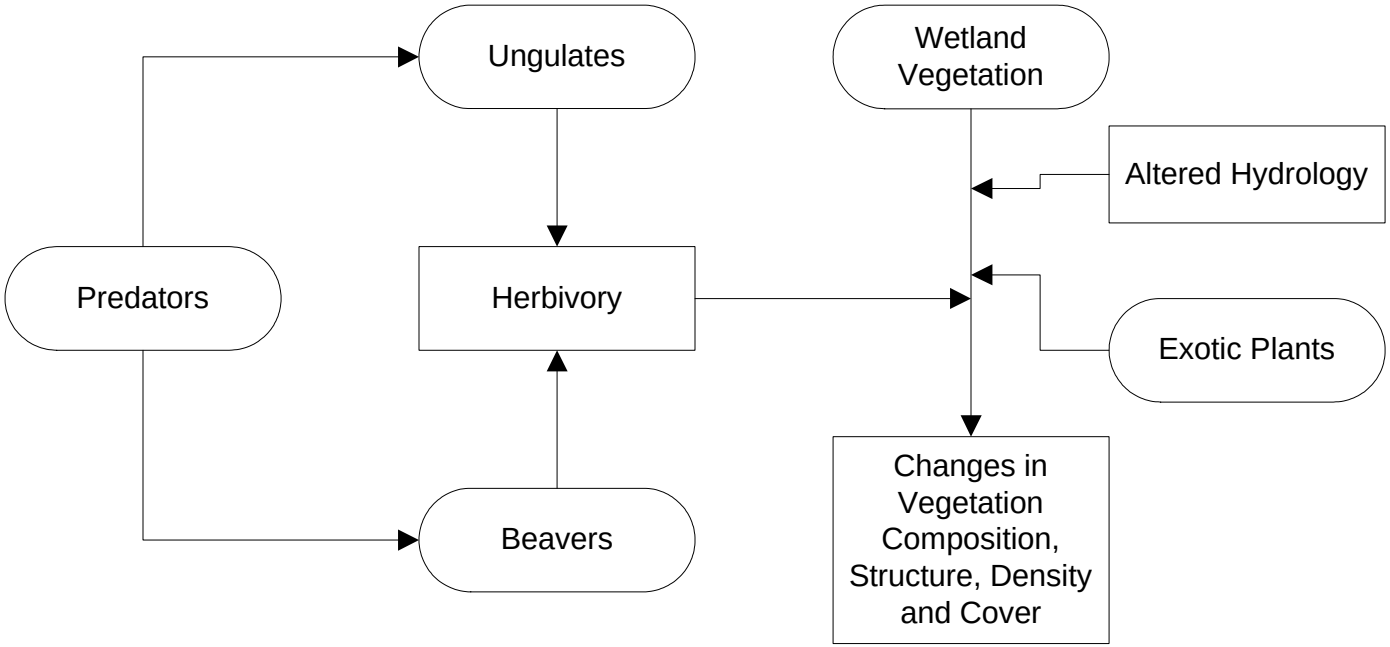
Wetland Submodels (continued)-Duncan Patten

Hydrology Dynamics

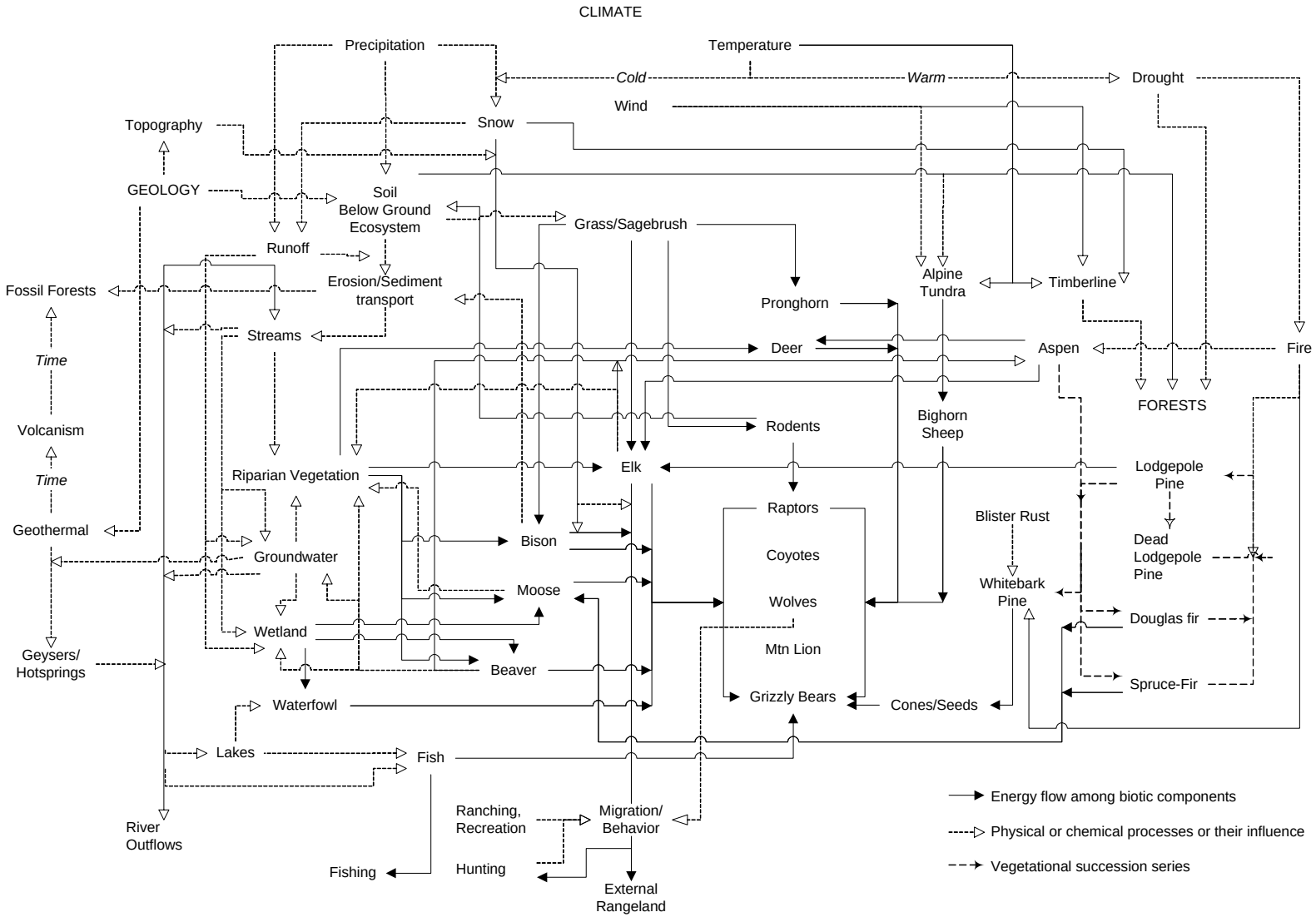


Wetland Submodels (continued)-Duncan Patten

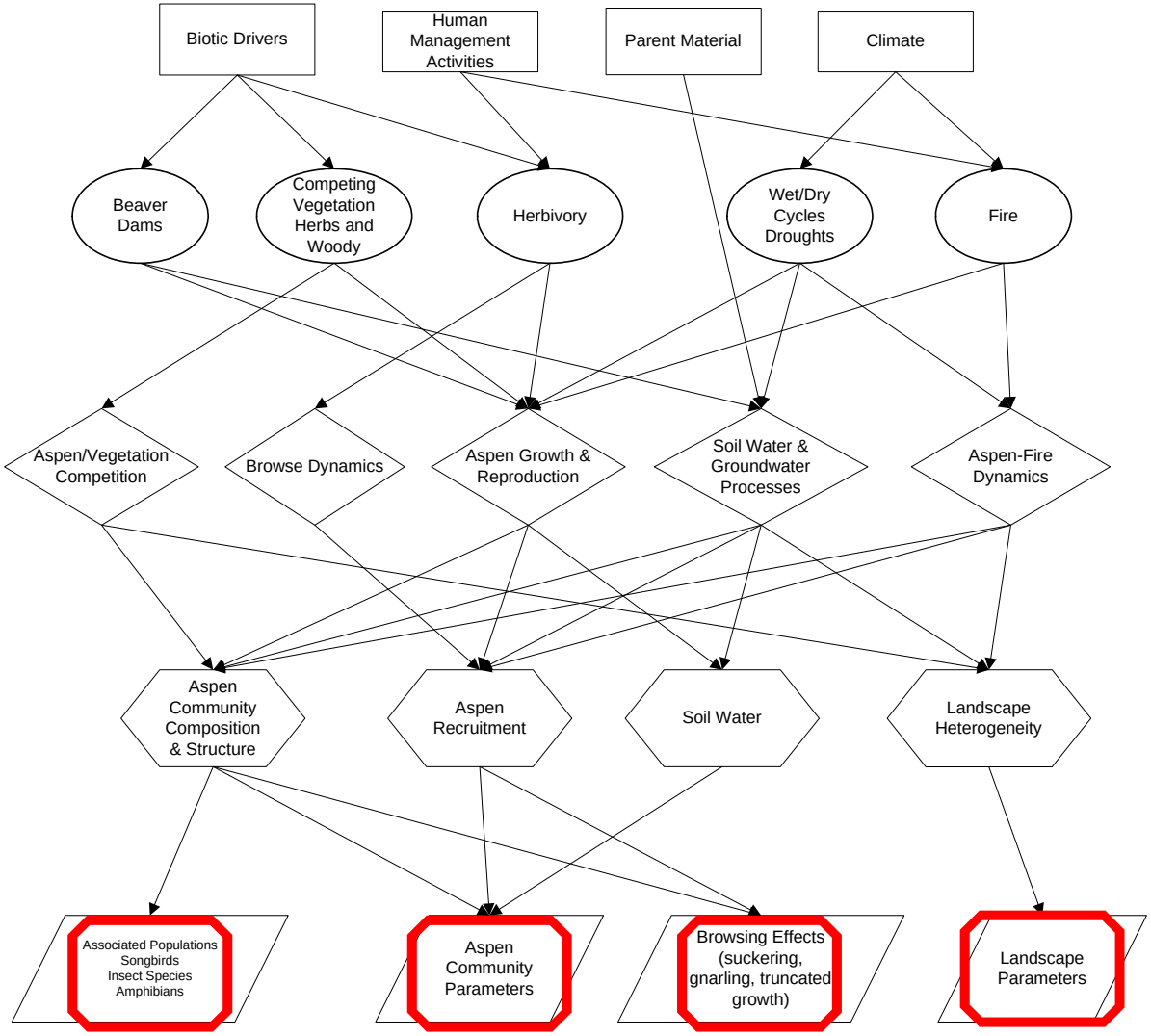
Wetland Vegetation Dynamics



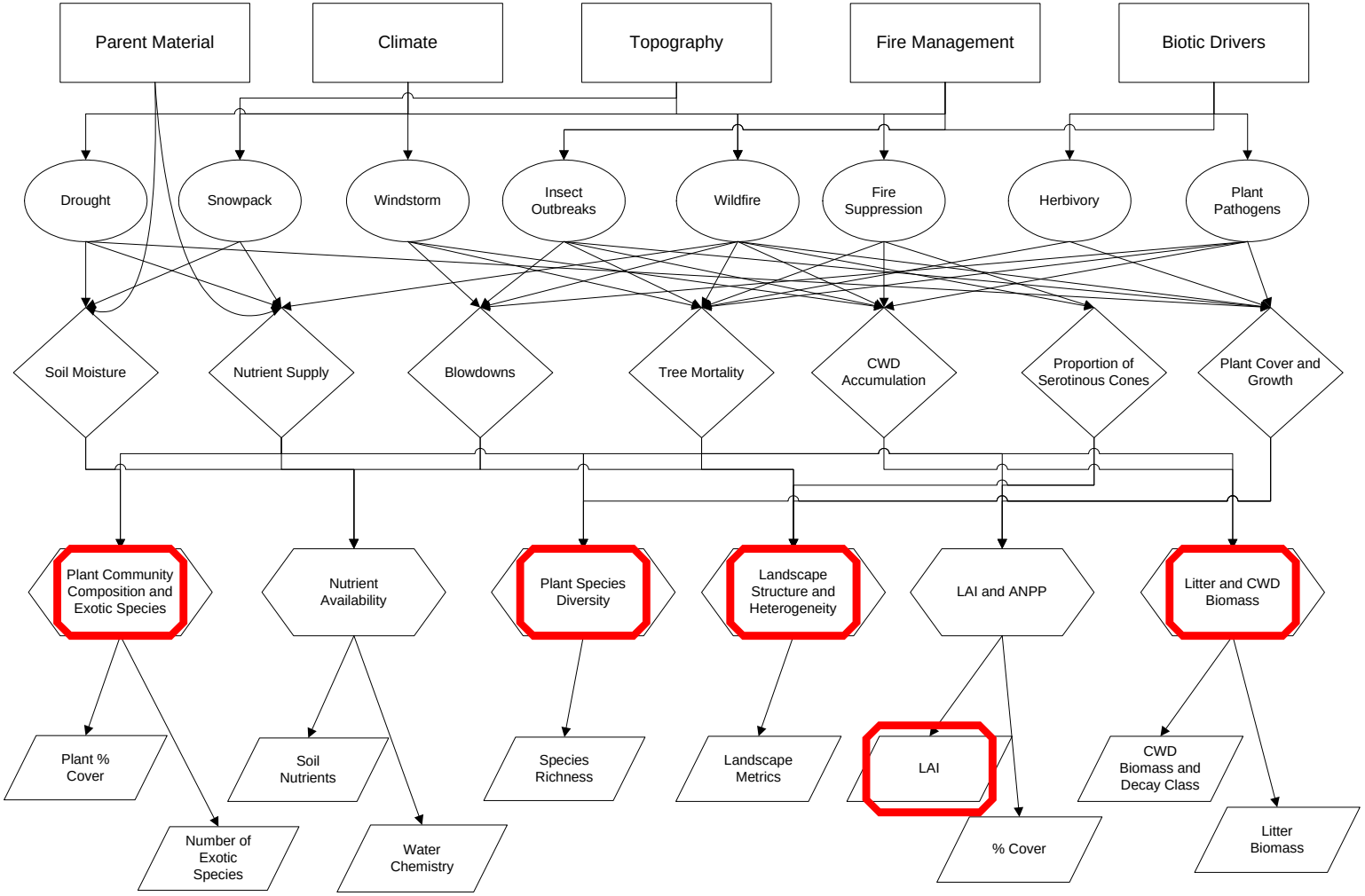
Yellowstone National Park Model-Duncan Patten



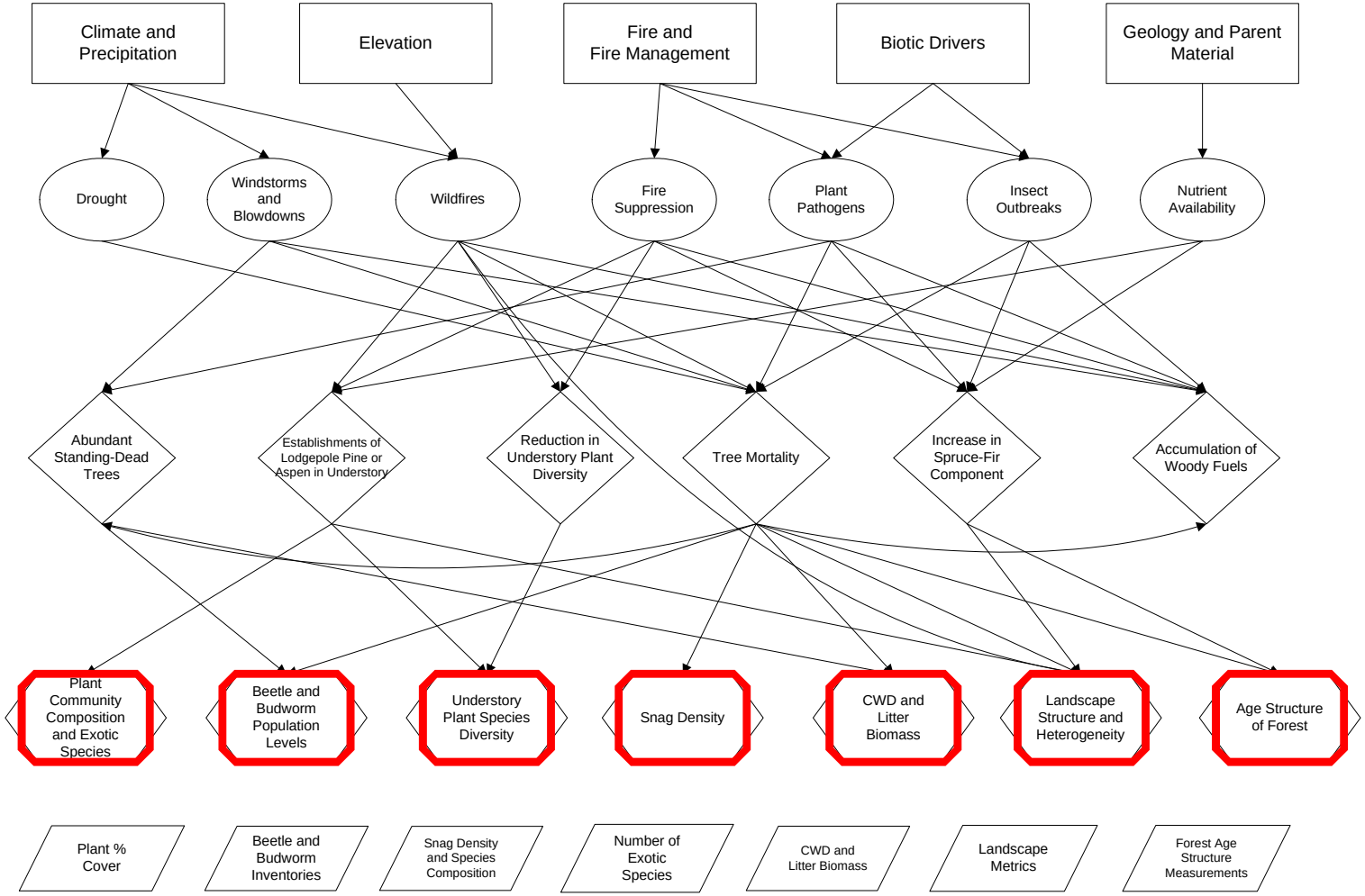
Aspen Model-Duncan Patten and Dan Tinker



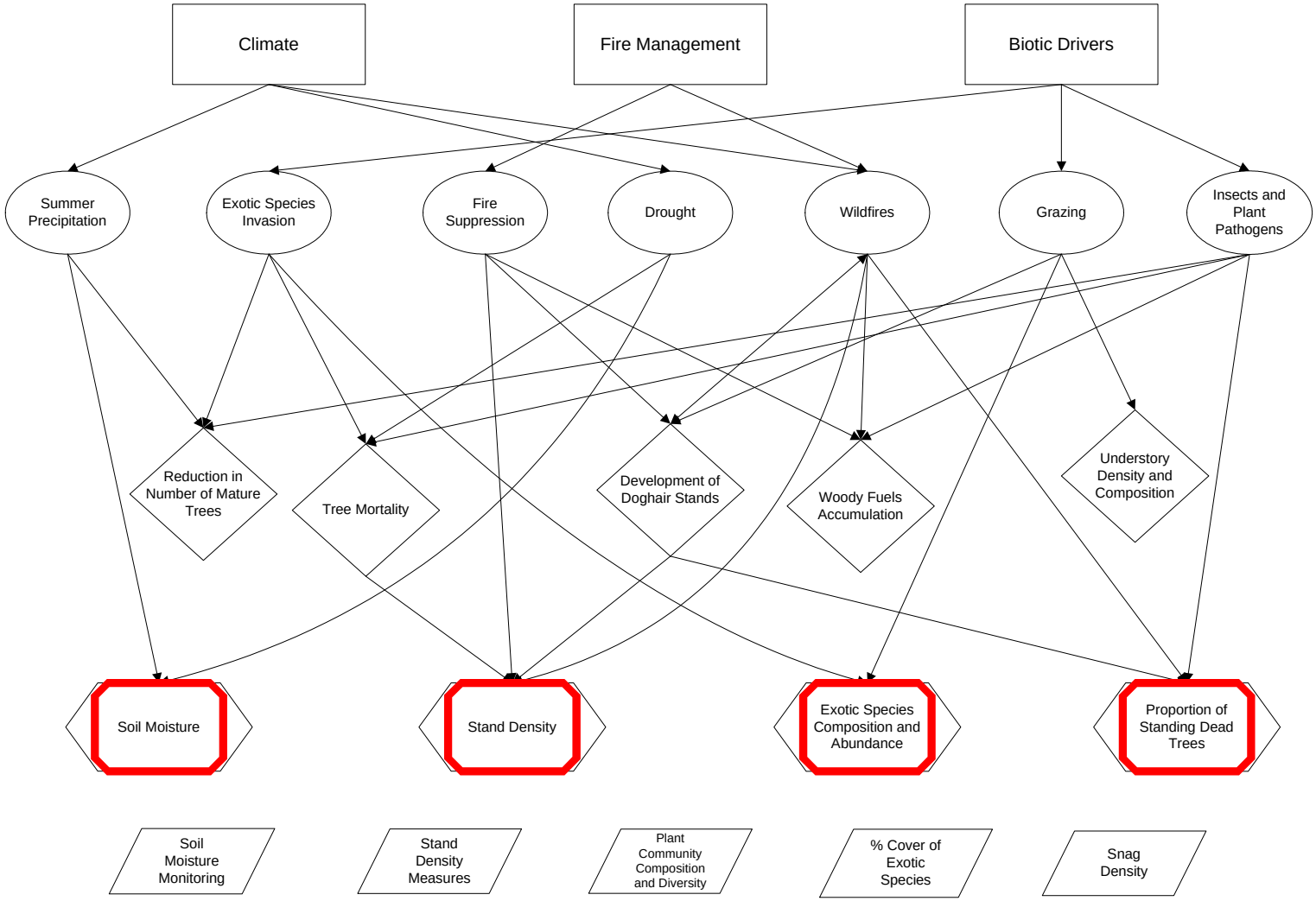
Lodgepole Pine Model-Dan Tinker



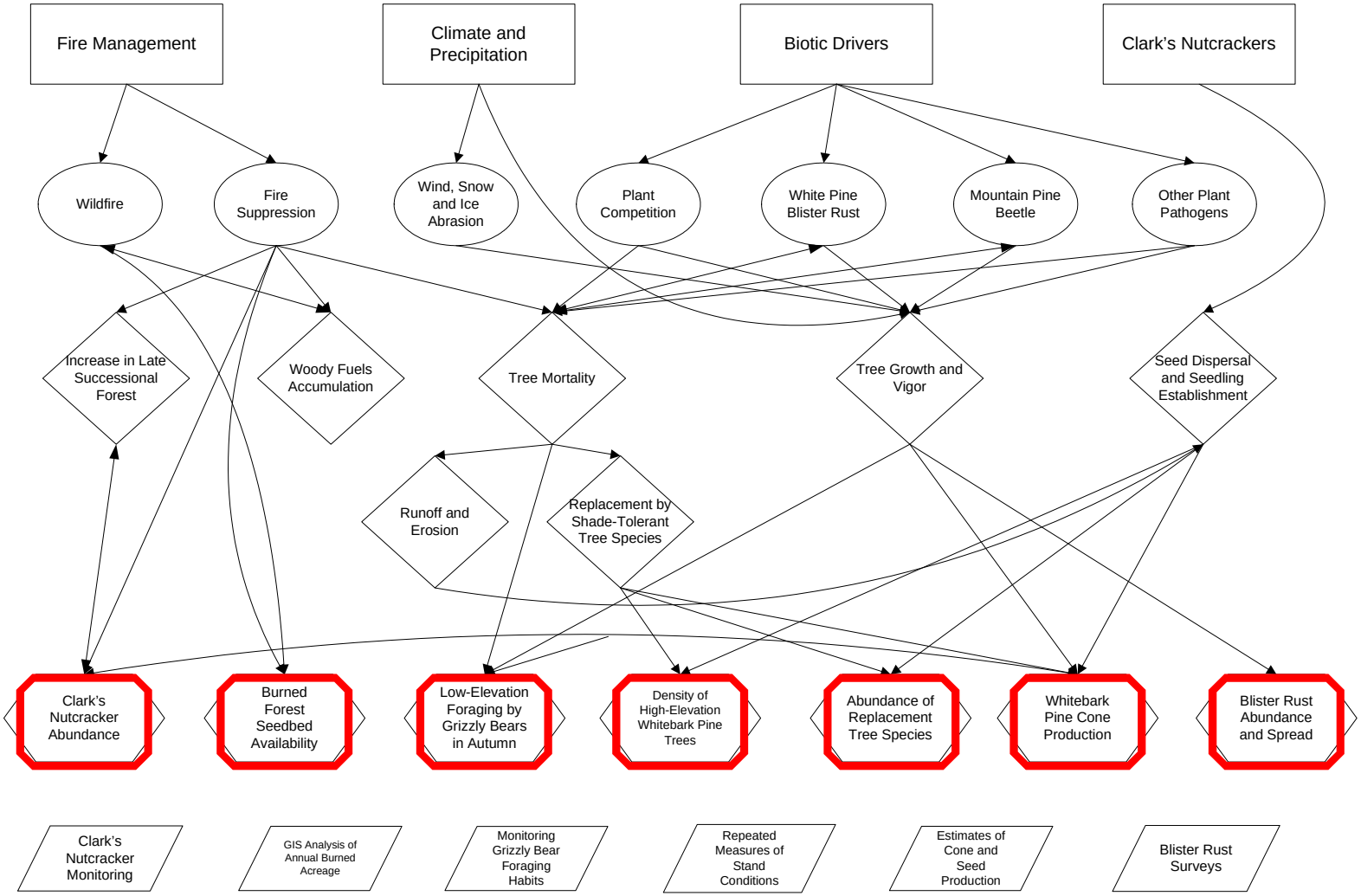
Mixed Conifer Model-Dan Tinker



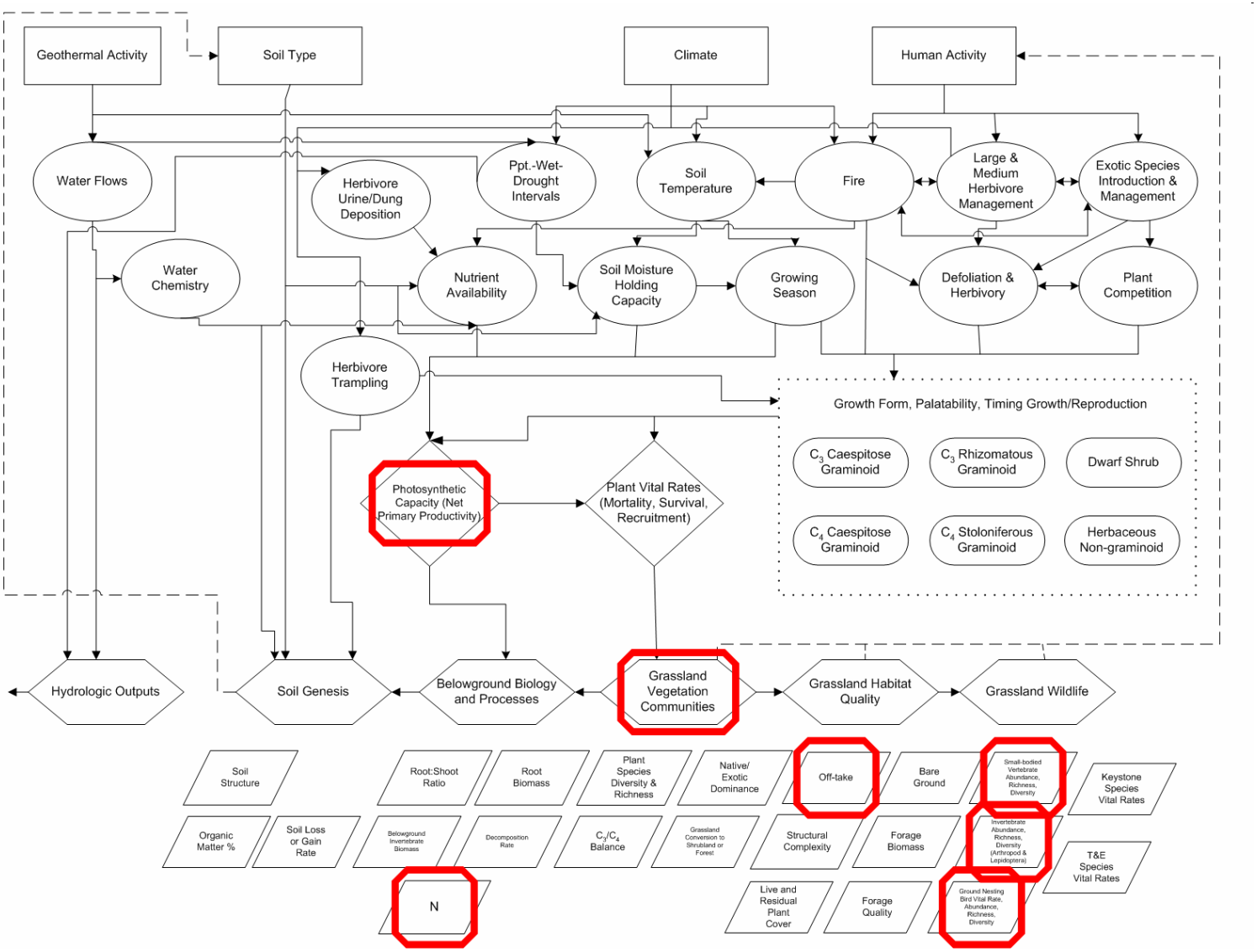
Ponderosa Pine Model-Dan Tinker



Whitebark Pine Model-Dan Tinker

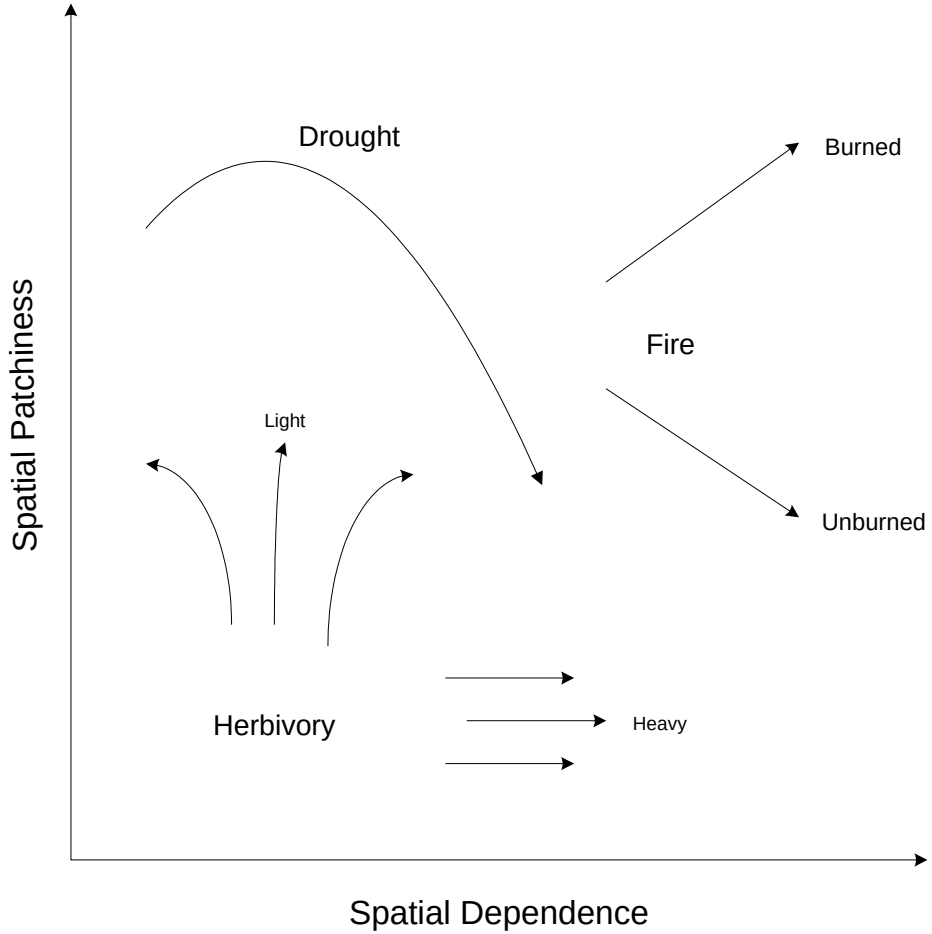


Grassland Model-Glenn Plumb



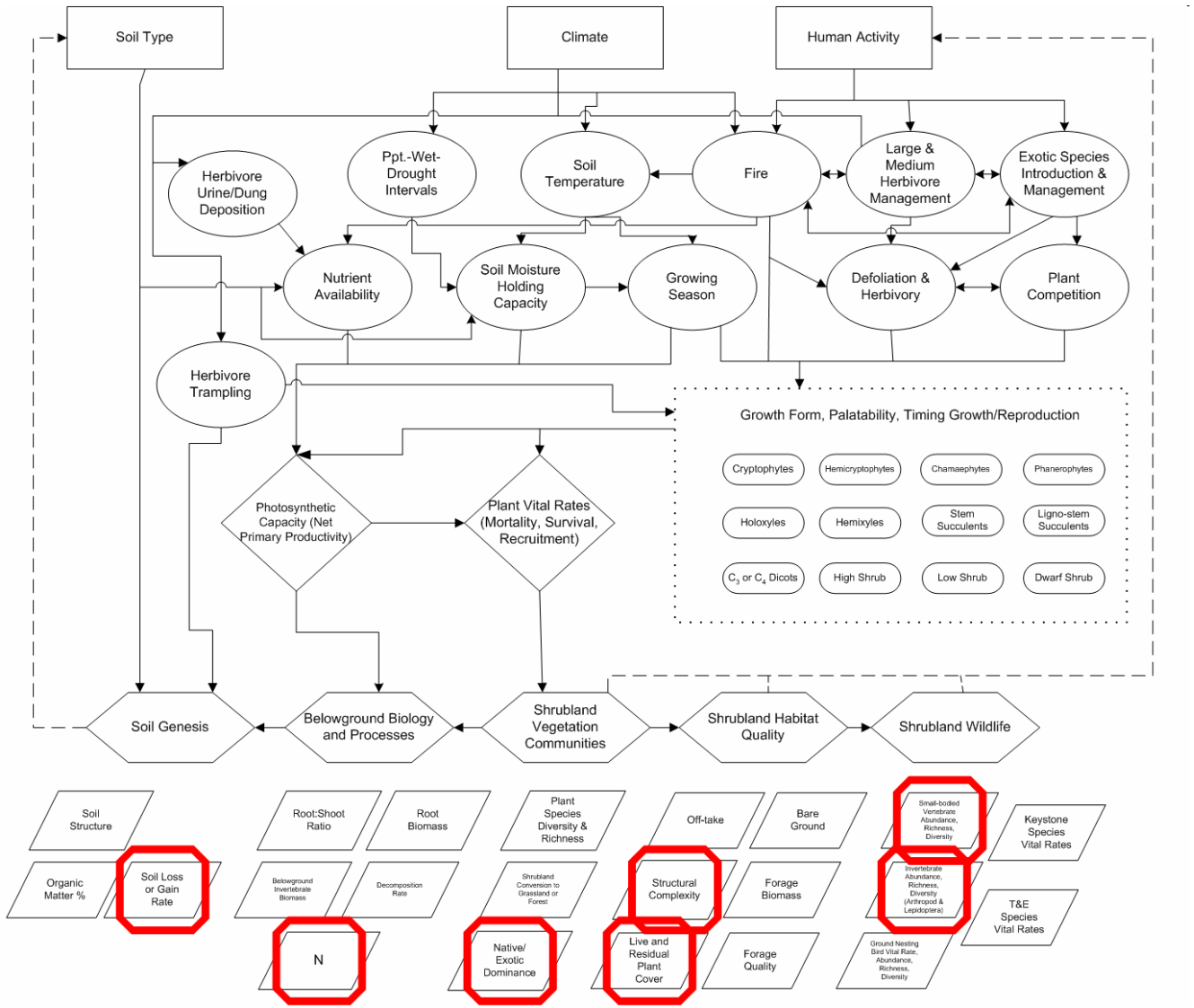
Grassland Submodel-Glenn Plumb

Net Primary Productivity

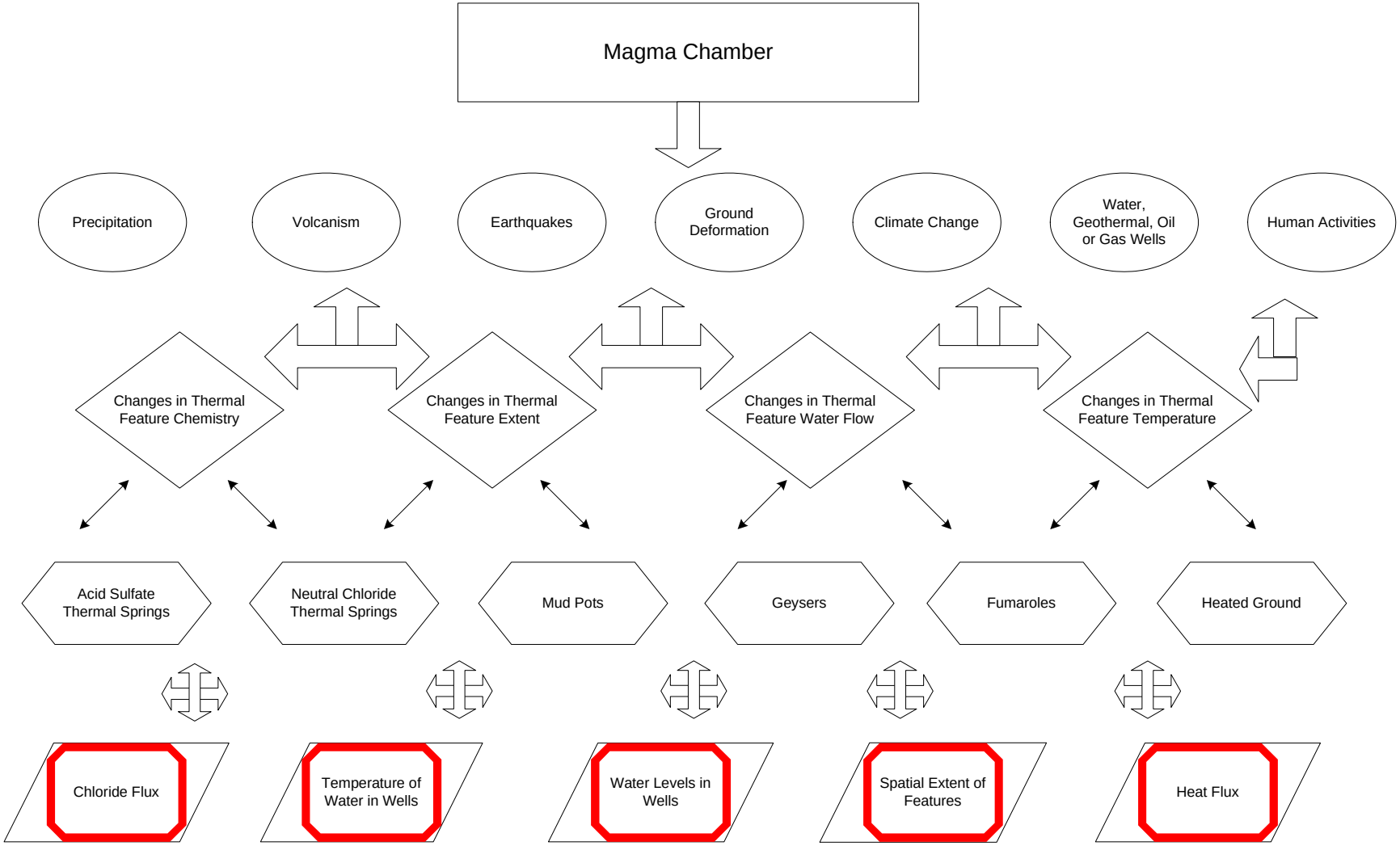


Adapted from *Briggs, et al. 1998. A landscape perspective of patterns and processes. In: Grassland dynamics. Eds. A.K. Knapp, J.M. Briggs, D.C. Hartnett, S.L. Collins. LTER Publications, Oxford University Press, New York.*

Shrubland Model-Glenn Plumb



Geothermal Model-Henry Heasler and Cheryl Jaworowski



APPENDIX E-BREAKOUT GROUP MEMBERS

**Please note: this list reflects those participants who were part of the decision-making process in the resource-area breakout groups.

Air Quality/Climate

Kathy Tonnessen-Moderator	Rocky Mountains-CESU
Ellen Porter	NPS-Air Resources Division
Leora Nanus	USGS
Phil Farnes	Snowcap Hydrology
Cathy Whitlock	University of Oregon

Aquatic/Water Quality

Bob Hall-Moderator	University of Wyoming
Alisa Mast	USGS
Myron Brooks	USGS
Jeff Arnold	Yellowstone National Park
Scott Woods	University of Montana
Sue O'Ney	Grand Teton National Park
Tina Laidlaw	EPA
Alexander Zale	Montana State University
Brian McGlynn	Montana State University

Geotherml/Geology

Duncan Patten-Moderator (morning)	Montana State University
Ann Rodman-Moderator (afternoon)	Yellowstone National Park
Hank Heasler	Yellowstone National Park
Bill Inskeep	Thermal Biology Institute
Kirk Nordstrom	USGS
Ken Pierce	USGS

Terrestrial Vegetation

Dan Tinker-Moderator	University of Wyoming
Duncan Patten-Moderator (afternoon)	
Steve Haynes	Grand Teton National Park
Mary Hektner	Yellowstone National Park
Don Despain	USGS
Jennifer Whipple	Yellowstone National Park
Lisa Rew	Montana State University
Bruce Maxwell	Montana State University
Mary Manning	U.S. Forest Service
Elizabeth Crowe	MT Natural Heritage Program
Roy Renkin	Yellowstone National Park

Terrestrial Vertebrates

Glenn Plumb-Moderator	Yellowstone National Park
Susan Patla	Wyoming Game and Fish

Bob Crabtree	Yellowstone Ecological Research Center
Peter Gogan	USGS
Scott Creel	Montana State University
Chuck Peterson	Idaho State University
Stephen Corn	USGS
Doug Keniath	WY Natural Diversity Database
Susan Wolff	Grand Teton National Park

Invertebrates

Steve Fancy-Moderator	National I&M Coordinator
Diane Debinski	Iowa State University
John Varley	Yellowstone National Park
Michael Ivie	Montana State University

Human Use

Tom Olliff-Moderator	Yellowstone National Park
Dan Burgette	Grand Teton National Park
Laura Gianakos	Bighorn Canyon NRA

APPENDIX F-COMPLETE LIST OF PROPOSED CANDIDATE VITAL SIGNS

**Please note: this list reflects the proposed candidate vital signs given to the participants at the *beginning* of day two. For the ranked list of candidate vital signs, please refer to Appendix I. The code to the right of the proposed candidate vital sign represents its unique ID for database purposes.

All Proposed Candidate Vital Signs

Grouped by Primary and Secondary Resource

Resource	Candidate Vital Sign	
Air Quality		
Air, Biotic and Abiotic		
	Atmospheric deposition and response in sensitive headwater catchments	AiQu_003
	Atmospheric deposition of nitrogen, sulfur and all major anions and cations	AiQu_006
	Atmospheric deposition of sulfur	AiQu_002
	Change in visibility deciviews	AiQu_005
	Deposition and accumulation of mercury in biota	AiQu_004
	Deposition of trace organics and metals	AiQu_010
	Loading chemical species in snowpacks	AiQu_001
	Loss of forest productivity	AiQu_007
	Nitrogen concentration in streams during spring snowmelt	AiQu_009
	Over-snow vehicles emissions and effects	AiQu_281
	Ozone exposure index--W126	AiQu_008
	Vegetation chemistry	AiQu_207
Aquatic Communities		
Aquatic Exotic species		
	Exotic fish abundance	AqCo_130
	Exotic fish distribution patterns	AqCo_131
Aquatic Pathogens/disease		
	Fish pathogens and disease	AqCo_133
Aquatic Species at risk		
	Cutthroat trout responses to exotic predators	AqCo_276
	Native and exotic community structure, composition, stability	AqCo_127
	Native fish genetic integrity	AqCo_126
	Native fish spawning population vital rates	AqCo_128
Aquatic Habitats		
Rivers and Streams		
	Channel dimensions	AqHa_123
	In-stream habitat complexity and cover	AqHa_125
	Stream reach geomorphology	AqHa_124
Climate		
Climate, Biotic and Abiotic		
	Alpine/subalpine climatic conditions and micro-environment	Clim_019
	Basic climatological measurements	Clim_020

Date of "spring green-up"	Clim_018
Date of ice on/off on major lakes	Clim_023
Date of lake overturn	Clim_026
Extent of frozen ground	Clim_024
Extreme Climatological Events	Clim_028
Extreme hydrologic events	Clim_014
Glaciers retreat or increase	Clim_021
Maximum air temperature	Clim_017
Number of cloudy days	Clim_031
Number of rain-on-snow events	Clim_030
Photosynthetically active radiation (PAR)	Clim_029
Plant phenology	Clim_013
Snow cover	Clim_016
Snow-water equivalence of snowpack	Clim_015
Soil climate	Clim_022
Soil temperature	Clim_027
Stream gauging	Clim_012
Surface UV	Clim_025
Total precipitation	Clim_011

Geology and Geothermal

Geothermal Ecosystem

Geothermal plant community composition and exotic species	GeGe_287

Geologic Processes

Earthquake activity	GeGe_051
Volcanic unrest	GeGe_055

Geothermal Microbiology

Contamination of thermal microbial populations	GeGe_056
Geothermal microbial diversity	GeGe_060

Geomorphic Processes

Landslide and debris flows	GeGe_057
Stream channel change	GeGe_290
Stream sediment transport	GeGe_282

Geothermal Processes

Chloride flux in thermal features	GeGe_068
Geothermal feature abundance & distribution	GeGe_054
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	GeGe_073
Geothermal water chemistry	GeGe_052
Geothermal water flow rate	GeGe_053
Geyser eruption volume and rate	GeGe_059
Heat flow	GeGe_069
Hydro-thermal soil chemistry	GeGe_062
Level and temperature of groundwater associated with thermal features	GeGe_071
Spatial extent of thermal features	GeGe_072
Temperature of ground water associated with thermal features	GeGe_070
Thermal heat transfer	GeGe_058

Soils

Below-ground biomass	GeGe_061

Cryptobiotic crust integrity	GeGe_066
Soil and sediment erosion	GeGe_067
Soil biodiversity	GeGe_065
Soil chemistry	GeGe_063
Soil moisture/temperature/structure	GeGe_293
Soil structure and stability	GeGe_064

Human Activities

Park Visitation

Levels of backcountry day use	HuAc_277
Levels of backcountry overnight use	HuAc_085
Park infrastructure	HuAc_089
Resource consumptive use and hydrologic modification	HuAc_090
Resource violations	HuAc_088
Visitor experience and satisfaction	HuAc_082
Visitor use levels	HuAc_087

Surrounding Environments

Land use and land cover	HuAc_081
Landscape and habitat fragmentation	HuAc_080
Night sky pollution	HuAc_083
Population census by area	HuAc_086
Soundscapes	HuAc_084

Invertebrates - Terrestrial and

Native and Exotic Insects

Critical habitat abundance, distribution and stability	TeIn_074
Exotic insects	TeIn_078
Forest/grassland/shrubland defoliators and consumers	TeIn_250
Insect biomass	TeIn_077
Insect herbivory	TeIn_076
Insect species distribution	TeIn_079
Native insect biodiversity and distribution	TeIn_075
Selected insect species of concern	TeIn_288

Terrestrial Vegetation

Alpine Meadow and Timberline Ecosystems

Alpine plant community characteristics	TeVeg_208
Timberline elevation boundaries	TeVeg_210
Timberline forest density and health	TeVeg_209

Aspen Forest Ecosystems

Aspen community composition and structure	TeVeg_263
Aspen stand extent and distribution in landscape	TeVeg_266
Browsing effects within aspen stands	TeVeg_265

Dry Woodland Ecosystems

Dry woodland community structure and composition	TeVeg_268
Extent and distribution of woodlands	TeVeg_269

Herbaceous Meadow and Grassland

Grassland annual net primary productivity	TeVeg_226
Grassland insect and vertebrate community structure	TeVeg_229
Grassland nitrogen	TeVeg_228
Grassland vegetation annual offtake	TeVeg_227

Grassland vegetation community composition and structure	TeVeg_218
Lodgepole Pine Forest Ecosystem	
Lodgepole pine forest floor litter and coarse woody debris	TeVeg_239
Lodgepole pine plant community composition and exotic species	TeVeg_237
Lodgepole pine snag density	TeVeg_297
Plant species diversity	TeVeg_238
Mixed Conifer Forest Ecosystems	
Age structure of forest	TeVeg_255
Landscape structure and heterogeneity	TeVeg_254
Mixed conifer forest floor litter and coarse woody debris	TeVeg_253
Mixed conifer plant community composition and exotic species	TeVeg_249
Mixed conifer snag density	TeVeg_252
Understory plant species diversity	TeVeg_251
Montane Shrubland Ecosystems	
Shrubland community composition and structure	TeVeg_223
Shrubland exotic species	TeVeg_274
Shrubland growth form diversity	TeVeg_270
Shrubland insect and small vertebrate community structure	TeVeg_271
Shrubland nitrogen	TeVeg_272
Shrubland soil erosion	TeVeg_273
Ponderosa Pine Ecosystems	
Ponderosa pine plant community composition and exotic species	TeVeg_258
Ponderosa pine stand density of live and dead trees	TeVeg_257
Proportion of standing dead trees	TeVeg_259
Soil moisture	TeVeg_256
Riparian and Riverine Wetland Ecosystems	
Browse effects on riparian woody vegetation	TeVeg_225
Exotic plants in riparian zone	TeVeg_211
Riparian condition	TeVeg_212
Riparian vegetation community structure and composition	TeVeg_219
Terrestrial Ecosystems	
Aboveground net primary productivity	TeVeg_241
Area occupied by rare or declining plant community types	TeVeg_236
Bighorn basin plant community composition and exotic species	TeVeg_231
Distribution and trends of exotic plant diseases	TeVeg_233
Exotic terrestrial plant species diversity and/or richness	TeVeg_214
Fire and fuel loading	TeVeg_222
Landscape structure and heterogeneity	TeVeg_240
Lichen distribution, abundance and chemical composition	TeVeg_235
Native terrestrial plant species diversity and/or richness	TeVeg_215
Shrub-steppe community structure and composition	TeVeg_217
Taxonomy and distribution of aquatic vegetation	TeVeg_224
Wet Meadow, Spring, and Depressional	
Wetland extent	TeVeg_291
Wetland plant cover and composition	TeVeg_213
Whitebark Pine Woodland and Forest	
Abundance of replacement tree species	TeVeg_246
Blister rust abundance and spread	TeVeg_248

Burned forest seedbed availability	TeVeg_243
Stand density of high-elevation live and dead whitebark pine trees	TeVeg_245
Whitebark pine cone production	TeVeg_247
Whitebark pine plant community composition and exotic species	TeVeg_286
Whitebark pine snag density	TeVeg_292

Terrestrial Vertebrates

Amphibian and Reptiles

Amphibian and reptile critical food abundance, distribution and stability	TeVer_033
Amphibian habitat quality, abundance, distribution and population vital rates	TeVer_032

Birds

Clark's Nutcracker abundance	TeVer_242
Colony nesting bird population abundance, distribution, vital rates and productivity	TeVer_037
Neotropical bird population abundance, distribution and vital rates	TeVer_035
Raptor population abundance, distribution and productivity	TeVer_038
Riparian wildlife species	TeVer_260
Selected sensitive bird species abundance, distribution and productivity	TeVer_034
Song bird population abundance and distribution	TeVer_036

Mammals

Bat occurrence, distribution and abundance	TeVer_045
Beaver presence and population estimates	TeVer_261
Bighorn sheep vital rates	TeVer_267
Human-carnivore interactions	TeVer_044
Large carnivore population abundance and distribution	TeVer_039
Low-elevation foraging by grizzly bears in autumn	TeVer_244
Meso-carnivore population abundance and distribution	TeVer_285
Native ungulate behavior and migration dynamics	TeVer_042
Predator-prey dynamics	TeVer_041
Rodents and insectivores (<250g) population, abundance and distribution	TeVer_283
Rodents and Lagomorphs (>250g) population, abundance and distribution	TeVer_284
Small-mammal population abundance, distribution and vital rates	TeVer_043
Ungulate population abundance, distribution and productivity	TeVer_040

Terrestrial Vertebrates

Amphibian occurrence	TeVer_279
Associated animal populations	TeVer_264
Emerging pathogens on vertebrate species	TeVer_050
Invasive vertebrate species richness and distribution	TeVer_048
Native species richness	TeVer_047
Pattern of non-park land-use changes	TeVer_289
Reptile occurrence	TeVer_278
Vertebrate diseases	TeVer_049
Wetland associated wildlife species	TeVer_262
Wildlife habitat loss and degradation	TeVer_046

Water Quality

Ground Water

Ground water chemistry	WaQu_299
Ground water hydrology	WaQu_300
Groundwater level and aquifer volume	WaQu_195

Lakes and Reservoirs

Algal species composition and biomass	WaQu_275
Alkalinity	WaQu_105
Bed sediment chemistry (adsorbed)	WaQu_119
Chlorophyll a	WaQu_101
Continuous water temperature	WaQu_295
Core parameters	WaQu_094
Dissolved organic carbon	WaQu_106
E. coli	WaQu_097
Major ion chemistry	WaQu_091
Metals	WaQu_098
Phosphorus concentrations in aquatic ecosystems	WaQu_093
Phytoplankton community structure	WaQu_103
Reservoir elevation	WaQu_121
Secchi transparency	WaQu_099
Zooplankton community structure	WaQu_104

Rivers and Streams

Alkalinity	WaQu_118
Bed sediment chemistry (adsorbed)	WaQu_298
Chlorophyll a	WaQu_116
Continuous water temperature	WaQu_096
Core parameters	WaQu_112
E. coli	WaQu_113
Major ion chemistry	WaQu_107
Metals	WaQu_114
Nitrogen concentrations in aquatic ecosystems	WaQu_110
Periphyton community structure, chlorophyll a	WaQu_117
Phosphorus concentrations in aquatic ecosystems	WaQu_111
River invertebrate assemblages	WaQu_109
Streamflow	WaQu_120
Total suspended solids	WaQu_115

Watershed

Watersheds

Watershed budgets	Wate_301

APPENDIX G-SELECTION CRITERIA EXPLANATIONS AND APPENDICES

ECOLOGICAL RELEVANCE

Criterion #1 - *The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature.*

Often, the selection of a relevant indicator is obvious from the assessment question and from professional judgement. However, a conceptual model can be helpful to demonstrate and ensure an indicator's ecological relevance, particularly if the indicator measurement is a surrogate for measurement of the valued resource. It must be demonstrated that the proposed indicator is conceptually linked to the ecological function of concern. A straightforward link may require only a brief explanation. If the link is indirect or if the indicator itself is particularly complex, ecological relevance should be clarified with a description, or conceptual model. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.)*

Criterion #2 - *The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization.*

The term "multiple scales of ecological organization" refers to the hierarchical ecological structure including individuals, populations, communities, landscapes and ecosystems. Accordingly, information from one scale can sometimes provide insight relevant to other scales, thus increasing the applicability of the candidate vital sign if the information gathered from monitoring it can be useful at multiple scales of ecological organization. *(*Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

RESPONSE VARIABILITY

Criterion #3 - The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power.

Predictable manner refers to the lack of ambiguity in the response of the candidate vital sign to ecosystem stressors. The response should be clear and predictable even given gradual change in the stressor. In a best-case scenario, the candidate vital sign's response is observable before the system is actually threatened. *(Adapted from Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)* **Statistical power** refers to the ability of a candidate vital sign to have a low chance of Type I and II errors. If a change has occurred in an ecosystem, a vital sign will either detect the change or detect no change. If the vital sign detects a change when a real change has occurred, then no error has occurred. However, if the vital sign detects a change when no real change has occurred, then a false-positive,

or Type I, error has been made. Making a false positive error is costly, monetarily speaking, because usually unnecessary action ensues. If change has occurred and the vital sign does not detect this change, then a missed-change, or Type II, error has occurred. Therefore, although action should be taken, most likely the change will go unnoticed. *(*Adapted from *Booth, G.D. Monitoring data and the risks of management decisions. USDA Forest Service publication.)*

	No change has taken place	**There has been a real change**
Vital sign detects change	False-positive Error (Type I)	No Error
Vital sign detects no change	No Error	Missed-change Error (Type II)

Criterion #4 - *The candidate vital sign is anticipatory and sensitive enough to stressors to provide an early warning of change.*

In this case, **sensitivity** does not necessarily refer to a candidate vital sign that is responsive to any and all dramatic changes in the system; but, rather, those that react to subtle stressors in the system, giving early warning of potentially reduced system integrity. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.*)

Criterion #5 - *The candidate vital sign has low natural variability and has high signal-to-noise ratio.*

Signal-to-noise ratio refers to the measure of how the signal from the candidate vital sign compares with background noise. Noise is defined as the uncommon variance of the data. The strength of the signal is positively correlated with the quality of the candidate vital sign as an indicator of ecosystem health. Therefore, the higher the signal-to-noise ratio, the better the candidate vital sign is at predicting ecosystem changes. If the signal and noise are of equal strength, the signal borders on unreadable because the noise strongly competes with it. (Adapted from *Cook, E.R. and L.A. Kairiukstis. Methods of dendrochronology: applications in the environmental sciences. 1990. Dordrecht, The Netherlands.*)

MANAGEMENT RELEVANCE

Criterion #6 - The candidate vital sign is stated in specific park management goals, GPRA goals or Business Plan Standards.

Park Management Goals - The overall natural resource management goal of the National Park Service is as follows: *The National Park Service will preserve the natural resources, processes, systems and values of units of the national park system in an unimpaired condition, to perpetuate their inherent integrity and to provide present and future generations with the opportunity to enjoy them.* (Adapted from *Management Policies 2001. National Park Service publication.*)

The key management-related provision stated in the National Park Service Organic Act of 1916 is: *[The National Park Service] shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified...by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.* (Adapted from *Management Policies 2001. National Park Service publication.*) **Please refer to specific park management goals for Grand Teton and Bighorn Canyon in Appendix A.

GPRA Goals - The **Government Performance and Results Act (GPRA) goals** can be divided into four focal areas: 1) preserve park resources, 2) provide for the public enjoyment and visitor experience of parks, 3) strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners and 4) ensure organizational effectiveness. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific GPRA goals in the appendix.

Business Plan Standards - *According to Yellowstone National Park's Business Plan (Fiscal Year 2002), resource protection encompasses all activities related to the management, preservation and protection of the park's cultural and natural resources. Activities include research, restoration efforts, species-specific management programs, wildland fire management, archives and collections management, and historic site protection and information integration activities. (Adapted from* Yellowstone National Park Business Plan Fiscal Year 2002.*) **Please refer to specific business plan standards for Yellowstone National Park in Appendix A.*

Criterion #7 - There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions, or for evaluating past management decisions.

Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions. Policy makers and resource managers must be able to recognize the implications of indicator results for stewardship, regulation, or research. An indicator with practical application should display one or more of the following characteristics: responsiveness to a specific stressor, linkage to policy indicators, utility in cost-benefit assessments, limitations and boundaries of application, and public understanding and acceptance. Detailed consideration of an indicator's management utility may lead to a re-examination of its conceptual relevance and to a refinement of the original assessment question. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.) **Please refer to the Threats and Management Issues table in Appendix A.*

FEASIBILITY OF IMPLEMENTATION

Criterion #8 - The candidate vital sign's cost of measurement is not prohibitive.

Cost is often the limiting factor in considering to implement an indicator. Estimates of all implementation costs should be evaluated. Cost evaluation should incorporate economy of scale, since cost per indicator or cost per sample may be considerably reduced when data are collected for multiple indicators at a given site. Costs of a pilot study or any other indicator development needs should be included if appropriate. The vital sign not only has to be relevant to monitoring but implementation also has to be feasible, practical and affordable. Sampling methods may include simple, low-tech or low-cost data collection methods, or more complex or expensive collection methods may be cost-effective, e.g. data collection every five years results in low annual costs. Consideration should be given to data collection methods, logistical requirements, data processing and information management, data quality, and costs in terms of time, money and personnel *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp.*).

Criterion #9 - *Impacts of the candidate vital sign's measurement meet NPS standards.*

Sampling activities for indicator measurements should not significantly disturb a site. Evidence should be provided to ensure that measurements made during a single visit do not affect the same measurement at subsequent visits or, in the case of integrated sampling regimes, simultaneous measurements at the site. Also, sampling should not create an adverse impact on protected species, species of special concern, or protected habitats. Any impact due to data collection of a specific park resource on that resource or

on the surrounding environment can be considered impairment of a National Park Service natural resource or value if it impacts a resource or value whose conservation is:

- Necessary to fulfill specific purposes identified in the enabling legislation or proclamation of the park
- Key to the natural or cultural integrity of the park or to opportunities for enjoyment of the park
- Identified as a goal in the park's general management plan or other relevant NPS planning documents.

However, an impact is less likely to be considered impairment if it is the unavoidable result of an action necessary to restore or conserve the integrity of a park natural resource or value. All proposals for natural resource use and measurement within a National Park are evaluated against the following four points:

- Consistency with applicable laws, Executive Orders, regulations and policies
- Consistency with existing plans for public use and resource management
- Actual and potential effects on park resources and values
- Total costs to the Service, and whether the public interest will be served.

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.) **Please refer to specific NPS standards in Appendix B.

Criterion #10 - *The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel.*

A vital sign should be straightforward with methodology that is relatively easy to understand, and simple to apply. Measurement of the vital sign should not be dependent on a single expert, but rather should incorporate expert systems that can be implemented by adequately trained field staff. The logistical requirements should warrant practical implementation and the length of time required to collect, analyze and report the data of a vital sign should not be prohibitive. *(*Adapted from *Jackson, L.E., J.C. Kurt and W.S. Fisher, eds. 2000. Evaluation guidelines for ecological indicators. EPA/620/R-99/05. U.S. E.P.A, Office of Research and Development, Research Triangle Park, NC. 107pp. and Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10.)*

INTERPRETATION AND UTILITY

Criterion #11 - *The candidate vital sign's response can be distinguished between natural variation and anthropogenic impact-induced variation.*

The vital sign should have a well-documented reaction to both natural disturbances and anthropogenic stresses in the system. This criterion would then apply to metrics that have been extensively studied and have well-developed models and clearly established patterns of response. (Adapted from *Dale, V.H. and S.C. Beyeler. Challenges in the development and use of ecological indicators. 2001. Ecological Indicators 1:3-10 and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practicies, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #12 - *The candidate vital sign is helpful in identifying the causal mechanism of an ecological response.*

Although overlooked in the emerging literature on ecological vital signs (also indicators), the ability for one or more integrative vital signs to provide insight into the causal mechanisms of an observed ecosystem response will be crucial to NPS needs. In order for vital sign information to be translated into management responses, park managers will need to be able to utilize the vital sign information to assess what processes are causing the measured ecosystem response and then translate this understanding into deliberate management decisions to intervene and attempt mitigation or accept that the observed departure from the range of natural variability cannot be mitigated. (Adapted from *Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, NY and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P. Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)*

Criterion #13 - *Historic databases and baseline conditions for the candidate vital sign are already known.*

Threshold values or ranges of values are often established to facilitate the ability to interpret whether vital sign information suggests an important departure from the range of natural variability. This is because there can be important natural spatial and temporal variation in measurable ecosystem responses with and across years. The ability for a vital sign to permit discrimination of natural variability along known condition gradient(s) from unacceptable ecological conditions will need to be based upon documented baseline conditions, known thresholds, historical records or observed responses at reference sites along an important condition gradient. (Adapted from *Environment Canada. 2000. Selecting core variables for tracking ecosystem change at EMAN sites. Final Report to Environment Canada. Geomatics International, Inc., Guelph, Ontario. http:/www.eman-rese.ca and Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pp: 49-65. In: Williams, J.E., C.A. Wood, and M.P.*

Dombeck, eds. Watershed Restoration Principles and Practices, American Fisheries Society, Bethesda, MD. 559 pp.)

APPENDIX A

**This information appends the expanded selection criteria information.

MANAGEMENT RELEVANCE

Park Management Goals

Specific park management goals are taken from each park's General Management Plan or Master Plan. The specific management goals of Bighorn Canyon National Recreation Area, according to its General Management Plan, are:

> *The preservation of the natural environment for the enjoyment of the recreation area visitors and for the integrity of the ecosystems...*

According to the Master Plan of Grand Teton National Park states the following purpose:

> *To protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life. The Park will interpret these natural and scenic values, in association with the historical significance of the region, in a manner that preserves these resources for the benefit and d pleasure of present and future generations.* (Adapted from *Greater Yellowstone Network Phase I Report.*)

GPRA Goals

Each of the four GPRA goal focal areas can be separated into specific mission goals, as follows:

Preserve park resources: 1) natural and cultural resources and associated values are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context; and 2) the National Park Service contributes to knowledge about natural and cultural resources and associated valued; management decisions about resources and visitors are based on adequate scholarly and scientific information.

Provide for the public enjoyment and visitor experience of parks: 1) visitors safely enjoy and are satisfied with the availability, accessibility, diversity and quality of park facilities, services and appropriate recreational opportunities; and 2) park visitors and the general public understand and appreciate the preservation of parks and their resources for this and future generations.

Strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners: 1) natural and cultural resources are conserved through formal partnership programs; 2) through partnerships with other federal, state and local agencies and non-profit organizations, a nationwide system of parks, open space, rivers and trails provides educational, recreational and conservation benefits for the American people; and 3) assisted through federal

funds and programs, the protection of recreational opportunities is achieved through formal mechanisms to ensure continued access for public recreational use.

Ensure organizational effectiveness: 1) the National Park Service uses current management practices, systems and technologies to accomplish its mission; and 2) the National Park Service increases its managerial resources through initiatives and support from other agencies, organizations and individuals. (Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

Specific GPRA goals for the Network parks are included in the table below.

NPS GPRA GOALS	**Bighorn Canyon National Recreation Area**	Exotic Vegetation Species: by September 30, 2005, exotic vegetation on 70.25 (2.81%) acres of an estimated 2,500 targeted acres of Bighorn Canyon lands, as of FY 1999, is contained.
		Water Quality: by September 30, 2005, Bighorn Canyon has unimpaired water quality.
		Natural/Cultural Resource Inventories: by September 30, 2005, 4 (66.6%) of 6 Bighorn Canyon primary natural/cultural resource inventories are completed.
		Vital Signs: by September 30, 2005, Bighorn Canyon has identified its vital signs for natural resource monitoring.
	Yellowstone National Park	Natural Resources Fauna: by September 30, 2005, 356 (95%) of the 375 self-sustaining and free-ranging wildlife, native fish and birds identified in Yellowstone National Park as of 1999 are preserved and maintained.
		Geothermal Features: By September 30, 2005, 90 (90%) of the 100 indicator geothermal features identified in Yellowstone National Park as of 1999 are in good condition.
		Native Species of Special Concern: by September 30, 2005, four of Yellowstone National Park's native species of special concern (trumpeter swan, white pelican, pronghorn antelope and Yellowstone sand verbena), as of 1999, have an improved or stable status.
		Exotic Plant Species: by September 30, 2005, invasive exotic vegetation species on 20-22 (2.6%) of 822 targeted acres of Yellowstone National Park lands, as of FY 1999, are eradicated or contained.
		T&E Species Improved: by September 30, 2005, one (the gray wolf) (33%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, has an improved status.
		T&E Species Stable: by September 30, 2005, two (the grizzly bear and bald eagle) (66%) of Yellowstone National Park's three identified populations of federally listed threatened and endangered species with critical habitat on park lands and/or requiring NPS recovery actions, as of 1999, have a stable status.
		Air Quality: by September 30, 2005, air quality in Yellowstone National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Yellowstone National Park has unimpaired water quality.
		Vital Signs: by September 30, 2005, Yellowstone National Park has identified its vital signs for natural resource monitoring.
	Grand Teton National Park	Exotic Plant Species: by September 30, 2005, spotted knapweed and other alien vegetation species are contained on 20,000 (100%) of 20,000 acres targeted in Grand Teton National Park and the John D. Rockefeller Jr. Memorial Parkway.
		T&E Species: by September 30, 2005, 2 of the 4 federally listed threatened and endangered species NOT having critical habitat in Grand Teton and the Parkway and NOT requiring NPS recovery actions, as of 1997, have an improved status. Monitoring continues on the remaining 2 federally listed species.

		Native Species of Species Concern: by September 30, 2005, 1 of 2 (50%) of Grand Teton National Park and Parkway populations of plant and/or animal species of special concern (e.g. state-listed threatened and endangered species, endemic or indicator species, or native species classified as pests) are at scientifically acceptable levels.
		Air Quality: by September 30, 2005, air quality in Grand Teton National Park has remained stable or improved relative to FY 1998 conditions.
		Water Quality: by September 30, 2005, Grand Teton National Park and Parkway continue to have unimpaired water quality.
		Wildlife Research and Monitoring: by September 30, 2005, 9 of 9 (100%) of Grand Teton National Park and Parkway species of concern will continue to be monitored to provide sufficient information to assist in management decisions.
		Resource Inventories: by September 30, 2005, 50% of the available natural resource data sets for Grand Teton National Park will be collected and evaluated.
		Vital Signs: by September 30, 2005, Grand Teton National Park has identified its vital signs for natural resource monitoring.

(Table adapted from *Strategic Plan for Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway October 1, 2001- September 30, 2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/GRTE%2Edoc> *(3 Apr. 2003); The Strategic Plan for Yellowstone National Park 2001-2005. Strategic Plans. 2000.* <http://im.den.nps.gov/Documents/GpraPlans/YELL%2Epdf> *(3 Apr. 2003)*; *The Strategic Plan for Bighorn Canyon National Recreation Area 2001-2005. Strategic Plans. 2001.* <http://im.den.nps.gov/Documents/GpraPlans/BICA%2Epdf> *(3 Apr. 2003)*)

Business Plan Standards

The following aspects of Yellowstone's natural resources are included in the Natural Resource Protection section of Yellowstone National Park's Business Plan:

- Air, Soils and Geology-including the monitoring of geothermal features, weather, air quality, river gauging stations and volcanic and earthquake unrest
- Backcountry and Wilderness Management-including 300 remote sites and 1,000 miles of trails
- Bear Management-including the reduction of bear-human conflicts and the monitoring of bear populations and ecology
- Bison Management-including the Interagency Bison Management Plan (a brucellosis transmission risk management strategy relying on strategic hazing and capture and removal techniques) and vaccination of bison calves and yearlings
- Elk and Other Ungulate Management-including monitoring of elk, pronghorn antelope, bighorn sheep, mountain goats, moose and whitetail and mule deer populations and ecology
- Fisheries and Aquatic Resources-including the control of invasive exotic species (e.g. lake trout, whirling disease, New Zealand mud snails) and the management of consumptive use through fishing permits and regulations
- Natural Resource Protection-including the protection of resources from human-caused threats and the protection of humans from wildlife, geothermal and other natural threats

- Natural Resource Research, Publications and Events-including the creation of a resource management-based research program that will benefit residential education programs and produce publications for various audiences
- Other Wildlife Management-including the management of birds, reptiles, amphibians, invertebrates, small mammals and mid-sized carnivores (e.g. Canada lynx, cougars, wolverines) and the Integrated Pest Management program
- Vegetation Management-including wetlands mapping and preservation, invasive exotic species control, rare vascular plant documentation, hazard tree removal and vegetation ecology studies
- Wildland Fire-including the encouragement of natural fires except when they threaten irreplaceable historic structures and sharing fire management resources with surrounding National Forest land
- Wolf Management-including monitoring wolves and their impacts on the ecosystem

Additionally, included in the Yellowstone Business Plan is the vision of the park, which encompasses the following areas:

- Public enjoyment and visitor experience
- Resource preservation
- Efficiency and effectiveness
- Safety

(Adapted from *Yellowstone National Park Business Plan Fiscal Year 2002*.)

APPENDIX B

Feasibility of Implementation

National Park Service Standards

For example, the following uses of National Park Service land are restricted and require special prior approval:

- Off-road vehicle use (Executive Order 11644)
- Aircraft over flights (Director's Order 47)
- Telecommunication antenna sites (Director's Order 53)
- Consumptive uses (i.e. collecting natural products) are only allowed when they are:
    - Specifically authorized by federal law or treaty rights
    - Specifically authorized pursuant to other existing rights
    - Some pre-specified grazing activities
    - Traditional visitor activities that are authorized in accordance with NPS general regulations.

(Adapted from *Management Policies 2001. National Park Service publication.*)

These additional conditions are placed on research permits obtained for Yellowstone National Park:

- All equipment left in the field including plot markers must be specifically authorized in advance. If you are authorized to place plot markers in Yellowstone, they must be eight-penny nails with an optional washer
- All VHF and GPS collars on wildlife must be camouflaged to blend in with the animal. The antennas on the collars must also be as invisible as possible. All collars must be removed at the completion of the study by either blow-off capabilities or cotton (rot-away) spacers
- Specific authorization must be obtained in advance before using chemicals or hazardous materials
- A research permit does not authorize you to enter closed or restricted areas in Yellowstone. Examples of restricted areas include most service roads, bear management areas, some thermal areas, some bird nesting areas, and wolf den sites, and trout spawning areas
- Cultural resources must not be adversely impacted by your research activities. Any ground disturbances must be specifically authorized in advance
- If your research requires flying in the park, you must request authorization in advance. You must also comply with FAA and Yellowstone National Park flight regulations
- The Permittee agrees to notify the Superintendent of Yellowstone National Park of every subject discovery or invention that relates in any respect to research results derived from use of any research specimens or other materials collected from Yellowstone National Park, or that may be patentable or otherwise protected under the intellectual property (IP) laws of the United States or other jurisdiction

- Travel within the park is restricted to only those methods that are available to the general public unless otherwise specified in additional stipulations associated with this permit.

(Adapted from *Yellowstone National Park Permit Conditions 2003.*)

The following conditions apply to specimen collection in Yellowstone National Park:

- Collection of archeological materials without a valid Federal Archeology Permit is prohibited.
- Collection of federally listed threatened or endangered species without a valid U.S. Fish and Wildlife Service endangered species permit is prohibited.
- Collection methods shall not attract undue attention or cause unapproved damage, depletion, or disturbance to the environment and other park resources, such as historic sites.
- New specimens must be reported to the NPS annually or more frequently if required by the park issuing the permit. Minimum information for annual reporting includes specimen classification, number of specimens collected, location collected, specimen status (e.g., herbarium sheet, preserved in alcohol/formalin, tanned and mounted, dried and boxed, etc.), and current location.
- Collected specimens that are not consumed in analysis or discarded after scientific analysis remain federal property. The NPS reserves the right to designate the repositories of all specimens removed from the park and to approve or restrict reassignment of specimens from one repository to another. Because specimens are Federal property, they shall not be destroyed or discarded without prior NPS authorization.
- Each specimen (or groups of specimens labeled as a group) that is retained permanently must bear NPS labels and must be accessioned and cataloged in the NPS National Catalog. Unless exempted by additional park-specific stipulations, the permittee will complete the labels and catalog records and will provide accession information. It is the permittee's responsibility to contact the park for cataloging instructions and specimen labels as well as instructions on repository designation for the specimens.
- Collected specimens may be used for scientific or educational purposes only, and shall be dedicated to public benefit and be accessible to the public in accordance with NPS policies and procedures.
- Any specimens collected under this permit, any components of any specimens (including but not limited to natural organisms, enzymes or other bioactive molecules, genetic materials, or seeds), and research results derived from collected specimens are to be used for scientific or educational purposes only, and may not be used for commercial or other revenue-generating purposes unless the permittee has entered into a Cooperative Research And Development Agreement (CRADA) or other approved benefit-sharing agreement with the NPS. The sale of collected research specimens or other unauthorized transfers to third parties is prohibited. Furthermore, if the permittee sells or otherwise transfers collected specimens, any components thereof, or any products or research results developed from such specimens or their components without a CRADA or other approved benefit-sharing agreement with NPS, permittee will pay the NPS a royalty rate of twenty percent (20%) of gross revenue from such sales or other revenues. In addition to such royalty, the NPS may seek other damages to which the NPS may be entitled including but not limited to injunctive relief against the permittee.

(Adapted from *General Conditions for Scientific Research and Collection Permit. Department of the Interior*.)

APPENDIX H-CANDIDATE VITAL SIGNS SCORING COMMENTS

**Please note: not all candidate vital signs are represented in the following table. Only those candidate vital signs that had recorded comments from day two of the workshop are found in this table.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Deposition and accumulation of mercury in biota	GRYN	Air, Biotic and Abiotic	(q1)-n/a; mercury is an important toxic air contaminant that affects human health; needs further study to assess ecological impact and addresses linkages between deposition and accumulation in biota	(q2,3,4)-not enough information on this important vital sign to assess variability			(q11)-this is an important issue (q13)-some information from ice and sediment cores
Change in visibility deciviews	GRYN	Air, Biotic and Abiotic	We are mandated to do this. Already underway in YELL, need to do GRTE and BICA because it is difficult to extract information from YELL to other parks.				
Atmospheric deposition of nitrogen, sulfur and all major anions and cations	GRYN	Air, Biotic and Abiotic	This is a stressor variable; needed in all parks; comprehensive, continuous coverage is essential.				
Over-snow vehicles emissions and effects	GRTE	Air, Biotic and Abiotic		(q3) N/A variable is a stressor (q4) N/A (q5) N/A			

Candidate Vital Sign	**Applicable Park (GRYN=all three)**	**Secondary Resource Category**	**Comment (Ecological Relevance)**	**Comment (Response Variability)**	**Comment (Management Relevance)**	**Comment (Feasibility of Implementation)**	**Comment (Interpretation and Utility)**
Fish pathogens and disease	GRYN	Aquatic Pathogens/disease					(q12) whirling disease is an exception
Stream reach geomorphology	GRYN	Rivers and Streams		(q3)-only change is predictable, not the direction of change			
Stream gauging	GRYN	Climate, Biotic and Abiotic	(q1)-comprehensive coverage of stream gauging in all parks and networks; need cooperation of USGS	(q3)-variable is critical stressor and response variable; needs to be long-term continuous monitoring.			
Snow cover	GRYN	Climate, Biotic and Abiotic	(q1)-easy to measure with remote sensing				
Date of "spring green-up"	GRYN	Climate, Biotic and Abiotic	One opinion in group is that we can estimate this parameter with weather data. We want to correlate weather data with spring green-up. Spring green-up is a remotely sensed variable. Need comprehensive coverage.	This is one of many variables that could be remotely sensed. Needs to be long-term continuous monitoring.			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Basic climatological measurements	GRYN	Climate, Biotic and Abiotic	We feel that these measurements are critical to all parks and should have comprehensive coverage of all ecosystems. All measurements should be coordinated with NWS and NRCS and across NPS. Should be coordinated across all NPS networks and parks.	This is stressor variable, not response variable, so we've answered 'yes' to all. Needs to be long-term continuous monitoring.			
Date of ice on/off on major lakes	GRYN	Climate, Biotic and Abiotic	Observational data=should be used to verify remotely sensed information				
Extreme Climatological Events	GRYN	Climate, Biotic and Abiotic	Snow crusting can also be important; extreme events are important variables to measure for climate change; important human safety variables	(q3)-not appropriate for variable			
Geyser eruption volume and rate	YELL	Geothermal Processes		(q4)-with some		(q8)-may make sense in some places; volume is a problem	(q13)-'yes' not for volume

Candidate Vital Sign	**Applicable Park (GRYN=all three)**	**Secondary Resource Category**	**Comment (Ecological Relevance)**	**Comment (Response Variability)**	**Comment (Management Relevance)**	**Comment (Feasibility of Implementation)**	**Comment (Interpretation and Utility)**
Chloride flux in thermal features	YELL	Geothermal Processes	(q1)-measurement of heat flux to surface	(q3)-disagreement on stressor		(q8)-technique relies upon river gauging stations	
Level and temperature of groundwater associated with thermal features	YELL	Geothermal Processes	activity of geothermal systems			(q8)-assumes use at existing wells (q9)-assumes use at existing wells	
Geothermal gaseous emissions in the atmosphere over Yellowstone National Park	YELL	Geothermal Processes	part of geothermal system				(q13)-spotty
Stream sediment transport	GRYN	Geomorphic Processes	(q1)-landscape stability	(q5)-over many years of measurements	(q6)-required by NAQWA	(q8)-suspended sediment easier to measure than bedload	(q13)-yes in some areas; no in others
Landscape and habitat fragmentation	GRYN	Surrounding Environments		(q3) vital sign is a stressor	(q6) In park-driven by mgmt plans, outside-driven by counties, therefore, varies by county.	(q8,q10) Remotely sensed data can be used to classify land use and fragmentation. Cover is more difficult and costly.	

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Levels of backcountry overnight use	GRTE	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	
Levels of backcountry overnight use	YELL	Park Visitation	(q1) Concern about on-site impacts and impacts that migrate off-site. (q2) Concern about pristine areas that will become less pristine through use - this is not ecologically important until you get off-site impacts	(q3)This vital sign is an ecosystem stressor. (q4)Based on Cole and others, this vital sign is predictable.		(q8) Measuring levels of use is very cheap. Measuring impact of use is more costly, but not prohibitive.	
Visitor use levels	GRYN	Park Visitation	(q1)Visitor use and associated infrastructure is the biggest ecological impact in parks.	(q3)vital sign is a stressor.		(q8)Visitor use levels are easy to measure, impacts are difficult. visitor use levels are easy to measure, impacts are difficult.	

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Resource violations	GRYN	Park Visitation	(q1) Yes for BICA (cattle trailing) No for YELL, GRTE. (q2) Yes for BICA with cattle trailing.	(q1) vital sign is a stressor			
Park infrastructure	GRYN	Park Visitation	(q1) This vital sign is a stressor	(q3) Depends on species, individual, habitat type. (q4) Anticipating in that one can predict roads will bring exotics and increased roadkill. (q5) Some things (roadkill) are well known, some are not known at all.		(q8) But depends on which metric one chooses (q10) Again, depends on metric	(q12) depends on metric (q13) yes-vegetation, roadkill, etc.
Resource consumptive use and hydrologic modification	GRYN	Park Visitation	(q1) Hunting has possible ecological impact to muledeer and raccoons (BICA) and small mammals	(q3) vital sign is an ecosystem stressor			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Levels of backcountry day use	GRTE	Park Visitation	(q1) Some impacts, but this is more of a social impact issue	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Levels of backcountry day use	YELL	Park Visitation	(q1) Some impacts, but this is more of a social impact issue than a (unfinished	(q3)vital sign is a stressor.		(q8) Cost of monitoring this sign can be very high (e.g.. GRTE has a proposal to monitor day use for around 150,000) but it is not prohibitive.	(q11) This VS is a social issue primarily. (q12) YELL has numbers of day users measured in 1992-93, GRTE has numbers from 1986-87.
Native insect biodiversity and distribution	GRYN	Native and Exotic Insects			(q6) need to check	(q8) quite in expensive per species, but more costly by indicator (q10) collection easy, but identification is difficult and expensive	(q13) some data available, but not adequate

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Exotic insects	GRYN	Native and Exotic Insects		(q3) Presence of insects are an ecosystem stressor		(q8) high cost for one species, but low considering number of species involved.	(q13) Some species
Forest/grassland/ shrubland defoliators and consumers	GRYN	Native and Exotic Insects	(q1) combined 3 previous vital signs: Beetle and budworm pop., Insect herbivory and Insect biomass				(q13) Yes for forest-related species but not for grasshoppers
Selected insect species of concern	GRYN	Native and Exotic Insects			(q7) Maybe lady bird beetles ephidrid flies and geothermal		(q11) depends on the species
Alpine plant community characteristics	GRTE	Alpine Meadow and Timberline Ecosystems		(q4) for mountain goats			
Fire and fuel loading	GRYN	Terrestrial Ecosystems				(q8) could be restricted to small areas	
Shrubland community composition and structure	GRYN	Montane Shrubland Ecosystems					(q12) could be combination of causes
Browse effects on riparian woody vegetation	GRYN	Riparian and Riverine Wetland Ecosystems					(q13) limited in extent

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Grassland annual net primary productivity	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) However, there are models addressing certain stressors			(q13) selected park areas access to remote sensing
Grassland vegetation annual offtake	GRYN	Herbaceous Meadow and Grassland Ecosystems			(q6) but maybe in BICA	(q8) n/a - need to develop metric (q9) N/a (both scored no)	
Grassland nitrogen	GRYN	Herbaceous Meadow and Grassland Ecosystems		(q3) models in development, (q4) Need to consult N-expert	(q6) could be good mgmt tool.	(q9,10) N/A	
Bighorn basin plant community composition and exotic species	BICA	Terrestrial Ecosystems		(q5) beyond our expertise			
Lichen distribution, abundance and chemical composition	GRYN	Terrestrial Ecosystems		(q3) particularly in regard to growth and climate variables			(q13) yes in YELL, no in GRTE and BICA
Lodgepole pine plant community composition and exotic species	GRTE	Lodgepole Pine Forest Ecosystem		(q3) dependent upon resolution of data			(q13) for limited areas

Candidate Vital Sign	**Applicable Park (GRYN=all three)**	**Secondary Resource Category**	**Comment (Ecological Relevance)**	**Comment (Response Variability)**	**Comment (Management Relevance)**	**Comment (Feasibility of Implementation)**	**Comment (Interpretation and Utility)**
Lodgepole pine forest floor litter and coarse woody debris	GRTE	Lodgepole Pine Forest Ecosystem			(q7) indirect for YELL		
Landscape structure and heterogeneity	BICA	Terrestrial Ecosystems		(q3) This VS has high value, despite this issue			(q13) yes, but only for limited areas
Aboveground net primary productivity	GRYN	Terrestrial Ecosystems					(q12) this is ecosystem specific
Stand density of high-elevation live and dead whitebark pine trees	GRTE	Whitebark Pine Woodland and Forest Ecosystems					(q13) if low density stands, can use old photos
Mixed conifer plant community composition and exotic species	YELL	Mixed Conifer Forest Ecosystems					(q13) for limited areas
Mixed conifer snag density	GRTE	Mixed Conifer Forest Ecosystems					(q13) possibly some surveys

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Ponderosa pine plant community composition and exotic species	BICA	Ponderosa Pine Ecosystems					(q12) more useful for vegetation. responses than animal responses
Aspen community composition and structure	GRTE	Aspen Forest Ecosystems		(q5) variable often high			
Aspen stand extent and distribution in landscape	GRTE	Aspen Forest Ecosystems					(q13) Based upon estimates
Shrubland nitrogen	GRYN	Montane Shrubland Ecosystems		(q3) models in development	(q6) could be good management tool (q7) need to contact N- expert		
Shrubland exotic species	GRYN	Montane Shrubland Ecosystems					(q11) cannot be causal in interpretation (12) specific to different species (13) mostly anecdotal.

Candidate Vital Sign	**Applicable Park (GRYN=all three)**	**Secondary Resource Category**	**Comment (Ecological Relevance)**	**Comment (Response Variability)**	**Comment (Management Relevance)**	**Comment (Feasibility of Implementation)**	**Comment (Interpretation and Utility)**
Selected sensitive bird species abundance, distribution and productivity	GRYN	Birds		(q3)unknown cause of trumpeter decline (q5) Harlequins: yes, swan? Loons? Occupancy (PAO) is less variable, so yes			current, ongoing debate
Song bird population abundance and distribution	GRYN	Birds	(Q1) Many species which effect many levels of food web (q2) migratory, many habitats	(q3) relative to abiotic factors (q4) e.g.. DDT. (q5) perhaps use a PAO methodology, but not from a territorial male perspective	(q6) neotropical migrants (q7) e.g.. Cavity nesters in burns, people get exited about bird watching	(q8) point sampling methods are relatively straightforward (q9) point counts non-invasive (q10) requires use of highly trained personnel	(q11) esp. because of migration & wintering sites (q13) much historic data, but in different formats. Monitoring must be correlated with other methods
Colony nesting bird population abundance, distribution, vital rates and productivity	GRYN	Birds		(q3)"reasons for declines are uncertain" (q5) site occupancy is not variable, but abundance is more so.	(q7) colony nesting birds specifically noted in state of park reports	(q8) easy (q10) low-training	(q11) seeq 3 above. (q12) see q3 above. (q13) good historic data
Raptor population abundance, distribution and productivity	GRYN	Birds		(q5) using to site fidelity			

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Large carnivore population abundance and distribution	GRYN	Mammals	(q1) food web = top predators	(q4) food switching, functional response		(q8) very expensive due to life history. (q10) not easy, collaring animals is labor intensive	(q13) good for grizzlies. Short term for wolves. Questionable for mountain lions
Ungulate population abundance, distribution and productivity	GRYN	Mammals		(q4) long-lived so low sensitivity. (q5) high variability			(q11) don't know enough about compensatory mechanisms in the absence of hunting
Bat occurrence, distribution and abundance	GRYN	Mammals	(q2) trophic factors. Dispersed forager, roosts, foraging areas, and commuting zones	(q3,4) known responses but qable statistical power.	(q6) never mentioned, often conflicting with park maintenance issues. (q7) cave use, building and historic sites, mine use, forest roost structures.	(q8) abundance of non-colony roosters potentially labor-intensive	(q11) In many cases, yes (especially for roosts.) However, population fluctuations may require additional research to determine causation. (q13) Inventory is currently occurring, but virtually no older data.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Native species richness	GRYN	Terrestrial Vertebrates		(q4) does not provide early warning. (Q5) The SNR increases with the proportion of rare animals in the richness calculation. This rank assumes focus on the species with high to moderate detectibility	(q6) maintenance of diversity at national level is a goal of NPS. (q7) Management action very difficult to tie to a list of species, as opposed to particular species.	(q8) see note at bottom of page	(q13) Inventories are currently being done to establish baselines.
Invasive vertebrate species richness and distribution	GRYN	Terrestrial Vertebrates	(q1) Key taxa: bullfrogs, raccoons, English sparrows, starlings, pigeons, turkeys, pheasants, mute swans, feral cats. Species displacement, disease.	(q4) early warning of change. (q5) without 'natural' in wording of q. Its presence or absence, not abundance			(q11) It is an anthropogenic impact. (q13) Historic (or prehistoric) baseline is zero- they were not here before.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Vertebrate diseases	GRYN	Terrestrial Vertebrates		(q3) much current research to uncover causes of spread			(q11) Anthropogenic causes can interact with diseases, making wildlife more susceptible. (q13) Many diseases are recently discovered or recently prevalent. With molecular techniques the history of diseases can often be traced back in time.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Beaver presence and population estimates	GRYN	Mammals		(q3) Known response to predators and habitat structure.(q4) Responsive to multi-scale phenomena (floods, fire, drought, stressors, geomorphology). Sensitive at local scales, but anticipatory at larger scales.		(q8) East to identify and measure.	(q13) Beaver flights have been conducted for years in YNP. Some survey data for GRTE.
Reptile occurrence	BICA	Terrestrial Vertebrates	(q1) Function: Trophic relationships. (q3) Links to various spatial scales are more tenuous than other groups (e.g.. Amphibians.)	(q3,4) Relative to other groups. (q5) PAO doesn't work well with reptiles		(q8) drift fences /funnel traps labor intensive. (q9)) drift fences /funnel traps are invasive but feasible in BICA.	(q11) insufficient baseline data. (q12) relative to amphibians

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Amphibian occurrence	GRYN	Terrestrial Vertebrates	(q1) Predator and prey in aquatic systems . Nutrient transport. Larvae are important herbivores. Function: connected food web. (q2) contingent of noted change in description- ('scales' changed to 'levels' 'and spatial and temporal scale' added at end	(q3) Sometimes, depending on a stressor. Usually predictable although power is qable. Using PAO methods may be statistically feasible. (q4) Amphibians are sensitive relative to other vital signs. (q5) Low variability if PAO is used as metric.	(q6) Direct impacts on: road construction, fish stocking, water management, water diversion, fuels reduction and prescribed burns. Mgmt. goals, GRPA, Business plan: People understand, Applications, Resource is cared about.	(q9,10) Contingent upon using PAO to monitor.	(q11) Yes, given that we have baseline data. (q12) There is documented use of amphibians to identify contaminants, water issues, fish stocking, etc. (q13) Extensive monitoring via PAO has been done for 3 yrs. Other survey data collected for 20-30 yrs
Rodents and insectivores (<250g) population, abundance and distribution	GRYN	Mammals	(q1) Key taxa; Red-backed voles, Microtus spp.. Pocket gophers. Key reasons: prey base, burrows for amphibians.		(q3,4,5) high variability		(q13) except BICA
Rodents and Lagomorphs (>250g) population, abundance and distribution	GRYN	Mammals	(q1) prey base	(q3) responsive to some major stressors that restructure systems. (q4,5) high variability			(q11) see response above. (q13) variable by park unit. Selected data, but not across the board.

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Meso-carnivore population abundance and distribution	GRYN	Mammals	(q1) many populations are remnant or restricted. (e.g.. Fisher, lynx) . Wolverine tied to ungulates, marten to old forest, lynx to hares, others qable.		(q6) e.g.. Lynx, wolverine	(q10) Low abundance hard to detect, difficult to prove breeding, abundance hard to show	q11) poor knowledge on linkages. (q13) species and park specific
Pattern of non-park land-use changes	GRYN	Terrestrial Vertebrates		(q3) Stressors may be socio-economic trends and land-use change is the response.			
Major ion chemistry	GRYN	Lakes and Reservoirs	(q1)-includes alkalinity (q1)-especially in areas subject to atmospheric deposition and possible salinity changes	(q3)-acidification has highest sensitivity (q3)-may be 'no' for other uses	(q7)-assumes future management decisions as well as past	(q8)-assumes cost effective protocols; maintain this core set at sites-recommend	(q11)-for individual ions 'yes'; others 'no' (q13)-may be available on a case-by-case basis
E. coli	GRYN	Lakes and Reservoirs			(q6)-this is mainly an issue for BICA		(q11)-'no' unless typing methods are employed (q13)-GRTE has a recent baseline

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Metals	GRYN	Lakes and Reservoirs	(q2)-it may be more valuable to monitor biota (for bioaccumulation) in addition to monitoring water or sediment	(q3)-behavior of species is often coupled to episodic events (q5)-but YELL provides an extremely high level of spatial variability		(q8)-there may be exceptions, Hg is an example	(q13)-data are limited in some geographic areas
Zooplankton community structure	GRYN	Lakes and Reservoirs					(q12)-but could be useful for major (catastrophic) change
Core parameters	GRYN	Rivers and Streams	(q1)-not as important as major ion chemistry; 'yes' in some cases (q2)-unless under the context of a specific q, such as lake thermal structure	(q3)-'yes' in extreme situations			
Periphyton community structure, chlorophyll a	GRYN	Rivers and Streams	(q1)-linkage may not be as strong as that demonstrated in lakes	(q5)-further research needed in the area 'community structure and nutrient concentration relationships'		(q8)-however the identification costs for algae may be high	(q11)-unless there is a major change

Candidate Vital Sign	Applicable Park (GRYN=all three)	Secondary Resource Category	Comment (Ecological Relevance)	Comment (Response Variability)	Comment (Management Relevance)	Comment (Feasibility of Implementation)	Comment (Interpretation and Utility)
Continuous water temperature	GRYN	Lakes and Reservoirs					(q11)-depends on the magnitude of the change
Watershed budgets	GRYN	Watersheds	(q1)-integrates among ecosystems and among other ecological indicators (q2)-provides a foundation to integrate other measurements			(q8)-but many of these data are collected as part of other indicators; may be cheap	(q11)-but over decadal time scales

APPENDIX I-RANKED LIST OF CANDIDATE VITAL SIGNS BY RESOURCE AREA

**Please note: an overall ranked list of candidate vital signs is available upon request.

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
Air Quality						
	Atmospheric deposition of nitrogen, sulfur and all major anions and cations		1.00	X	X	X
	Atmospheric deposition and response in sensitive headwater catchments		1.00	X	X	
	Change in visibility deciviews		1.00	X	X	X
	Deposition and accumulation of mercury in biota		0.57	X	X	X
	Over-snow vehicles emissions and effects		0.40	X	X	
Aquatic Communities						
	Native and exotic community structure, composition, stability	Aquatic Species at risk	1.00	X	X	X
	Native fish genetic integrity	Aquatic Species at risk	1.00	X	X	
	Fish pathogens and disease	Aquatic Pathogens/disease	0.77	X	X	X
Aquatic Habitats						
	Stream reach geomorphology	Rivers and Streams	0.78	X	X	X
Climate						
	Basic climatological measurements	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of "spring green-up"	Climate, Biotic and Abiotic	1.00	X	X	X
	Date of ice on/off on major lakes	Climate, Biotic and Abiotic	1.00	X	X	X
	Snow cover	Climate, Biotic and Abiotic	1.00	X	X	X
	Stream gauging	Climate, Biotic and Abiotic	1.00	X	X	X
	Glaciers retreat or increase	Climate, Biotic and Abiotic	0.80	X	X	
	Soil climate	Climate, Biotic and Abiotic	0.75	X	X	X
	Extreme Climatological Events	Climate, Biotic and Abiotic	0.53	X	X	X
Geology and Geothermal						
	Chloride flux in thermal features	Geothermal Processes	1.00		X	
	Geothermal water chemistry	Geothermal Processes	0.95	X	X	
	Heat flow	Geothermal Processes	0.95	X	X	
	Stream sediment transport	Geomorphic Processes	0.95	X	X	X
	Earthquake activity	Geologic Processes	0.87	X	X	X
	Emission rates of CO_2, H_2S, SO_2, volatile Hg, and He to the atmosphere over Yellowstone NP	Geothermal Processes	0.87		X	

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Stream channel change	Geomorphic Processes	0.87	X		
	Landslide and debris flows	Geomorphic Processes	0.87		X	
	Landslide and debris flows	Geomorphic Processes	0.82	X		X
	Level and temperature of groundwater associated with thermal features	Geothermal Processes	0.82		X	
	Soil moisture/temperature/structure	Soils	0.82	X	X	
	Plant community composition and exotic species	Geothermal Ecosystem	0.78	X	X	
	Geothermal feature abundance & distribution	Geothermal Processes	0.73	X	X	
	Geothermal microbial diversity	Geothermal Microbiology	0.73	X		
	Geyser eruption volume and rate	Geothermal Processes	0.72		X	
	Stream channel change	Geomorphic Processes	0.67		X	X
	Soil chemistry	Soils	0.61	X	X	X
	Geothermal water flow rate	Geothermal Processes	0.51		X	
	Soil structure and stability	Soils	0.47	X	X	X
Human Activities						
	Landscape and habitat fragmentation	Surrounding Environments	1.00	X	X	X
	Park infrastructure	Park Visitation	0.83	X	X	X
	Levels of backcountry day use	Park Visitation	0.75	X	X	
	Levels of backcountry overnight use	Park Visitation	0.75	X	X	
	Resource consumptive use and hydrologic modification	Park Visitation	0.57	X	X	X
	Visitor use levels	Park Visitation	0.52	X	X	X
	Resource violations	Park Visitation	0.45	X	X	X
Invertebrates - Terrestrial and Aquatic						
	Forest/grassland/shrubland defoliators and consumers	Native and Exotic Insects	0.77	X	X	X
	Exotic insects	Native and Exotic Insects	0.70	X	X	X
	Native insect biodiversity and distribution	Native and Exotic Insects	0.56	X	X	X
	Selected insect species of concern	Native and Exotic Insects	0.42	X	X	X
Terrestrial Vegetation						
	Grassland vegetation community composition and structure	Herbaceous Meadow and Grassland Ecosystems	1.00	X	X	X
	Alpine plant community characteristics	Alpine Meadow and Timberline Ecosystems	0.95	X	X	
	Lichen distribution, abundance and chemical composition	Terrestrial Ecosystems	0.95	X	X	X

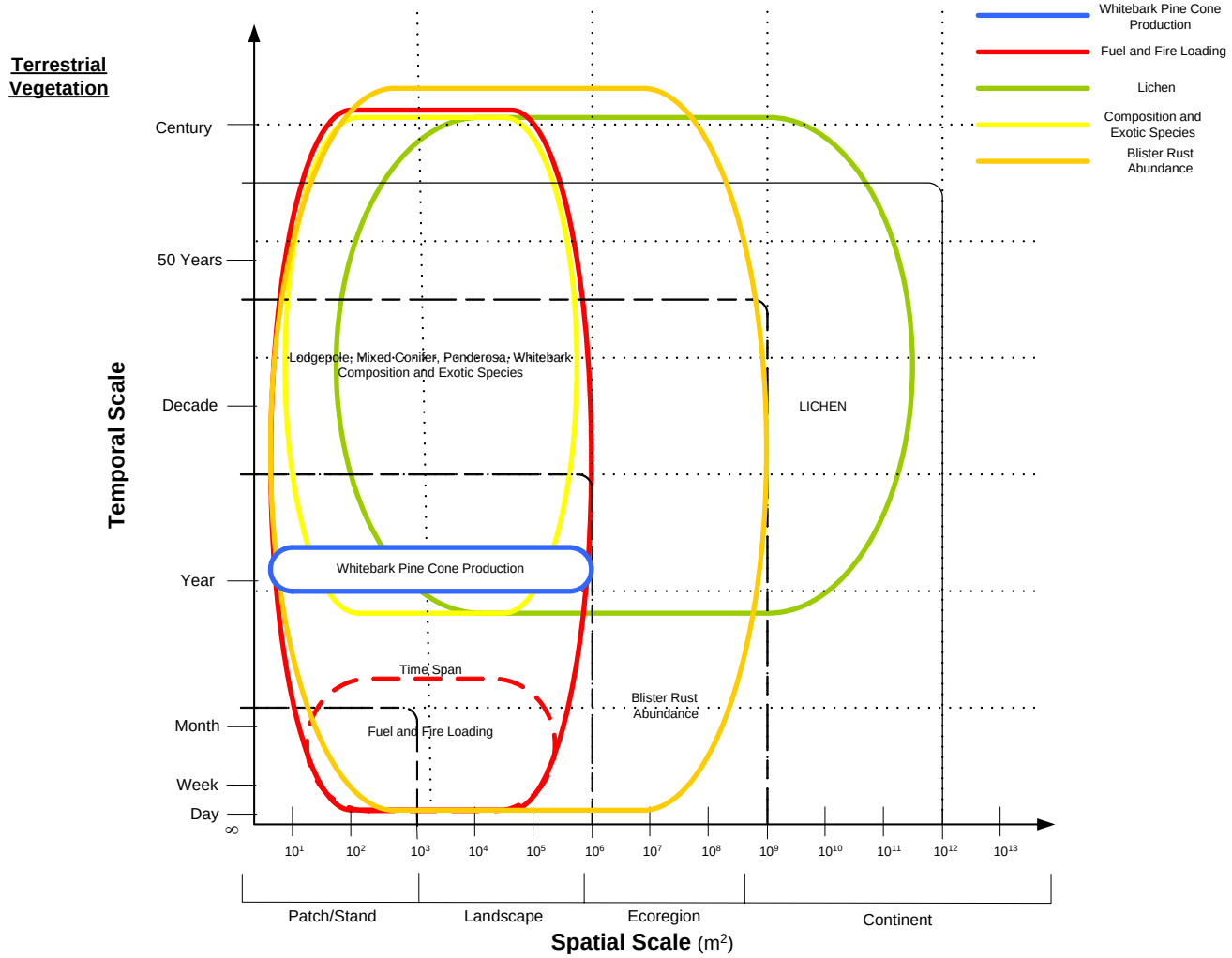
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Shrubland community composition and structure	Montane Shrubland Ecosystems	0.95	X	X	X
	Aspen community composition and structure	Aspen Forest Ecosystems	0.92	X	X	
	Browse effects on riparian woody vegetation	Riparian and Riverine Wetland Ecosystems	0.92	X	X	X
	Fire and fuel loading	Terrestrial Ecosystems	0.92	X	X	X
	Plant community composition and exotic species	Whitebark Pine Woodland and Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Mixed Conifer Forest Ecosystems	0.92		X	
	Plant community composition and exotic species	Lodgepole Pine Forest Ecosystem	0.92	X	X	
	Riparian vegetation community structure and composition	Riparian and Riverine Wetland Ecosystems	0.90	X	X	X
	Shrubland exotic species	Montane Shrubland Ecosystems	0.90	X	X	X
	Wetland extent	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.90	X	X	X
	Exotic plants in riparian zone	Riparian and Riverine Wetland Ecosystems	0.87	X	X	X
	Wetland plant cover and composition	Wet Meadow, Spring, and Depressional Wetland Ecosystems	0.85	X	X	X
	Blister Rust abundance and spread	Whitebark Pine Woodland and Forest Ecosystems	0.83	X	X	
	Browsing effects within aspen stands	Aspen Forest Ecosystems	0.83	X	X	
	Plant community composition and exotic species	Terrestrial Ecosystems	0.83			X
	Plant community composition and exotic species	Ponderosa Pine Ecosystems	0.83			X
	Timberline forest density and health	Alpine Meadow and Timberline Ecosystems	0.82	X	X	
	Whitebark pine cone production	Whitebark Pine Woodland and Forest Ecosystems	0.78	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.75	X		
	Dry woodland community structure and composition	Dry Woodland Ecosystems	0.70			X
	Extent and distribution of woodlands	Dry Woodland Ecosystems	0.70			X
	Snag density	Whitebark Pine Woodland and Forest Ecosystems	0.68	X	X	
	Snag density	Mixed Conifer Forest Ecosystems	0.68	X	X	

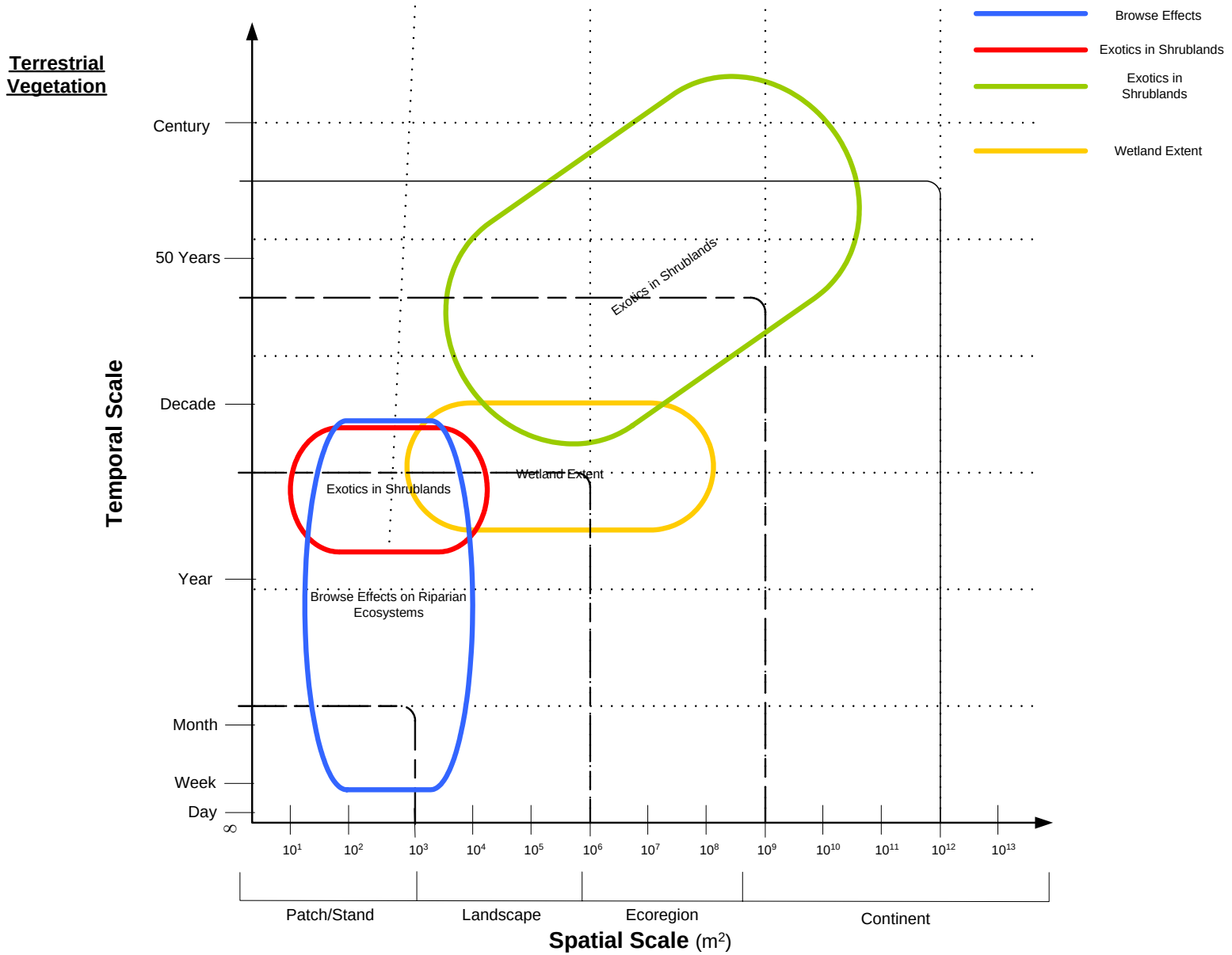
	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Snag density	Lodgepole Pine Forest Ecosystem	0.68	X	X	
	Timberline elevation boundaries	Alpine Meadow and Timberline Ecosystems	0.67	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.65		X	
	Stand density of high-elevation live and dead whitebark pine trees	Whitebark Pine Woodland and Forest Ecosystems	0.63	X	X	
	Aspen stand extent and distribution in landscape	Aspen Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Mixed Conifer Forest Ecosystems	0.60	X	X	
	Forest floor litter and coarse woody debris	Lodgepole Pine Forest Ecosystem	0.55	X	X	
	Landscape structure and heterogeneity	Terrestrial Ecosystems	0.55			X
	Stand density of live and dead trees	Ponderosa Pine Ecosystems	0.53			X
	Aboveground net primary productivity	Terrestrial Ecosystems	0.50	X	X	X
	Grassland annual net primary productivity	Herbaceous Meadow and Grassland Ecosystems	0.45	X	X	X
	Grassland nitrogen	Herbaceous Meadow and Grassland Ecosystems	0.38	X	X	X
	Shrubland nitrogen	Montane Shrubland Ecosystems	0.38	X	X	X
	Grassland vegetation annual offtake	Herbaceous Meadow and Grassland Ecosystems	0.13	X	X	X
Terrestrial Vertebrates						
	Amphibian occurrence	Terrestrial Vertebrates	1.00	X	X	X
	Beaver presence and population estimates	Mammals	1.00	X	X	X
	Pattern of non-park land-use changes	Terrestrial Vertebrates	1.00	X	X	X
	Invasive vertebrate species richness and distribution	Terrestrial Vertebrates	0.92	X	X	X
	Vertebrate diseases	Terrestrial Vertebrates	0.92	X	X	X
	Raptor population abundance, distribution and productivity	Birds	0.87	X	X	X
	Selected sensitive bird species abundance, distribution and productivity	Birds	0.87	X	X	X
	Colony nesting bird population abundance, distribution, vital rates and productivity	Birds	0.82	X	X	X
	Ungulate population abundance, distribution and productivity	Mammals	0.78	X	X	X
	Song bird population abundance and distribution	Birds	0.73	X	X	X
	Bat occurrence, distribution and abundance	Mammals	0.72	X	X	X

	Attribute	Secondary Resource	Score	GRTE	YELL	BICA
	Large carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Meso-carnivore population abundance and distribution	Mammals	0.60	X	X	X
	Rodents and Lagomorphs (>250g) population, abundance and distribution	Mammals	0.58	X	X	X
	Native species richness	Terrestrial Vertebrates	0.53	X	X	X
	Rodents and insectivores (<250g) population, abundance and distribution	Mammals	0.50	X	X	X
	Reptile occurrence	Terrestrial Vertebrates	0.22			X
Water Quality						
	Ground water hydrology	Ground Water	1.00	X	X	X
	Reservoir elevation	Lakes and Reservoirs	1.00	X		X
	Streamflow	Rivers and Streams	1.00	X	X	X
	Algal species composition and biomass	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Lakes and Reservoirs	0.95	X	X	X
	Continuous water temperature	Rivers and Streams	0.95	X	X	X
	Ground water chemistry	Ground Water	0.95	X	X	X
	Major ion chemistry	Rivers and Streams	0.95	X	X	X
	Major ion chemistry	Lakes and Reservoirs	0.95	X	X	X
	River invertebrate assemblages	Rivers and Streams	0.95	X	X	X
	Bed sediment chemistry (adsorbed)	Rivers and Streams	0.82	X	X	X
	Bed sediment shemistry (adsorbed)	Lakes and Reservoirs	0.82	X	X	X
	Metals	Rivers and Streams	0.69	X	X	X
	Metals	Lakes and Reservoirs	0.69	X	X	X
	Periphyton community structure, chlorophyll a	Rivers and Streams	0.58	X	X	X
	Zooplankton community structure	Lakes and Reservoirs	0.48	X	X	X
	E. coli	Rivers and Streams	0.38	X	X	X
	E. coli	Lakes and Reservoirs	0.38	X	X	X
	Field parameters	Rivers and Streams	0.38	X	X	X
Watershed						
	Watershed budgets	Watersheds	0.90	X	X	X

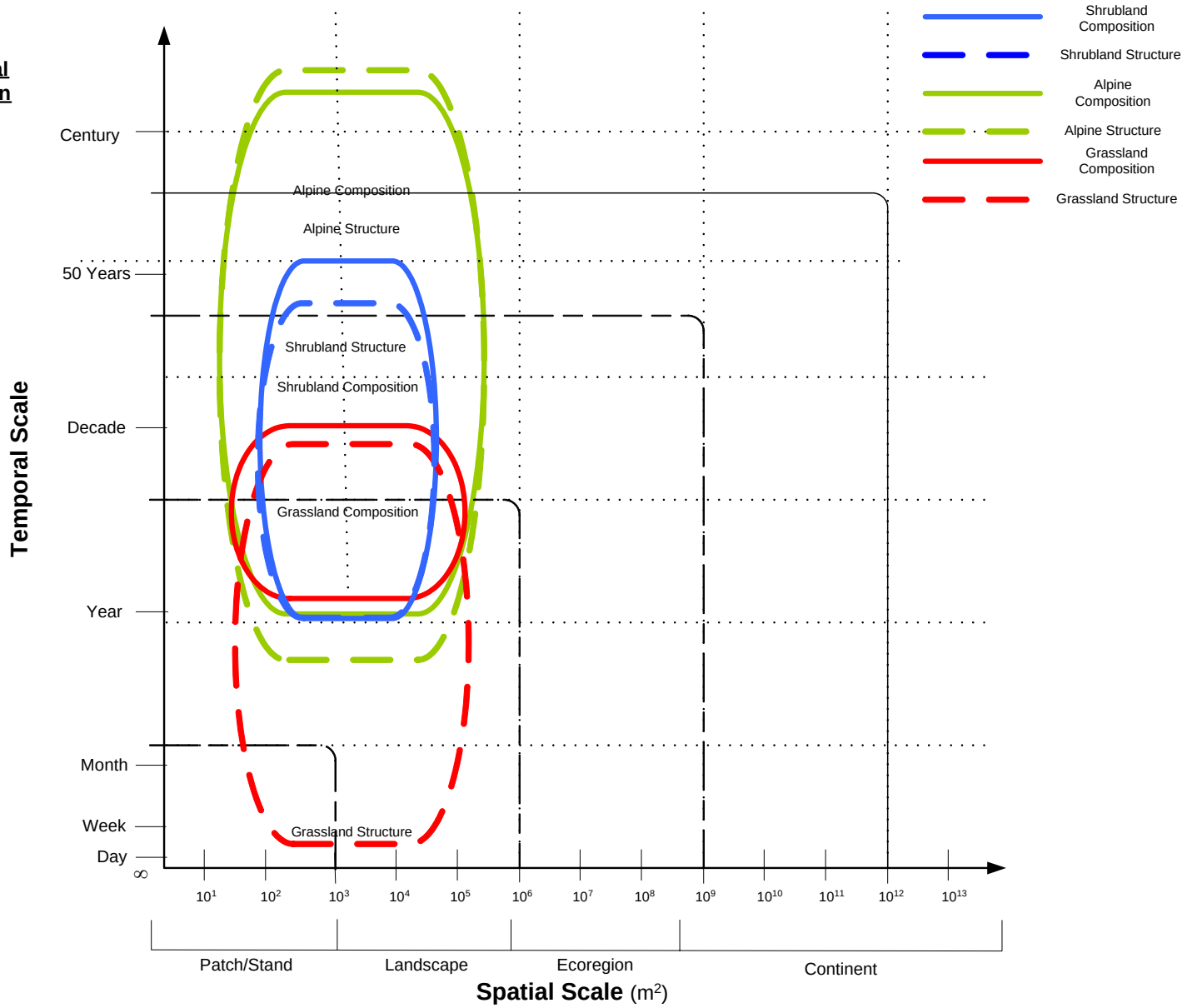
APPENDIX J-SPATIO-TEMPORAL MODELS

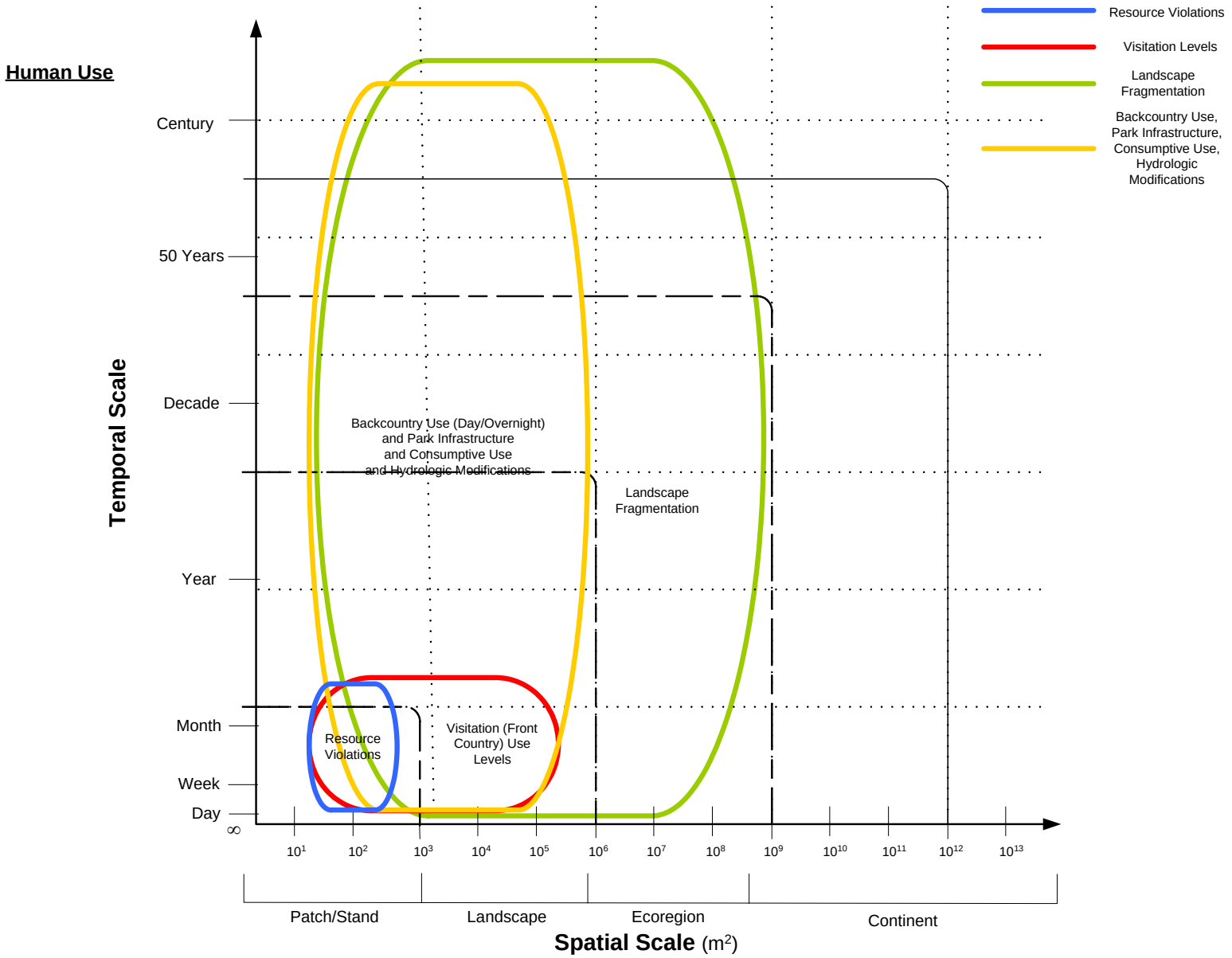
**Please note: these models are reproduction of those made by the breakout groups on day three of the workshop.



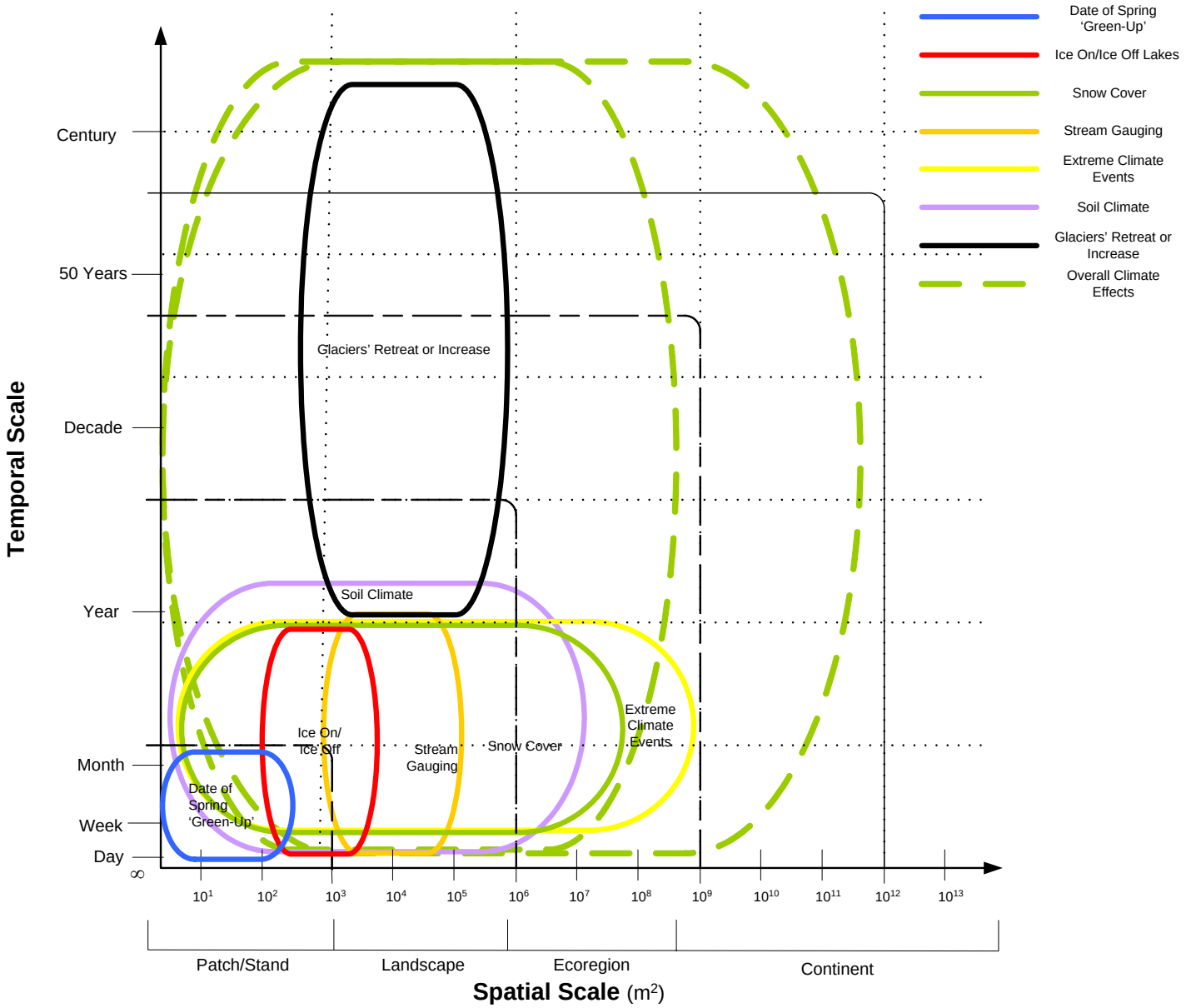

Terrestrial Vegetation
Browse Effects
Exotics in Shrublands
Exotics in Shrublands
Wetland Extent
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Exotics in Shrublands
Exotics in Shrublands
Wetland Extent
Browse Effects on Riparian Ecosystems
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

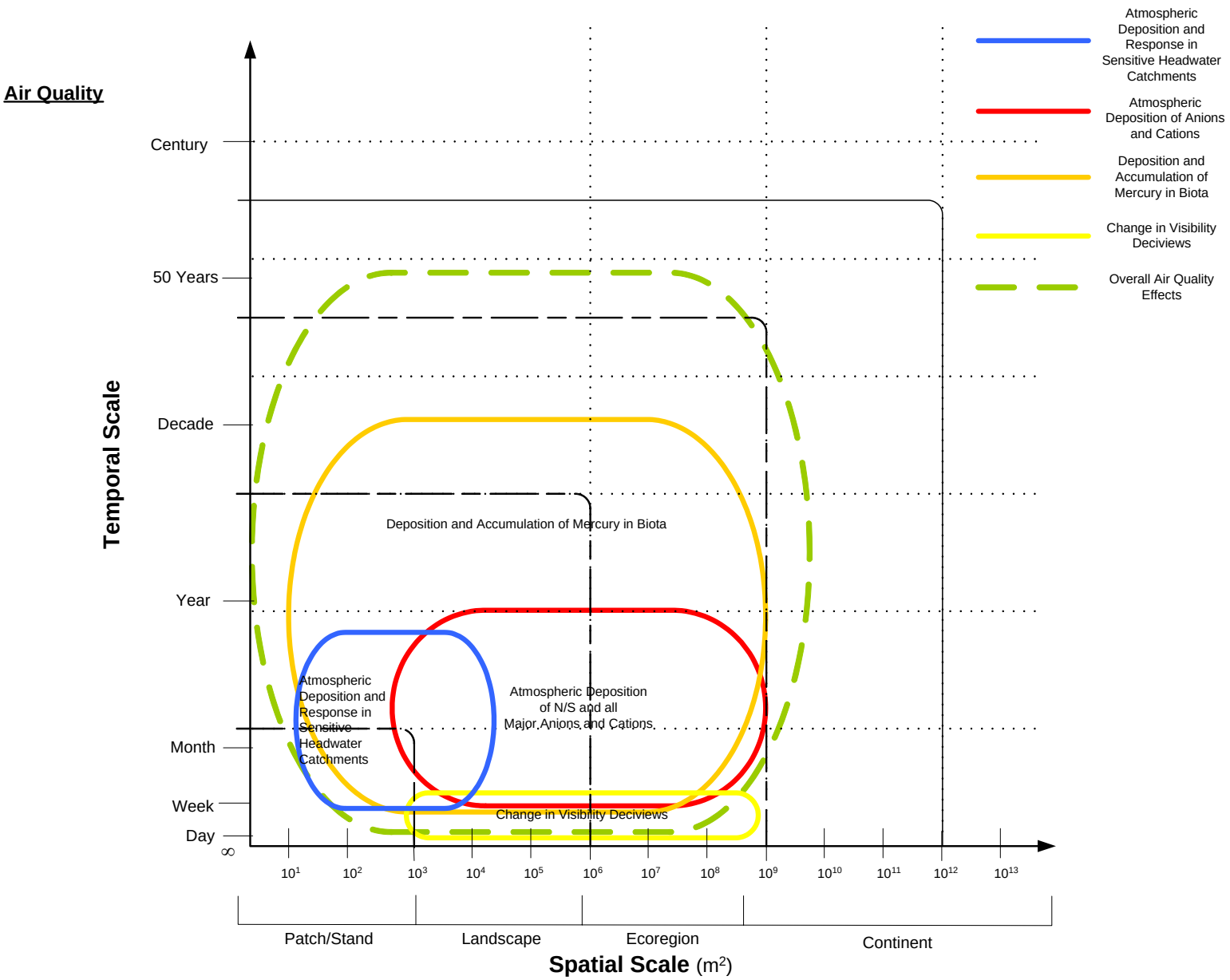
Terrestrial Vegetation



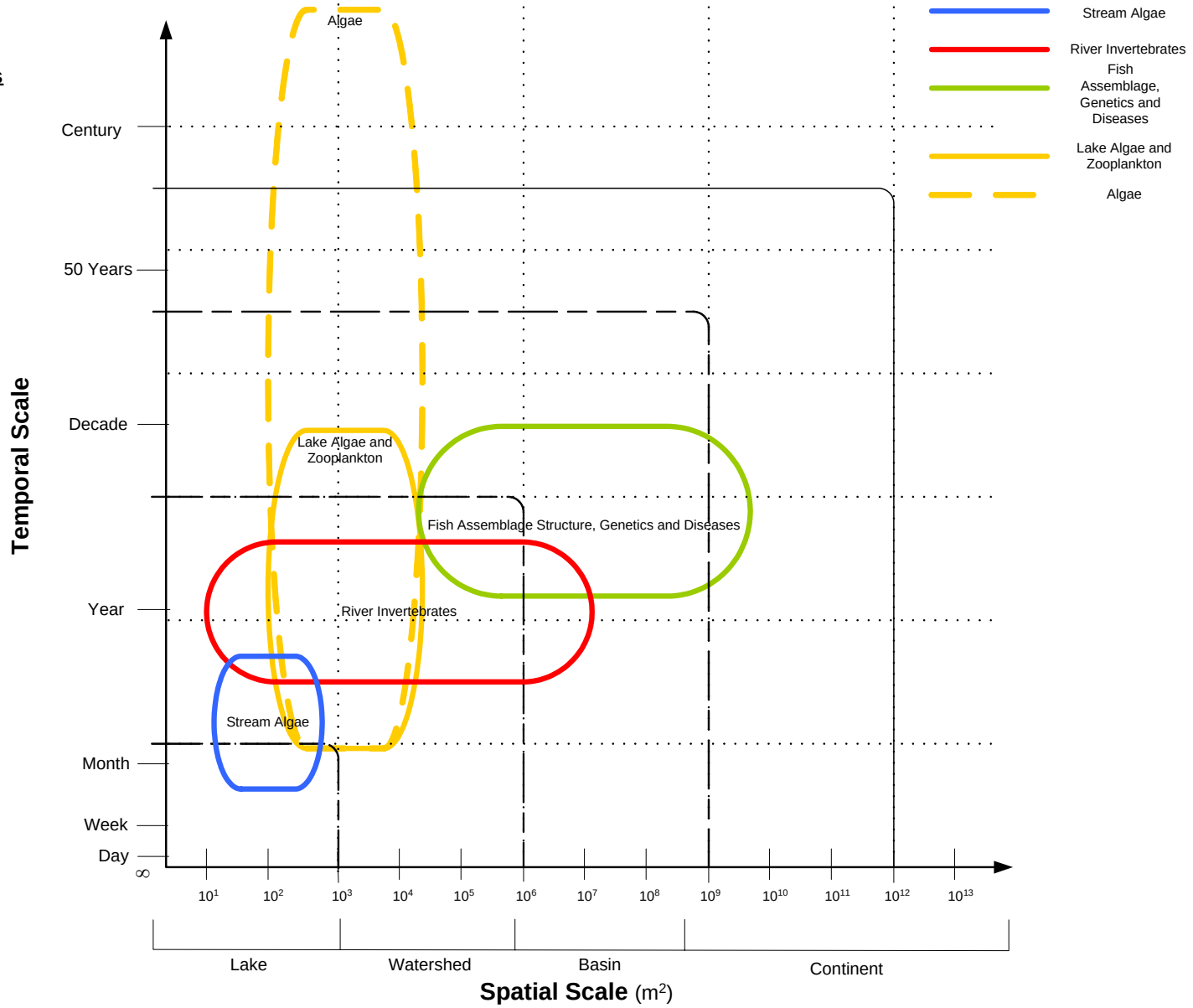

Human Use
Resource Violations
Visitation Levels
Landscape Fragmentation
Backcountry Use, Park Infrastructure, Consumptive Use, Hydrologic Modifications
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Backcountry Use (Day/Overnight) and Park Infrastructure and Consumptive Use and Hydrologic Modifications
Landscape Fragmentation
Resource Violations
Visitation (Front Country) Use Levels
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

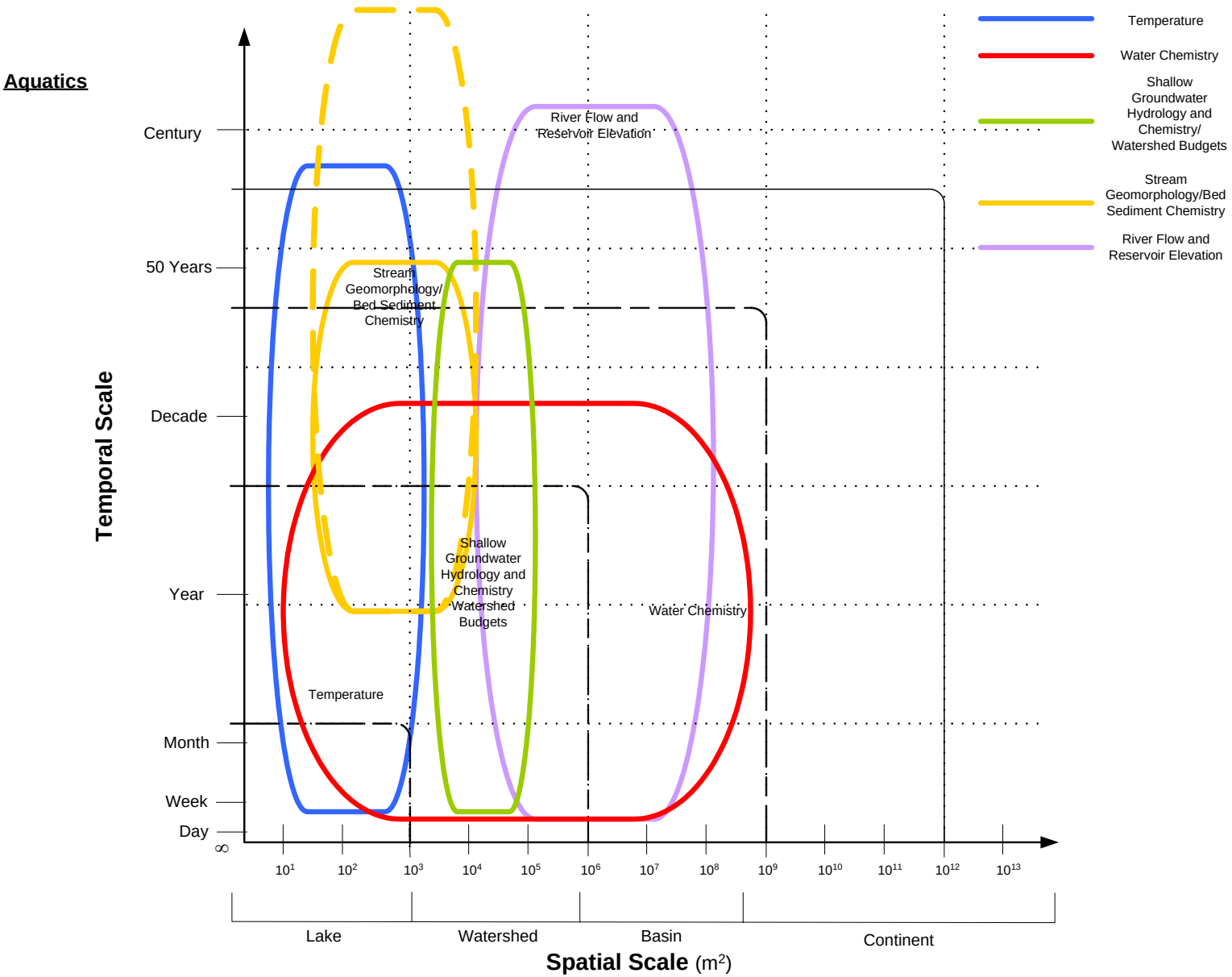
Climate


Date of Spring 'Green-Up'
Ice On/Ice Off Lakes
Snow Cover
Stream Gauging
Extreme Climate Events
Soil Climate
Glaciers' Retreat or Increase
Overall Climate Effects
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
Glaciers' Retreat or Increase
Soil Climate
Ice On/ Ice Off
Stream Gauging
Snow Cover
Extreme Climate Events
Date of Spring 'Green-Up'
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)

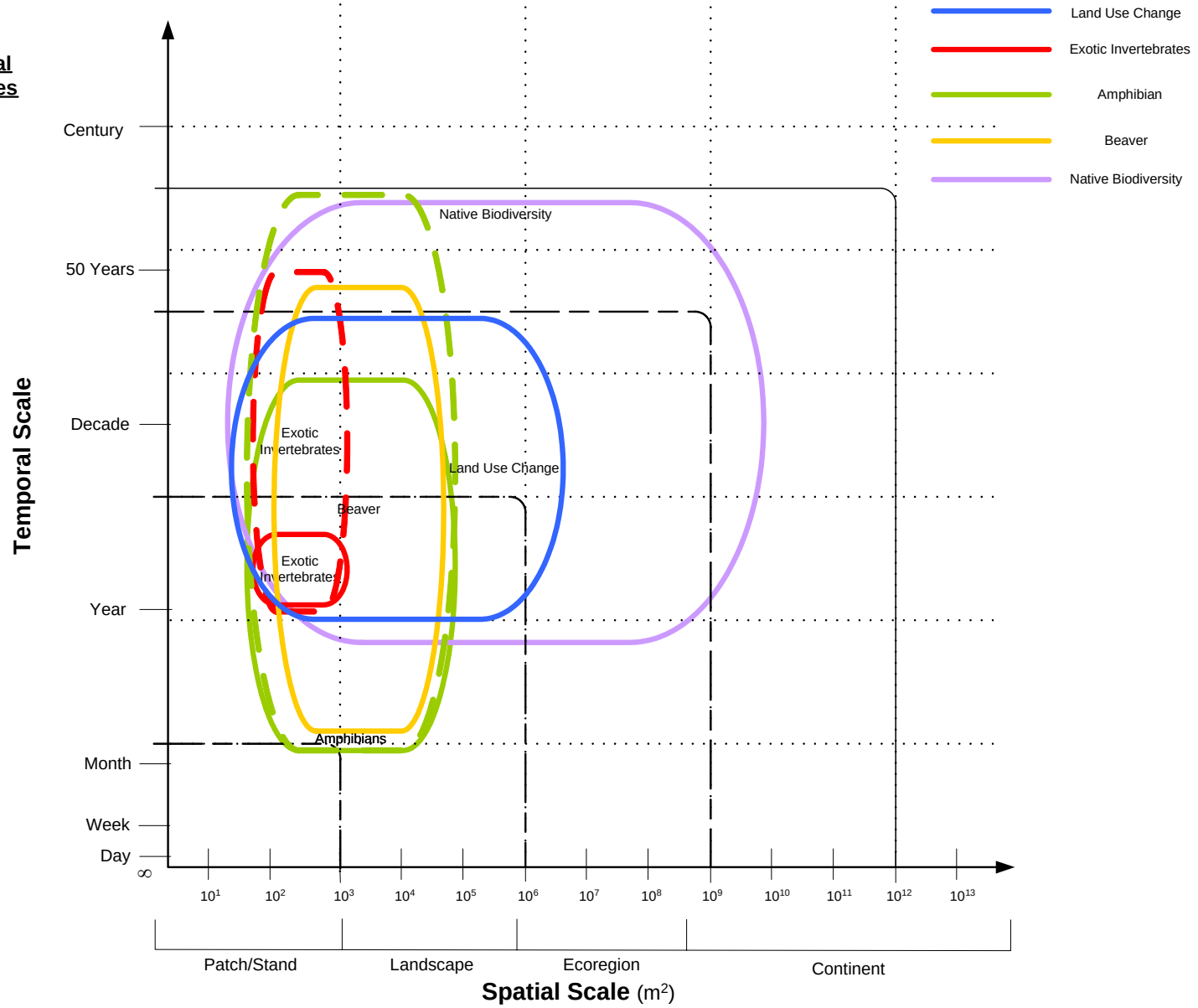

Air Quality
Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of Anions and Cations
Deposition and Accumulation of Mercury in Biota
Change in Visibility Deciviews
Overall Air Quality Effects
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Deposition and Accumulation of Mercury in Biota
Atmospheric Deposition and Response in Sensitive Headwater Catchments
Atmospheric Deposition of N/S and all Major Anions and Cations
Change in Visibility Deciviews
10¹ 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m²)

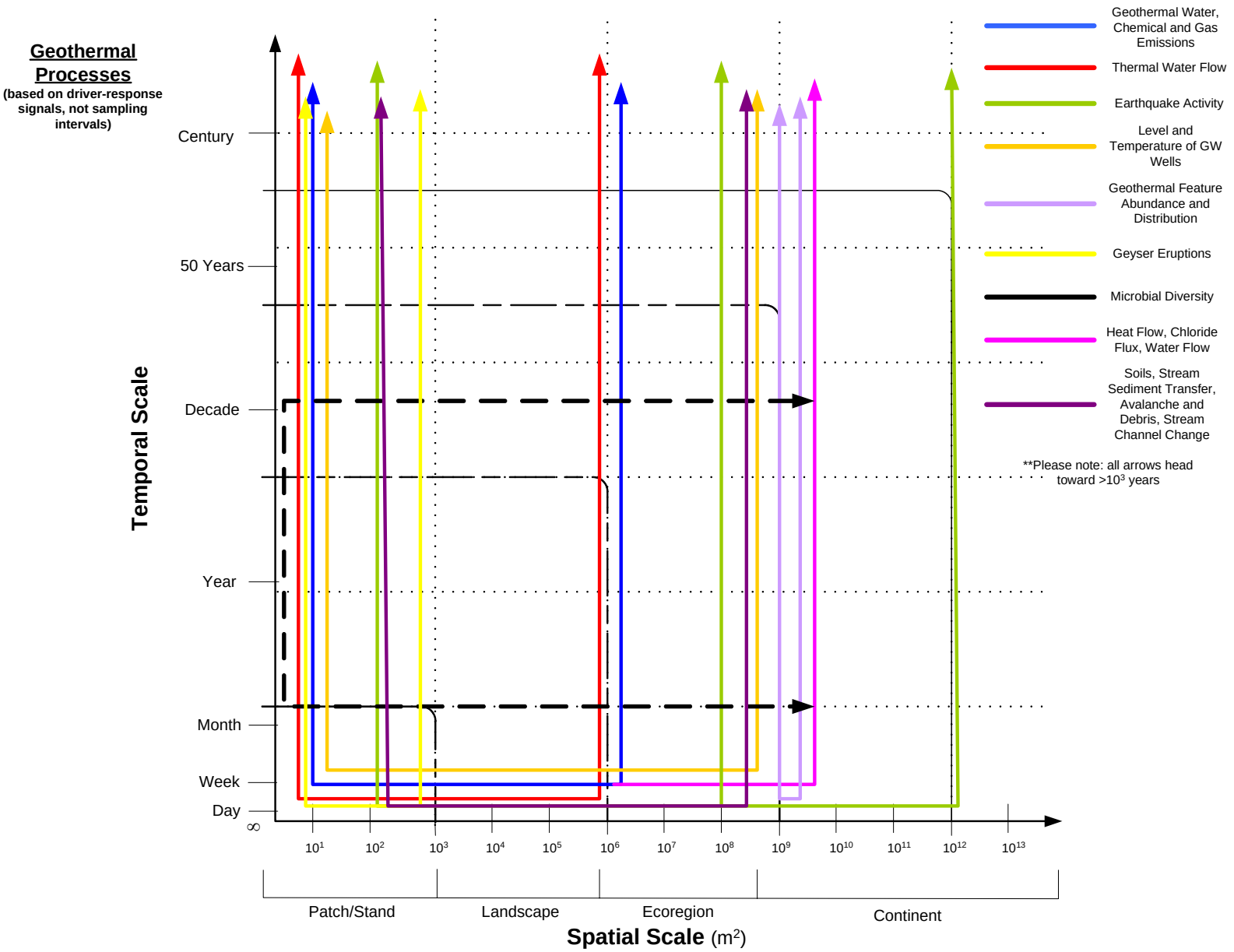
Aquatics


Stream Algae
River Invertebrates
Fish Assemblage, Genetics and Diseases
Lake Algae and Zooplankton
Algae
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
Algae
Lake Algae and Zooplankton
Fish Assemblage Structure, Genetics and Diseases
River Invertebrates
Stream Algae
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m^2)


Aquatics
Temperature
Water Chemistry
Shallow Groundwater Hydrology and Chemistry/ Watershed Budgets
Stream Geomorphology/Bed Sediment Chemistry
River Flow and Reservoir Elevation
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
River Flow and Reservoir Elevation
Stream Geomorphology/ Bed Sediment Chemistry
Shallow Groundwater Hydrology and Chemistry Watershed Budgets
Water Chemistry
Temperature
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Lake
Watershed
Basin
Continent
Spatial Scale (m^2)

Terrestrial Vertebrates




Geothermal Processes
(based on driver-response signals, not sampling intervals)
Temporal Scale
Century
50 Years
Decade
Year
Month
Week
Day
∞
10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
Patch/Stand
Landscape
Ecoregion
Continent
Spatial Scale (m^2)
Geothermal Water, Chemical and Gas Emissions
Thermal Water Flow
Earthquake Activity
Level and Temperature of GW Wells
Geothermal Feature Abundance and Distribution
Geyser Eruptions
Microbial Diversity
Heat Flow, Chloride Flux, Water Flow
Soils, Stream Sediment Transfer, Avalanche and Debris, Stream Channel Change
**Please note: all arrows head toward >10^3 years

APPENDIX VI:
PROTOCOL DEVELOPMENT SUMMARIES

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PROTOCOL DEVELOPMENT SUMMARY

Protocol: Amphibians

Parks Where Protocol will be Implemented: YELL, GRTE, BICA

***Justification/Issues being addressed*:** Declines in the abundance and distribution of amphibians have been widely recognized as an emerging issue (Stuart et al. 2004). Concerns regarding such declines resulted in the funding of the Amphibian Research and Monitoring Initiative (ARMI) in 2000. ARMI is a national program coordinated by the U.S. Geological Survey (USGS), with the goal of better understanding the dynamics of amphibian population trends and providing the information necessary to guide management decisions to manage and conserve amphibian populations.

Our specific monitoring objectives are intended to answer the following question(s): Is the occurrence of amphibians decreasing within the Greater Yellowstone Network of parks (GRYN) and is there any evidence regarding likely underlying causes of any observed declines that might warrant further directed research or management actions consistent with National Park Service policies? Although our specific monitoring objectives are targeted for inferences to the GRYN, they are also intended to complement broader objectives of ARMI that would seek to answer similar questions at more regional and/or national scales.

Monitoring Questions Addressed by the Protocol:

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the proportion of breeding sites (wetlands) within the GRYN occupied by each species of amphibian?
- What are the extinction and colonization rates of breeding sites within the GRYN, and are these rates associated primarily with whether or not sites are inundated within a given year?

Specific Monitoring Objectives:

Objective 1. To estimate the proportion of catchments (approximately 8th order) within YELL and GRTE used for breeding by each of each species of amphibian and to estimate the rate at which use of these sites for breeding is changing over time (except boreal toads, see Objective # 2).

***Justification/Rationale for this objective*.--** Actual population estimates for most amphibians are not logistically feasible due to substantial variability in detection of adults and in highly variable populations both within and among years (Corn et al. 2004). The use of sites for breeding should provide a more consistent measure of the occupancy of sites, at least for this life stage.

Objective 2. To estimate the proportion of catchments (approximately 8th order) and targeted

breeding sites within YELL and GRTE used for breeding by boreal toads (*Bufo boreas)* and to estimate changes in occupancy of targeted breeding sites over time.

***Justification/Rationale for this objective*.--** Boreal toads present a special case in that they are sufficiently rare so as to make estimation of rates of change difficult from a sampling scheme with a targeted scope of inference to the entire parks. Preliminary sampling indicates that the proportion of sites occupied by boreal toads is too low to enable reliable estimation of rates of change. Thus, the major distinction between this objective for boreal toads and that of the other species is that our sampling frame for change over time would be restricted to a targeted set of known potential breeding locations. This will limit our inference to change over time for these specific sites, but these probably represent the primary breeding sites for this species.

Objective 3. To estimate the proportion of potential breeding sites (i.e. wetlands) that are minimally suitable for breeding (i.e., have standing water) in any given year.

***Justification/Rationale for this objective*.--** For reliable comparisons of change in occupancy over time, the sampling frame must be the same from year to year. The occupancy estimator carries the assumption that sites have a non-zero probability of being occupied at the time that estimates are made. However, during some years, some wetlands have a probability of zero that amphibians will be breeding, given the hydrologic fluctuation that can occur. This objective is intended to account for that dynamic by incorporating the wetland dynamic into the likelihood whereby the occupancy estimator will be conditional on those sites with a non-zero probability of breeding.

BASIC APPROACH:

We are currently working with the USGS and the Idaho State University to refine a protocol that will meet the needs of ARMI as well as the GRYN. ARMI has widely adopted use of occupancy as their basic approach. Occupancy provides a measure that: (1) explicitly enables estimation of local extinctions and colonization of sites; (2) takes into account detectability of individual species; (3) enables estimation of confidence intervals; (4) is comparable across sites; and (5) is becoming a widely accepted approach for reliable estimates of occupancy.

The general design will be a cluster design, with the primary design unit approximately equivalent to an 8th order. The size of these units resulted from an extensive collaborative effort with the USGS EROS Data Center as well as field testing as part of a pilot effort. All wetlands will be surveyed within each unit. The general suitability of hydrologic units—based on the quantity of NWI wetland types within each unit—will be used to define unequal sampling probabilities. This is necessary because most hydrologic units within the parks are of poor quality for amphibians. Thus, using an unequal inclusion probability will enable us to invest most of our resources in those units that are most important to amphibians.

The overall design will likely be modified for BICA because most of the suitable amphibian habitat is contained within a series of impounded wetlands. Monitoring in BICA will consist of targeted surveys conducted collaboratively with the Wyoming Game and Fish Commission.

Principal Investigators and NPS Lead:

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Development Schedule, Budget, and Expected Interim Products:
The GRYN recently hosted a small workshop to address several issues of concern. Participants included staff members from the GRYN, GRYN network parks, ARMI, University of Idaho, and the USGS-Patuxent Wildlife Research Center. Based on the outcome of the workshop and subsequent workshops, we modified the existing ARMI methods to an approach that will be consistent throughout the Rocky Mountains from Montana to Colorado. We have just completed field testing of those modifications in collaboration with ARMI during FY05, with an expectation for a full protocol ready for review in fall of 2005. We anticipate full implementation by spring of 2006. The total cost to NPS will be approximately $35,000 per year with additional funds at least equivalent to the NPS contribution coming from USGS ARMI program.

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Protocol Development Summary

Protocol: Aridland Seeps and Springs

Parks Where Protocol Will Be Implemented: BICA

Justification/Issues Being Addressed:
Seeps and springs are often the only localized water source within a desert/arid environment during the drier periods of the year, since there are few perennial tributaries within the NRA. Also, Bighorn Lake (a reservoir behind Yellowtail Dam) is located within a deep canyon with vertical cliffs through much of the NRA and is difficult to access, and the water level is subject to tremendous variability depending on yearly and seasonal irrigation demands and on-going water rights disputes. Seeps and springs maintain the flow in many streams and in some cases are the sole sources for tributaries feeding Bighorn Lake. Plant and insect populations thrive in seeps and springs. By supporting the base of the food chain, seeps and springs indirectly support upland communities through trophic energy transfer. Some springs support known rare, endemic flora (e.g., *Sullivantia hapemanii* var. *hapemanii*) and possibly rare invertebrates. Other fauna are potentially strongly dependent on these scarce and vital water sources.

There are threats to seeps and springs within Bighorn Canyon that could reduce their potential to support wildlife, biodiversity, and streamflow. These threats include trampling and herbivory of vegetation and degradation of water quality by human visitors and ungulates (cattle and wild horses), and potential degradation of water quality and loss of water quantity through influence of industrial and agricultural activities and changes in water rights both inside and outside of the NRA on local and regional aquifers.

Of the three Greater Yellowstone Network units, Bighorn Canyon NRA is most susceptible to long-term climate changes affecting the primary water sources away from the mainstem of Bighorn River and Bighorn Lake behind Yellowtail Dam.

Specific Monitoring Questions and Objectives to be Addresses by the Protocol:

Specific monitoring questions are:

1. What are the current hydrological and ecological condition of the seeps and springs in BICA?
2. Which springs are affected by natural climatic changes or stochastic events vs. human-caused disturbance?

And more specifically:

3. Are there springs/seeps vulnerable to degradation from human activities both inside and outside the park?
4. Are the springs/seeps vulnerable to climatic changes?
5. Are there specific activities that degrade water quality, reduce water quantity (discharge) or change hydroperiod characteristics?

Specific monitoring objectives are:

Objective 1: Estimate discharge, variation in discharge, and change in discharge over time of seeps and springs within BICA, taking into account seasonal annual, and decadal variation.

***Justification for this objective*.--**
Spring locations in BICA are documented on USGS topographic maps and in cultural references. However, spring ecosystems have not described beyond the occurrence of a rare wetland plant—*Sullivantia hapemanii* var. *hapemanii*. Thus, baseline data are necessary to understand the current status of the resource and serve as a reference point for change detection. Discharge at the orifice is the first to respond to changes in climate, groundwater volume and groundwater flow.

Objective 2. Determine the status and change over time of water chemistry parameters at the orifice of seeps and springs within BICA including, but not limited to, conductivity, dissolved oxygen, pH, water temperature. Additional assessments of herbicides, fertilizers, pesticide usage, septic leach fields and chemical spills from machinery may be warranted.

***Justification for this objective*.--**
Water quality at spring orifices is a product of the contributing groundwater environment and the influence of the surface environment. Changes in water quality at the orifice indicate alterations to the groundwater environment. Changes in groundwater flow paths through different rock strata may alter the pH, temperature, specific electrical conductivity, etc. Groundwater pollution will also influence water chemistry in various ways depending on the pollutants. In BICA, the recharge areas nearest the orifice are susceptible to herbicide, fertilizer, and pesticide usage, septic leach fields and chemical spills from machinery. Detecting changes in water quality at the orifice will alert BICA staff to consider management actions that alleviate threats to groundwater quality.

Once at the surface, water quality parameters change with distance from the orifice due to interactions with the surface environment (e.g., evaporation, soil chemistry, biological transformations). If discharge is stable, then water quality at a particular distance from the orifice remains relatively stable. Long-term exposure to a particular set of stable aquatic chemical conditions results in specialized, often endemic, macroinvertebrate and plant communities.

Objective 3. Determine the status and change over time of aquatic macroinvertebrate composition along the first 100 m of runout of seeps and springs within BICA.

***Justification for this objective*.--**
Decreases in specialists and increases in generalist species often occur when variability in environmental conditions increases (Sada et al.2005). Many spring species have narrow environmental ranges (specialists) and therefore are susceptible to changes in water chemistry and habitat quality. Aquatic macroinvertebrates in spring ecosystems appear to display species-specific responses to disturbance due to a high degree of endemism (Heino et al. 2003, Sada et al. 2005).

Objective 4: Estimate spatial extent and change in spatial extent over time of mesic vegetation along the first 100 m of runout of seeps and springs within BICA.

***Justification for this objective*.--**
Changes in extent of spring wetlands and riparian areas along spring runout correspond to water flow changes whether natural (climate) or anthropogenic (water use). Lowered water tables, decreased flows and shorter flow duration result in smaller spring areas (Thompson et al. 2002). Because riparian and wetland plant communities vary with groundwater depth, changes in groundwater levels may result in shifts in community composition of spring ecosystems (Grootjans et al. 1988, Hendrickson and Minckley 1985). Numerous studies across the arid West have documented wetland and spring ecosystem shrinkage and losses in biodiversity due to groundwater depletion, regardless of cause.

Objective 5: Determine species composition and change in composition over time of vegetation along the first 100 m of runout of seeps and springs within BICA.

***Justification for this objective*.--**
Decreases in specialists and increases in generalist species often occur when variability in environmental conditions increases (Sada et al. 2005). A decrease in spring-related biodiversity could be indicated by a corresponding increase in upland or introduced aquatic and riparian species. While water quality and aquatic macroinvertebrates respond to acute environmental changes, soil chemistry and spring vegetation composition appear to respond to sustained environmental changes. Monitoring soil conditions in spring systems is fairly destructive which makes it a less appropriate monitoring attribute. Changes in spring vegetation composition indicate potential long-term, if not permanent, damage to spring ecosystems with the least amount of impact to the system. This objective owul also enable us to determine the extent of native vs non-native plant species changes in micro habitat diversity.

BASIC APPROACH:
Most spring and seep locations are known. A brief inventory to locate additional springs and seeps, especially along the canyon walls in the North District, has been undertaken. Threats to ecosystem functions of seeps and springs have be identified, including: long-term climate changes; groundwater withdrawals and additions of polluted water; additional or changing water rights on lands outside NRA boundary that are hydrologically connected to BICA seeps and springs; and effects of human and ungulate activities. Twenty-four springs were visited. Four springs are proposed as candidates for monitoring: one seep, one cattle-impaired spring, one pristine spring and one human-impacted spring. The overall sampling design will be developed cooperatively among the cooperators and Rob Bennetts. We will have alternative sampling design packages such that the costs and feasibility of implementation can be considered in light of trade-offs among exclusion of specific monitoring objectives, spatial or temporal extent of sites monitored and levels of precision or type II errors.

Field SOPs will be developed to identify changes in flow, water quality and aquatic and riparian vegetation, specific rare and/or sensitive plant species (and possibly specific invertebrates) associated with seeps and springs. Other standard operating procedures from protocols currently being developed will be incorporated as appropriate. These may include water quality and quantity SOPS from other spring/seep protocols (e.g., from NCPN), vegetation measurement SOPs from the landbird monitoring protocol and SOPs from the water chemistry protocol.

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Development Schedule, Budget and Expected Interim Products:
The sampling design and field data collection standard operating procedures as well as the data analysis and reporting protocols and final conceptual models will be completed by March 30, 2006.

The cost of the task agreement with the cooperators is $57,500. There are also some costs associated with the salary for Elizabeth Crowe's time as NPS project technical representative and Cathie Jean and NPS Lead, which are difficult to forecast accurately.

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Protocol Development Summary

Protocol: Aridland Soil Structure and Stability

Parks Where Protocol Will Be Implemented: BICA

Justification/Issues Being Addressed:
National Park Service staff at is concerned about the impacts of grazing animal populations on the structure and function of soils in Bighorn Canyon NRA. This concern is based on personal observations in the field and on the results of the rangeland health assessment of the Pryor Mountain Wild Horse Range (PMWHR) (Natural Resources Conservation Service 2004). The NRCS states that rangeland within the NRA portion of the PMWHR is in an unhealthy condition, reflecting attributes of the soils and plant communities that "may not be able to recover from degradation without energy inputs, such as mechanical alteration" (Natural Resources Conservation Service 2004). These poor soil conditions include: severe erosion, excessive loss of biological soil crust cover, and high bare soil and erosion pavement cover. The NRCS also states that "conditions are right for an explosion of noxious weeds" (Natural Resources Conservation Service 2004).

In aridlands, overgrazing by ungulates can cause soil compaction, loss of vegetation, loss of biological soil crust cover and diminishment of microbial activity and can ultimately lead to soil erosion (Belnap et al. 2001, Evenari 1981, Lee 1981, Metting 1991). Compaction of soils decreases water infiltration as well as reducing soil aggregates and pore space, which are important for soil stability and soil biota habitat (Belnap 1995, Lee 1981, Whitford 2002). Changes in aboveground vegetative cover or composition may result in reduction of belowground phytomass. In aridland environments, which have sporadic temporal and spatial precipitation, underground phytomass reserves are important reservoirs that provide resilience in face of erratic primary production rates (Evenari 1981). Loss of vegetative cover also reduces soil nitrogen retention (Hooper and Vitousek 1997, Tilman et al. 1997) and results in loss of food supply for soil bioturbators, such as ants and termites, which are essential for maintaining macropores and channels for water infiltration and redistributing and decomposing organic matter (Lee 1981, MacKay 1991, Polis and Yamashita 1991, West 1981).

Nitrogen is a limiting nutrient in aridland systems (Whitford 2002). Loss of biological soil crusts disrupts nitrogen and carbon cycles in interspaces between vascular plants (Belnap 1995, Harper and Pendelton 1993, Metting 1991). Biological soil crusts increase soil surface stability through the entrapment and binding together of soil particles by polysaccharides exuded by cyanobacteria and green algae and by lichen and moss rhizines (Belnap et al. 2001, Metting 1991, St. Clair and Johansen 1993). Accordingly, loss of biological crust cover decreases surface soil stability (Whitford 2002). Biological crusts also improve water infiltration on fine-textured soils (Metting 1991).

This initial assessment by the NRCS provides not only justification but a baseline to begin monitoring. Through development of a long-term monitoring protocol, we can provide more precise monitoring of soil structural and functional conditions. Long-term monitoring sites, sampled on a regular basis can also demonstrate whether range conditions correlate with short-

term (5-10 year) climatic changes in the NRA. This monitoring may also allow for more precise correlation of soil characteristics with increases and decreases in ungulate population sizes. Other studies in the PMWHR on the effects of grazing ungulates on vegetation (Fahnestock and Detling 2000, Fahnestock and Detling 2000, Gerhardt 2000, Gerhardt and Detling 2000) were conducted over such short time periods that results are ambiguous at best, and the studies did not apply to soil structure and function. Additionally, there is a proposal to expand the PMWHR into two more areas in BICA, the Sorenson Extension and East Trail Creek, both of which are north of the current National Park Unit boundary and both of which are currently in good condition. Should this extension occur, it would be opportune to install baseline monitoring sites before horses start grazing these areas and monitor conditions over time to supply information for future management decisions about grazing in the extension.

Specific Monitoring Questions and Objectives to be Addresses by the Protocol:
Specific monitoring questions are:

1. Are current soil structural and functional (nitrogen availability, soil moisture availability, wind and water erosion) attributes within the range of natural variability for different soil types?

2. Are there differences in soil structural and functional attributes and biological soil crust structure and composition in areas of ungulate grazing ranges compared to areas outside of ungulate grazing ranges? – see #1 above

Specific monitoring objectives are:

1. Determine the status and trend of unprotected bare soil, i.e., without biological crust cover or armoring by rocks, between vascular plants on each soil mapping unit paired both inside and outside of the PMWHR at three-year intervals.

BASIC APPROACH:

In FY2005 a literature review was completed, and threats and concerns were written. In July 2005 Dr. Jayne Belnap, world expert on biological soil crusts, who is helping to develop the soil monitoring protocols for the Northern Colorado Plateau and Southern Colorado Plateau Networks, joined GRYN and BICA staff on a two-day field trip to BICA to survey crusts in different soil mapping units inside and outside of the PMWHR and to discuss monitoring questions, objectives, sampling design and field methods.

NOTE: Communications Plan: This is an important Vital Sign to monitor, and we understand that it is a sensitive issue in that it involves the Pryor Mountain wild horse population. Thus, we will develop an appropriate communication plan along the same lines as the communication plan being developed for the Land use protocol.

Principal Investigators and NPS Lead:
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Development Schedule and Expected Interim Products:

FY2005-2006 – planning phase; development of protocol
FY2006 – pilot of sampling design and field procedures
FY2007 – approval of final protocol and start implementation

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PROTOCOL DEVELOPMENT SUMMARY

Protocol: Climate

Parks Where Protocol will be Implemented: YELL, GRTE, BICA.

Justification/Issues being addressed: Climate is a primary driver of almost all physical and ecological processes in the Greater Yellowstone Network (GRYN). Climate controls ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes underlying the distribution and structure these ecosystems (Jacobson et al. 1997, Schlesinger 1997, Bonan 2002). The effects of climate are especially visible in the strong zonation and steep elevational gradients displayed by vegetation types in the Greater Yellowstone Ecosystem (GYE) (Despain 1990, Whitlock 1993). Conceptual system models for the GRYN have also emphasized the influence of climate on other vital signs in the region (NPS 2003). Because YELL and GRTE are major sources of runoff for the Columbia and Missouri River Basins, climate variability in the GRYN has profound implications across large portions of North America.

Proxy records from archives such as glacial ice, lake sediments, tree rings and fossil corals show that, in both the recent and distant past, the earth's climate has varied significantly over timescales from months to millennia. Studies using combinations of instrumental records and paleo-proxies confirm, however, that global climate has changed rapidly over the 20th century and that the speed of these changes exceeds that of most previous fluctuations (Mann et al. 1999, IPCC 2001, USGCRP 2003). Global surface temperatures, in particular, have risen by 0.6 ºC ± 0.2 over the past century (IPCC 2001). Moreover, the bulk of scientific evidence indicates that this rise in global temperatures is related to human activities.

These global-scale changes will inevitably lead to significant alterations of Greater Yellowstone regional climate. Changing regional climate will, in turn, have a tremendous effect on natural systems in the GYE (Bartlein et al. 1997, Baron 2002, Wagner 2003). It is imperative that the parks of the GRYN have a climate monitoring system in place that allows for the detection and characterization of GYE climate change and provides climate data for use in monitoring and predicting the dynamics of other vital signs.

Weather and climate are also among the primary drivers of floods, fires and avalanches (NRC 1990, Singh 1996, Casale and Margotini 1999, Baker 2003). Timely and accurate weather and climate information can aid in predicting their occurrence and behavior, thus improving human safety and reducing negative economic impacts. Development and maintenance of weather and climate monitoring networks will provide invaluable information for the scientific study of these events.

Monitoring Questions Addressed by the Protocol:
Some of the specific monitoring questions that will be addressed by this protocol include:

- How does the climate of the Greater Yellowstone Ecosystem vary at different spatial and temporal scales relevant to the management of natural resources and the dynamics of other vital signs?

- Has the climate of the GYE changed significantly from that of past decades to centuries as a result of natural or anthropogenic forcing?
- Do these changes in climate warrant specific research or management actions to monitor or predict their effects on natural resources and other vital signs?

Specific Monitoring Objectives:

Objective 1: To measure precipitation and air temperature in the GRYN, including BICA, GRTE, YELL and surrounding areas.

Justification/Rationale for this objective: This objective will provide baseline data and continuously updated datasets to facilitate the detection of regional climatic change (both natural and human induced) and its effects on natural systems in the Greater Yellowstone Ecosystem (GYE) as a whole. Precipitation and temperature exert strong controls over almost all physical and ecological processes in the GRYN. Temperature and precipitation control ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes underlying the distribution and structure of these ecosystems (Jacobson et al. 1997, Schlesinger 1997, Bonan 2002). Because YELL and GRTE are major sources of runoff for downstream areas throughout North America, precipitation and temperature variability in the GRYN have profound implications outside the region as well.

Objective 2: To measure secondary climatic elements including wind speed/direction, relative humidity, soil temperatures and incoming solar radiation in the GRYN, including BICA, GRTE, YELL and surrounding areas.

Justification/Rational for this Objective: These data will complement information on temperature and precipitation gathered under Objective 1. Like the primary climatic elements (precipitation and temperature), wind, humidity, soil temperature and solar radiation exert strong controls over physical and ecological processes in the GRYN. These data are also tied to a large number of key GRYN vital signs. In the case of whitebark pine, for example, relative humidity and wind speed/direction are both key factors in controlling the spread of white pine blister rust (Kendall and Keane 2001). Wind and humidity influence fire behavior while soil temperatures and incoming solar radiation help control plant species distribution and ecosystem productivity.

BASIC APPROACH:

Unlike most vital signs, GRYN climate has been monitored continuously for over 100 yr. There is also a legacy network of monitoring stations maintained by a variety of state and federal agencies. Protocol development has focused on determining (1) if the legacy network provides adequate sampling of spatial and temporal variability in GRYN climate and (2) how best to address shortfalls in the current system.

Our basic approach involves a detailed analysis of existing climate monitoring stations in the GYE to determine if:

1. Current stations in the GRYN can adequately capture the key spatial and temporal components of climate variability in the region.

2. Strata of management interest or scientific importance are being adequately sampled.
3. The array of stations adequately provides data needed to understand and predict the dynamics of other vital signs in the GRYN.

Item #1 is being addressed using a combination of literature review and an examination of existing instrumental- and paleo-climate records for the GRYN. We are also examining sampling regimes and instrumentation at each site to determine if they meet National Weather Service surface observer guidelines (http://www.nws.noaa.gov/directives/010/010.htm), or if they must be updated to meet these standards.

Item #2 involves a series of geographic information systems (GIS) based analyses that will compare the locations of existing GYE climate stations (from Selkowitz 2003) against the vegetation and topography of the region.

Item #3 may also include a series of GIS-based analyses comparing station locations to key habitat types, populations of interest, sensitive ecosystems, etc., but will center on consultations with other cooperators and NPS personnel familiar with GRYN vital signs.

Efforts aimed at improving data transfer and archiving is also a key component of climate protocol development for the GRYN. Almost all high-quality climate data produced in the GRYN is now available via the Internet. These datasets, however, are hosted by a number of different agencies and navigating the vast amounts of available climate information can be a daunting and time-consuming task.

To maximize the usefulness and accessibility of GRYN climate data, we are exploring means to achieve:

1. Rapid data transfer.
2. Improved quality control and network-wide quality control standards.
3. Development of software and Web access that allows users to develop a mesoscale or synoptic view of current and past GRYN climate (*see* http://www.mesonet.org/ *for examples*).

The GRYN and Big Sky Institute also recently conducted a workshop in conjunction with MTNCLIM 2005, a research conference aimed at understanding interactions between climate and ecosystems in western North America (www.fs.fed.us/pnw/mtnclim). This workshop focused on integrating climate monitoring in the GRYN with efforts from surrounding networks.

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Development Schedule, Budget, and Expected Interim Products: In June 2005 the network received a draft monitoring protocol from the cooperator. This protocol will be augmented with products derived from the Cooperative Agreement between NPS WASO and the Western Regional Climate Center which are expected in late 2006. The final protocol will be ready for peer review and full implementation in 2007.

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PROTOCOL DEVELOPMENT SUMMARY

Protocol: Integrated Water Quality

Parks Where Protocol will be Implemented: YELL, GRTE, BICA.

Justification/Issues being addressed: Water quality monitoring is a fundamental tool in the management of freshwater resources. The chemical, physical and biological health of waters is considered of national value and is protected by the Federal Water Pollution Control Act. This act is designed to ensure that Americans have clean water for domestic, agricultural, commercial and recreational uses. Water quality monitoring helps ensure that a water body is suitable for its determined use. It can also be used for protective purposes to prevent degradation or to upgrade conditions. Chemical and physical tests give information that is accurate only at the moment the sample is taken. Physicochemical measures have predominated North American aquatic bioassements and monitoring programs despite the well-documented arguments that pollution assessment is primarily a biological problem. The use of macroinvertebrates as indicators of aquatic ecosystem health developed out of observations that specific taxa were restricted under certain environmental conditions (Richardson 1925, 1929 and Gaufin 1958). The presence of a mixed population of healthy aquatic insects usually indicates that the water quality has been good for some time. This then led to the development of a list of indicator organisms and the acceptance of using macroinvertebrates for use in water quality monitoring.

Water resources are especially important in the Greater Yellowstone Network (GRYN) because of the Outstanding National Resource Water designation for Yellowstone and Grand Teton National Parks. These important places are headwaters to the Yellowstone and Snake River watershed. Water resources also provide important public recreational opportunities in Bighorn Canyon NRA, critically important plant and wildlife habitat, and unique scenic vistas within all three network parks.

Aquatic resources across the GRYN face numerous and varied threats, including atmospheric deposition, altered hydrology, mining, agriculture, pollution from boats, non-native species, erosion, leaking underground storage tanks, improper sewage plant or drain field operations, and storm water runoff. Water quality monitoring to assess the effects of these threats has been underway for over 50 years, though not as a coordinated, comprehensive program focused on ecosystem health.

Specific Monitoring Questions and Objectives Addressed by the Protocol

Objective 1. Determine the status and trend of a primary set of water chemistry parameters including, but not limited to, conductivity, dissolved oxygen, pH, water temperature and discharge in perennial surface waters of all GRYN parks.

Justification/Rationale for this objective.-- The initial status and variation of core water quality parameters provides the background reference point to which all subsequent data will be compared. Although these data do not provide a measure of completely pristine conditions, they

do provide a measure of the status of aquatic systems at the start of the GRYN monitoring program.

Objective 2. Determine levels of substrate composition and embeddedness in perennial surface waters of GRYN parks.

Justification/*Rationale for this objective.*-- Sedimentation issues have been a concern in the parks for the past century. Sedimentation associated with grazing, construction (including roads), trail use and fire are of particular concern. Areas with steep slopes and geologically sensitive areas such as Mount Everts near Mammoth Hot Springs (YELL) and the Grand Canyon of the Yellowstone River (YELL) have been previously identified as areas of concern (www.nps.gov/yell/nature/nothernrange). Grazing of commercial livestock is of particular concern in GRTE. As of 2004, five ranches remain in the park with permits to graze 1,800 cows and horses on 36,000 acres of property (Smith 2004).

Objective 3. Determine the status and trend in benthic macroinvertebrate communities in flowing perennial in surface waters of GRYN.

Justification/*Rationale for this objective.*-- These data provide information on long-term trends in macroinvertebrate communities and will be used as an indicator of potential degradation. Changes in the macroinvertebrate community may indicate impacts (episodic events) on water quality missed in routine water chemistry monitoring. In addition, changes in the abundance or richness of macroinvertebrate may indicate changes in food-web dynamics that may impact both aquatic (fish) and terrestrial (birds, amphibians) ecosystems.

Objective 4. Determine the status and trend in the acid-neutralizing capacity of high-risk alpine lakes of the GRYN and estimate the rate at which water chemistry is changing over time in response to atmospheric deposition. Factors that determine high risk have been recently assessed through a complimentary research program that will enable us to identify this subset of lakes.

Justification/*Rationale for this objective.*-- Atmospheric deposition maps (for 1992 through 1999) of the Rocky Mountains show regions of high atmospheric deposition in the northern Rocky Mountains (Nanus and others 2003), including parts of Wyoming and Montana. High-elevation watersheds in the Rocky Mountains are particularly sensitive to the impacts of N-deposition because they are typically underlain by thin soils and resistant bedrock that provide little acid-neutralizing capacity, which makes the watersheds highly sensitive to chemical inputs (Williams and Tonnessen 2000, Clow and Sueker 2000, Nanus et al. 2003). Nitrogen deposition has been linked to high surface water nitrate levels, changes in zooplankton community composition (Barmuta et al. 1990), impacts on macroinvertebrate fauna (Kratz et al. 1994) and altered diatom composition (Williams and Tonnessen 2000, Lafrancois et al. 2003, Baron et al., 2000, Wolfe et al. 2001). Cutthroat and rainbow trout are particularly sensitive to acidic episodes that may result from nitrogen deposition (Baker et al. 1990). Current (2005) atmospheric deposition rates and proposed changes in atmospheric emissions, including increasing emissions from power plants and energy production near Grand Teton and Yellowstone, have the potential to further alter the chemistry of these aquatic ecosystems (Nanus et al. 2005).

Objective 5. Measure concentrations of polycyclic aromatic hydrocarbons (PAHs) and other constituents associated with two-stroke and four-stroke engines at targeted marinas within GRYN.

Justification/*Rationale for this objective.*-- Monitoring of surface waters will be designed to assess the impacts of two-stroke and four-stroke engines via direct deposition into the lakes (boating).

Objective 6. Determine input of nutrient enrichment and wastewater effluents through analysis of fecal coliform bacteria and macroinvertebrate communities at a small number of targeted sites of high concern within the GRYN.

Justification/*Rationale for this objective.*-- Surface waters located adjacent to or immediately downstream of old septic fields, park residential areas, heavily used backcountry sites, park lodging and dining areas may be susceptible to water quality impairments associated with waste water effluent.

Objective 7. To detect occurrence of aquatic invasive plant and animal species at select targeted locations most susceptible to initial invasion (marinas, areas of high fishing access, etc) with an emphasis on areas that coincide with water quality monitoring samples within GRYN.

Justification/*Rationale for this objective.*-- Detecting incipient populations of aquatic invasive species is crucial to preventing permanent establishment and/or spread. Eradication of an invader that is become established is rare (Mack and others 2000), so it is best to find and eliminate a species before it becomes established. Previous surveys have reported the presence of New Zealand mud snails in GRYN surface waters and initial investigations suggest the potential for others such as Zebra mussel (*Dreissena polymorpha*), Eurasian watermilfoil (*Myriophyllum spicatum*) and purple loosestrife (*Lythrum salicaria*). These organisms are likely to have significant impacts on native vertebrate and invertebrate fauna and a monitoring program designed to detect the distribution and determine the trend in spatial extent and abundance is critical to park managers.

Basic Approach:

Our approach is intended to balance several conflicting considerations of cost, feasibility, statistical validity, preserving the integrity and continuity of previous data, and multiple users of water quality data. From purely a statistical standpoint, the broadest inference would be obtained using a probabilistic design (e.g., a Generalized Random Tessellation Stratified Survey Design [GRTS]); however, this would: (1) potentially decrease, at least initially, the integrity and continuity of existing fixed monitoring stations; (2) be prohibitively expensive given the difficulty of access to many parts of the GRYN; and (3) decrease its value for other vitals signs for which some fixed stations were located (e.g., geothermal monitoring). After considerable debate and discussion, the direction that we are now taking would:

1. maintain existing fixed stations as part of a split panel design (see below).

2. incorporate a component of probabilistic sampling within realistic costs.
3. incorporate a few targeted sites for specific threats (e.g., polycyclic aromatic hydrocarbons [PAHs]).

We will use a split panel design that partitions (splits) the panels (i.e., collection of sites sampled during a given year) into two or more revisit designs. Such an approach constitutes a compromise between emphasis on spatial and temporal variation. Typically, split panels entail an always visit design in combination with some other revisit design (e.g., repeating panel). The "always visit" design is the strongest for detecting temporal variation but is weak for detecting spatial variation since the same panels are visited on each occasion. Combining this with an alternative panel can strengthen detection of spatial variation.

Fixed monitoring sites were selected that target specific waters of concern and/or act as integrator sites (i.e., located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions, intended to reflect conditions within that basin). As such, these are important data sources to the parks, which have placed high value on maintaining their continued monitoring. These sites also have sufficient access to enable feasible year-round monitoring. Thus, our intention is to maintain use of these sites in the context of the "always visit" component of the split panel design, where these sites are monitored every year and provide a temporal continuity that is used to help interpret sites selected through probability sample that have a repeating panel (see below).

The fixed sites would be augmented with additional sites selected through a probabilistic sample. These sites would be on a repeated panel design such that a subset of sites (probably within a given drainage basin) would be sampled in any given year. When all of the sites have been sampled (i.e., after a period of years), the sampling would then return to a repeat sampling of the first subset, and so on. This approach enables a sample of sites representing the spatial variation to be accumulated over several years (we are targeting 3-5). However, this type of panel structure can result in confounding of spatial and temporal variation, particularly when the samples within a given year are from the same basin. Given that logistical constraints of access precludes having the panels distributed throughout the parks within any given year, the fixed sites, which are monitored every year, will help to reduce the confounding of spatial and temporal variation.

The probabilistic approach that we will use will be the Generalized Random-Tessellation Stratified Design (GRTS [Stevens and Olsen 2004]), which is well suited to our needs. The GRTS design uses a hierarchical randomization process to achieve spatial balance across the region and resource and has good variance properties.

In addition to the design described above, we anticipate having a small set of targeted sites intended to assess specific threats. For example, sites in the vicinity of marinas will be targeted for monitoring polycyclic aromatic hydrocarbons and sites used for swimming may be targeted for fecal coliforms.

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The integrated water quality monitoring protocol is a collaborative effort among Rob Bennetts, who is lead on the sampling design, Rob Daley, who is lead on the data management, and park staff Susan O'Ney at GRTE, Cassity Bromley at BICA and Jeff Arnold at YELL.

Development Schedule, Budget, and Expected Interim Products:
The protocol narrative is a joint effort with help from the cooperator and network staff. The sampling design and protocol narrative will be completed and ready for peer review in FY06. Implementation will start in FY07.

The SOPs for this protocol were peer reviewed in 2005 as part of the review for the regulatory water quality plan, which covers objectives for 303(d) streams only (see the Regulatory Water Quality Protocol Development Summary for details). Changes specific to the integrated water quality protocol will be incorporated into the SOPs in FY06.

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Protocol Development Summary

Protocol: Invasive Plants

Parks Where Protocol Will Be Implemented: BICA, GRTE, YELL

Justification/Issues being addressed: Invasive exotic plants are a top priority vital sign for the Greater Yellowstone Network. There is a strong consensus among scientists around the world that, after habitat loss and landscape fragmentation, the second most important cause of biodiversity loss now and in the coming decades is invasion by alien plant, animal and other species (Allendorf and Lundquist 2003, Chornesky and Randall 2003, Walker and Steffen 1997). In all of the parks, invasive exotic plant species are a serious threat to natural and cultural resources. Yellowstone and Grand Teton are two of the more heavily visited national parks in the country and are visited by people from throughout the 50 states and the world, who bring a continuous influx of new species on their clothes and vehicles. Bighorn Canyon has fewer visitors but most of them come to the NRA for fishing and boating, and exotic aquatic species are spread even more quickly than terrestrial. Invasive exotic plants have replaced native vegetation in large areas of Grand Teton and Bighorn Canyon, are widespread in the Northern Range of Yellowstone, and present an ongoing threat of further displacement. This displacement affects not only native vegetative community structure, composition and succession but can also cause extirpation or extinction of endemic and/or endangered plant species (Mack et al. 2000, Walker and Smith 1997). Exotic plants that become invasive, aggressive and widespread create detrimental impacts to animal habitat and nutrition, soil nutrient cycling, and fire and flood processes in parks (DiTomaso 2000, Goodwin 1992, Mack et al. 2000). Park Service national management policy states that exotic species will not displace native species if displacement can be prevented (NPS 2001). In order to prevent this displacement, monitoring of new populations and established species is essential. In addition it is vital to monitor the effects of both the existence of exotic populations and the management of exotic populations on native species and ecosystems. Inventory or mapping of infestations has been completed for BICA, GRTE, and the Northern Range, along major roads and in some backcountry areas of YELL.

BASIC APPROACH:
There are four general areas of invasive plant monitoring that are addressed in this protocol: early detection, status and trend, effects of invasive plants on native vegetation and ecosystems, and restoration of native vegetation and ecosystems following control/treatment of invasive plants. Through the process of researching background material and writing threats and concerns for this vital sign as well as meeting with park staff about their needs and priorities, we are approaching these four areas of monitoring as described below.

Early Detection

FRONTCOUNTRY
The three park units in the GRYN have been conducting informal early detection surveys for species new to frontcountry areas of the parks in conjunction with their invasive plant control programs. The parks would like to standardize data management of the 11 standard NAWMA (North American Invasive Plant Mapping Standards) fields that are in the databases of the three park units in order to be able to share and consolidate information. Searching these frontcountry

areas has been found to be highly effective in detecting incipient populations of new species. GRYN staff will assist the parks in developing standard operating procedures (SOPs) for data collection, training of personnel and data management.

BACKCOUNTRY

For backcountry early detection monitoring GRYN staff will test procedures currently being developed by USGS researchers in various parks and I&M networks throughout the country. These procedures will be available in 2007. If these procedures are found to be practical for use in the GRYN park units, staff will develop SOPs for backcountry early detection monitoring in 2007-2008.

Status and Trend

Status and trend monitoring of invasive species will emphasize Priority 1-3 species (see below) and will likely be conducted by park staff. The GRYN will develop the SOPs and assist staff in initial implementation.

Effects of Invasive Plants on Native Vegetation and Ecosystems

GRYN staff will develop SOPs and conduct monitoring of the effects of invasive exotic plant populations on the native plant communities and ecosystems. This monitoring will emphasize Priority 4 species (see table below for definition of priority levels), which are so widespread in the parks that they are no longer considered treatable but are thought to have serious impacts on resources.

Restoration of Native Vegetation and Ecosystems Following Treatment/Control of Invasive Plants

GRYN staff will develop SOPs and conduct monitoring on the restoration of native plant communities and ecosystems following treatment/control of invasive plants.

A list of invasive exotic plants has been compiled for the three parks and a network classification of priorities for species has been created based on individual park prioritization categories (Table 1). These priority categories, based primarily on need for and ability to control populations, have been applied to specific monitoring objectives as shown below. The priority classifications will be updated over time as population demographics of established species and management priorities change and as new species arrive in the parks. If necessary, classifications will also be revised to reflect monitoring priorities rather than primarily control priorities.

We are currently developing a matrix of the 125 prioritized invasive exotic species on: phenology; demographics; general growth characteristics; reproduction; habitat affinities; tolerances; invasiveness; documented effects on native vegetation, nutrient cycling, soil biota, and higher trophic levels; and successful or recommended monitoring methods. This matrix will be used to develop final specific monitoring objectives. Currently, we have draft general objectives (see below) that will potentially apply to specific species in specific habitats or targeted sites in the parks.

Researchers at Montana State University are currently refining monitoring methodologies for tracking the changes in density and spread of invasive species (especially those that grow in definable patches, such as smooth brome) on national forest land north of Yellowstone National

Park. A main focus of their research is to determine the difference in invasiveness of a given species in different habitats. We will work as closely as possible with the researchers and YELL park staff to coordinate with and complement (rather than overlap) these efforts.

Monitoring of all important invasive plant species may be costly, especially in terms of field data collection. We will develop a set of sampling designs to answer different monitoring objectives that can be evaluated in terms of cost and feasibility and that will offer trade-offs in levels of precision or type II error rates.

Table 1. Definitions for GRYN Prioritization of Invasive Species

Watch List (WL): Exotic species not documented/established in the park(s).
Priority 1: Species that have produced seed in the park, but populations are small and limited in number. These species have a high probability for eradication with continued annual monitoring and treatment. They are also the most cost effective species to control. SMALL POPULATIONS, CONTROLLABLE
Priority 2: Species that are invasive and aggressive and capable of rapid spread within the parks. Most are confined to relatively small localized areas. These species are capable of disrupting or displacing native plants. Many of these species are well established in the park, but aggressive control can be effective by limiting the spread. Containment will be the primary goal for these species with eradication as a secondary goal. Individual plants or small infestations away from core infestation areas will be a high priority for aggressive control. AGGRESSIVE INVADERS, CONTROLLABLE
Priority 3: Species that are invasive but less aggressive and less capable of displacing native species. They are undesirable, but not necessarily as invasive as Priority 2 species. Control actions have a greater chance of containing or eradicating the populations. LESS AGGRESSIVE. CONTROLLABLE
Priority 4: Aggressive exotics that are dispersed over large areas of the parks and have deleterious effects on the park ecosystem. Control efforts are likely to be ineffective and costly and have lower probability of reducing, containing, or eradicating populations. However, work may be done to confine the spread of these plants in sensitive areas. These species may be treated with other treatment activities (i.e., roadside treatments, vegetation restoration work) but will not be aggressively treated until more feasible methods are found and approved. Biological controls will be utilized when available to reduce populations. Monitoring would be beneficial, but will come after Priorities 1 and 2. AGGRESSIVE, WIDESPREAD,(CURRENTLY) NOT CONTROLLABLE EXCEPT IN LOCALIZED AREAS
Priority 5: Exotics, for which little or no control efforts are foreseen. Even though many of these plants displace native vegetation, control of high priority species takes precedence. Limited monitoring actions may be undertaken. Approximately 138 species fall into this category. None of the plants in this category are listed as noxious by the surrounding states. ???
Priority 6: New species that have been found during inventory efforts throughout the park. Species are non-native, escaped ornamentals about which little is known. ???

Specific Monitoring Questions and Objectives to be Addresses by the Protocol:

Monitoring questions are:

1. Where are new populations of invasive exotic plant species being established?
2. In which habitats of our network parks are these species invasive?
3. How can we monitor invasive plants to ensure that our currently known weed-free areas, especially in habitats that are rare, sensitive or of particularly high value, remain in that condition?
4. What is the status and trend of existing populations of invasive species of interest, including species being actively treated and those that are currently considered beyond control?
5. What effects are existing populations of invasive plant species having on native vegetation and ecosystems?
6. What effect is the management of exotic plant species having on restoration of native vegetation and ecosystems?

Current **DRAFT** general monitoring objectives are:

(NOTE!!: background work is still ongoing that will used in refining monitoring objectives and making them specific to individual species and locations, i.e. inferential populations will be defined):

1. ***Management Objective***: Prevent the establishment of viable populations of invasive exotic plants new to the parks (Watch list species).

   Monitoring Objective: Detect occurrences of invasive exotic plants new to the parks before they become viable populations. Until USGS protocols are available to test in backcountry areas, this objective will be applied primarily to roads, developed sites and easily accessible areas of the parks, i.e. frontcountry areas.

2. ***Management Objective:*** Prevent the establishment of viable populations of invasive exotic plants (Priorities 1-3) in weed-free zones of the parks.

   Monitoring Objective*:* Detect occurrences of Priority 1-3 invasive exotic plants in weed-free zones of the park before they become viable populations.

   Justification/Rationale for Objectives 1 and 2.--
   Detecting infestations as soon as possible is crucial to preventing establishment or allowing invasion to begin. Eradication of an invader that has become established is rare (Mack et al. 2000), so it is best to find and eliminate a species before it becomes established. In addition, the costs associated with controlling an invasive species escalate as it becomes more widely distributed (McNeely et al. 2001). Propagule pressure is very important to the success of an exotic plant becoming established and invasive (Allendorf and Lundquist 2003, Colautti and MacIsaac 2004, D'Antonio and Vitousek 1992, Williamson 1996). Propagule pressure comprises not only the number of seeds or regenerative asexual parts that a species produces, but also the number of establishment sites of a species. The more infestation sites or invasion foci a species has, the greater are its chances of successful establishment (Moody and Mack 1988). Also, the lag time for a given species to become invasive in an area is unknown, and there is no way to predict the outcome of any particular introduction of an exotic species (Lodge 1993). No successful set of characteristics to predict invasibility has been determined (Rejmánek and Richardson 1996, Williamson 1996). All of these reasons demonstrate the importance of finding and eliminating an exotic species as soon as possible after its arrival in an area.

3. ***Management Objective***: Allow no establishment of viable populations of Priority 1-3 invasive species outside of control boundaries.

   Monitoring Objective: Determine status and trend of Priority 1-3 invasive exotic plants outside of control boundaries at 5 year intervals.

4. ***Management Objective*****:** Observe status and trend of selected Priority 4 & 5 invasive species throughout the parks in order to inform management.

Monitoring Objective: Determine distribution and abundance of Priority 4 & 5 invasive species at 5 year intervals.

Justification/Rationale for Objectives 3 & 4.--
Park weed management staff need information on the status of existing populations of invasive plants in order to prioritize yearly control efforts as well as to evaluate the success of containment of designated species. For some Priority 1-3 species control area polygons have been established within park boundaries. Management staff are less concerned with increases in abundances of species within these control areas than with establishment of species outside of control area boundaries. Control areas are specific to individual species and do not correspond to completely weed-free zones (see above). For example, Dalmation toadflax may have a 5 mi^2 control area in the vicinity of the Mammoth terraces in the northern range of YELL. The rest of the Northern Range is not weed-free but is outside of the Dalmation toadflax control area and may be targeted for status and trend monitoring for this species. For species that are widespread and untreated (Priority 4 & 5), no information is available on their population status. It may be that once a certain threshold of invasion pressure is exceeded, the whole structure of the native vegetative community collapses (Parker et al. 1999). Although traditional control efforts are not feasible for these species, information about their rates of spread and total coverage within the parks is potentially important information for management of threatened, endangered or sensitive plants, wildlife populations and fires.

5. ***Management Objective***: Maintain the current native plant community and ecosystem attributes (e.g., frequency and cover of native plants, forage, habitat, soil stability and primary productivity) at 80-100% of levels associated with habitat types not infested with invasive exotic plants.

Monitoring Objective: Determine status and trend of selected native plant community (e.g., frequency and cover of key native plants) and ecosystem attributes (e.g., forage, wildlife habitat, soil stability, primary productivity) at locations (e.g., in targeted habitats) infested with one or more specified Priority 4 invasive plant species in comparison to comparable sites not infested with invasive plant species at five year intervals.

Justification/Rationale for Objective 5:
Very few studies have been conducted that address community-level consequences of invasion by exotic species (Woods 1997). From these few studies, however, plant invaders have been found to completely alter nutrient cycling, disturbance regimes, hydrology and energy budgets and can greatly diminish the abundance or survival of native species (D'Antonio and Vitousek 1992, Ehrenfeld 2004, Mack et al. 2000, Walker and Smith 1997, Woods 1997). In addition, primary productivity can be diminished by invasive plants and subsequently affect, for example, grassland forage for grazing animals (Walker and Smith 1997). Although we have little information specifically documenting the effects of the majority of invasive exotic species found in the GRYN park units, we expect these species to have moderate to substantial undesirable effects on native vegetation and other ecosystem components and processes. Priority 4 species are targeted for these objectives because most of them are not being treated or controlled by

park staff, except in some localized areas, and there is concern about their effects on native vegetation and ecosystems within the parks. Also, most of these species are not listed as noxious on state weed lists, are not researched as thoroughly as Priority 1-3 species. Noxious weed status is granted to invasive plant species that pose a threat to agricultural systems rather than to natural resources and natural ecosystems. Priority 4 species may pose a much greater threat to park resources than higher priority species. Without quantitative data, however, park staff cannot divert attention and request management funding to address these species.

6. ***Management Objective***: Return native plant community and ecosystem attributes (e.g., frequency and cover of native plants, forage, habitat, soil stability and primary productivity) to levels associated with habitat types not infested with invasive exotic plants. To have statistically significant improvement in these ecosystem properties within three years of treatment.

Monitoring Objective: Determine status and trend of native plant community (e.g., frequency and cover of key native plants) and ecosystem attributes (e.g., forage, habitat, soil stability, primary productivity) of selected sites where invasive species have been treated/controlled in comparison to habitat types not infested with invasive exotic plants at five-year intervals.

Justification/Rationale for Objective 6:
Eradication of an exotic species can have unintended negative impacts on the ecosystem, including invasion by other exotic plant species or loss of critical habitat for a rare native species (Zavaleta et al. 2001). On the other hand, eradication of exotic species often allows native vegetation to become reestablished on the available site. Treatment of invasive plant species is not successful unless native ecosystem properties have returned to the functional level of similar uninvaded ecosystems.

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Development Schedule and Expected Interim Products:
In FY06, the GRYN will determine the primary focus of the invasive plant monitoring program and revise monitoring objectives accordingly. The schedule for protocol development and implementation is timed to take advantage of products developed by the national program, other networks and regions that have on-going task agreements for backcountry early detection monitoring etc. In FY06 the GRYN will work with the network parks to formalize the front country early detection 'repeat inventories' by developing protocols for data collection, data management and reporting for use by the parks.

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Protocol Development Summary

Protocol: Landbirds

Parks Where Protocol will be Implemented: YELL, GRTE, BICA

Justification/Issues being addressed: This vital sign measures the distribution and abundance of landbirds, other than those selected as "sensitive species".

Protection of native species and their habitats is one of the primary challenges outlined in the NPS Natural Resource Challenge (National Park Service 1999). The National Park Service Inventory and Monitoring Guidelines (NPS-75) further state that "…preserving the natural resources (and natural processes) in the national parks may be the most important legacy the Park Service can provide American conservation." Thus, monitoring the composition of native communities of concern and the changes occurring within and among these communities is essential to meeting our Natural Resource Challenge.

Because of the large number of habitat types within the Greater Yellowstone Network (GRYN) and the enormous variability within these habitat types, our initial efforts on landbirds will focus on estimating the status and trends of landbirds within four habitats (communities) of concern: alpine, aspen, shrub steppe (sage), and riparian. Although the overall objectives will be very similar among these habitat types, there may be subtle differences in the secondary objectives that reflect the potential threats to each of these habitat types.

Our specific monitoring objectives are intended to answer the following general question: Are there observable changes in the native bird communities for each of four habitats of concern that would indicate a systematic changes in abundance or distribution within these habitats that is indicative of that habitat becoming less suitable for persistence of the native avian fauna associated with these communities?

Monitoring Questions Addressed by the Protocol:
Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the proportion of sites within a given habitat of concern that is occupied by the obligate species of that habitat?
- What is the density and variation in density of obligate species within each of four habitats of concern?
- Are there systematic changes in community composition within the four habitats of concern that would be indicative of that habitat becoming less suitable for persistence of the native avian fauna associated with these communities?

Specific Monitoring Objectives:

Note: The scope of inference for all objectives will be four habitats of concern (alpine, aspen, riparian, and sage-shrub steppe), where they occur within the GRYN. Details of how these habitats are defined are provided in the full protocol.

Objective 1. To estimate the proportion of sites occupied (MacKenzie et al. 2002) in habitats of concern in BICA, GRTE, and YELL and to estimate the changes in occupancy over time. Although we will estimate occupancy and changes in occupancy for all species with sufficient data, our emphasis will be species identified as dependent on or obligates of the particular habitat of concern (see protocol for details).

Justification/Rationale for this objective.-- Changes in distribution are often used as indicators of environmental quality. Estimates of occupancy are a direct measure of distribution and the corresponding measures of local extinction and colonization of sites can provide valuable information as to the thresholds of that quality.

Objective 2. To estimate the abundance (density) of birds in habitats of concern in BICA, GRTE, and YELL and to estimate the changes in abundance over time.

Justification/Rationale for this objective.-- Population dynamics, hence changes in abundance, frequently depend on environmental factors (Buckland et al. 2001); thus, they are often used as indicators of environmental quality. Further, Bock and Jones (2004) recently examined 109 reported cases of 67 species in North America and Europe and concluded that in most cases density was a reliable indicator of habitat quality.

Objective 3. To estimate community composition and associated parameters of landbirds in habitats of concern in BICA, GRTE, and YELL and to estimate trends in these parameters over time. Specific parameters to be estimated include, but are not limited to, species richness and relative species richness (e.g., richness of native to exotic species).

Justification/Rationale for this objective.-- Biodiversity is "central to the productivity and sustainability of the earth's ecosystems" (Christensen et al. 1996), and preserving natural abundances and diversity of native plants and animals is one of the general principles guiding the management of biological resources in our national parks (NPS 2000).

BASIC APPROACH:

The general sampling for each of our objectives would be essentially the same, and these objectives would be reflected in different ways of analyzing the resulting data. Our sampling approach is based on distance-based "point transects" (Buckland et al. 1993, 2001) with some minor refinements in the design to facilitate estimation of some parameters. Although in some cases we may use actual line transects, the use of points allows us to measure some site-specific covariates that may be useful in interpreting the results.

Our measure of changes in distribution would be based on the proportion of sites occupied (MacKenzie et al. 2002). This measure: (1) explicitly enables estimation of local extinctions and colonization (MacKenzie et al. 2003); (2) takes into account detectability of individual species (MacKenzie and Kendall 2002); (3) enables estimation of confidence intervals; (4) is comparable across sites; and (5) is becoming a widely accepted approach for reliable estimates of occupancy.

Estimates of density, based on distance sampling, explicitly account for detectability of

individuals of a species through estimation of a detection function, given certain assumptions detailed in Buckland et al. (2001).

Estimates of community-level parameters (e.g., species richness and relative species richness) will be based on the approach developed by Boulinier et al. (1998) and Nichols et al. (1998) using program COMDYN (Hines et al. 1999). As for the other parameters, this approach explicitly takes into account species detectability.

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Development Schedule, Budget, and Expected Interim Products:
The general field methods and sampling design have been developed and will be compatible with the Rocky Mountain Bird Observatory (RMBO) protocol. We also recently completed a field testing of methods at GRTE and anticipate a full advanced draft of our protocol by late fall 2005. We anticipate full implementation by spring of 2006. The budget will depend on final details of the sampling design, but is expected to cost approximately $50k for full implementation of this program.

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Protocol Development Summary

Protocol: Land use

Parks Where Protocol Will Be Implemented: YELL, GRTE, BICA

Justification/Issues being addressed: Land-use activities surrounding park borders can significantly influence the status of ecological condition and functioning within parks. The Greater Yellowstone Network (GRYN) has identified land use change as a top priority vital sign for defining ecosystem health within parks. Long-term monitoring of land-use activities surrounding parks of the GRYN will provide information on trends in land-use and land-cover change and allow for analyses that quantify potential consequences for park resources. This will provide managers with the scientific background for incorporating the consequences of surrounding land-use activities into park management decisions.

Specific monitoring objectives will answer the following questions: How is land use changing around parks, and how do these changes impact park ecosystem components and processes?

Monitoring Questions Addressed by the Protocol:
The primary monitoring questions that will be addressed by this protocol are:

- What is the extent of different land-use activities, and how is this changing over time?

Specific Monitoring Objectives:

Objective 1 – To determine the density and location of homes on private and public lands within BICA, GRTE, and YELL, 20 counties comprising the Greater Yellowstone Ecosystem (Rasker 1991), and two additional counties surrounding BICA.

***Justification/Rationale for this objective*. --** Housing density can have significant ecological impacts, including: general loss of habitat, loss of unique habitat components, barriers to animal movements, increased disturbance and altered hydrologic regimes (including changes in water quantity and quality). Thus, understanding changes in housing density surrounding parks may have important implications for the functioning of the parks.

Objective 2 – To determine the number, length and type (i.e. size) of roads within 22 counties within and surrounding the GRYN, as well as measure changes in the existence and characteristics of roads over time.

***Justification/Rationale for this objective*. --** Roads can have significant ecological impacts, including: the fragmentation of habitats, direct wildlife mortality from collisions with cars, and increased accessibility to backcountry areas resulting in higher levels of human disturbance in remote areas. Therefore, quantifying the extent and characteristics of roads, and monitoring change over time, is relevant for considering the ecological impacts of land-use change on ecological condition of parks.

Objective 3 – To determine the distribution, area, and type of agricultural habitats within 22 counties within and surrounding the GRYN, as well as measure changes to those attributes over time.

***Justification/Rationale for this objective*. --** Although the effects of agriculture may be less intensive than some other types of land use (e.g., urban development), agriculture also can have significant ecological impacts, including: the conversion of important habitats, increased disturbance and altered hydrologic regimes (including changes in water quantity and quality). Further, the area of land surface altered by agriculture likely exceeds that of more intensive development. Thus, understanding changes in agriculture surrounding parks may have important implications for the functioning of the parks.

Objective 4 – To determine the distribution and area of major land use changes that can be detected using remotely sensed data (Landsat) within 22 counties within and surrounding the GRYN. This objective would not target successional vegetation changes; rather major abrupt changes such as clearcuts, new developments and fires.

***Justification/Rationale for this objective*. –** Some major land use changes are not recorded through government records used for housing, roads or agricultural. This objective would target only the most major and abrupt changes that could be detected through course scale image classification (e.g., clearcuts, new developments and fires).

Basic Approach:

The general approach for this vital sign will be to use land-cover maps derived from remotely sensed data to determine the general distribution of housing and agricultural development. These maps will provide only the crude distribution of primary land-use types equivalent to approximately the Level I features of the Anderson et al. (1976) classification scheme or the land cover classes used by the National Land-Cover Database (NLCD) (Vogelmann et al. 1998, Homer et al. 2004). Such maps will not provide sufficient accuracy or detail for monitoring change over time (Jones and Hansen 2005). As such, these data will be augmented with ancillary data (described below) for more detailed metrics.

Housing density- Ancillary data used to derive housing densities have been described in detail by Hernandez (2004) and Jones and Hansen (2005) and are derived from county tax-assessor offices, state Departments of Revenue, and the U.S. Census Bureau (USCB). Because of differences among states and/or counties in data storage and distribution, some compilation, processing and merging will be necessary. The scale of these data will likely be in 1 mi^2 units identified by township/range/section (TRS). The TRS field will also provide a basis for joining states, counties, etc. for this attribute. We anticipate compiling data on housing density and assessing change of this attribute every five years.

Roads- As part of the decennial census, the USCB also distributes TIGER/Line files which include geographic information about roads. This is the most extensive and reliable census of roads within the GRYN study area, and the only source for which roads are updated on a regular basis. TIGER files are used in conjunction with a Geographical Information System (GIS), so

that roads can be mapped at 1:100,000 scale across the entire study area. Roads are classified into five categories, including interstates, state and county highways, local roads, and four-wheel drive logging roads. We anticipate compiling data on roads and assessing change of this attribute every ten years.

Agriculture- The USDA NASS compiles a county-level census of agriculture every five years, and distributes this agricultural information for free on its Web site. The census of agriculture data quantifies most of the agriculture monitoring classes, including total agriculture, irrigated and non-irrigated cropland including hay and other crops, and irrigated and non-irrigated pastureland. Data for irrigated and non-irrigated cropland and pastureland classes are distributed separately from data for total agriculture. These two data sources can be manipulated and merged to create one database containing data for each county. These data can then be spatially referenced by linking to a county basemap. The final map quantifies all levels of agricultural classes for each of the counties within the GRYN study area. We anticipate completing an updated map of agriculture and assessment of change every five years.

Other Major Land use Changes- This objective would be accomplished through comparison of Landsat imagery from one time period to another. Te specific details/protocol has not yet been developed, but the methodology would likely be similar to other ratio techniques that are used for vegetation indices or fire severity indices.

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Development Schedule and Expected Interim Products:
A draft protocol, including SOPs, was submitted to the GRYN in January, 2005 and included a literature review of land-use change in the region surrounding GRYN parks, conceptual models identifying indicators of land-use change, and draft monitoring objectives. Monitoring objectives were subsequently revised after discussions with park and network personnel. This protocol from our cooperator needs to be augmented with information from the network on data management, reporting, etc. We anticipate a complete protocol ready for review in 2006.

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Protocol Development Summary

Protocol: Regulatory Water Quality

Parks Where Protocol will be Implemented: YELL, BICA

Justification/Issues being addressed: Regulatory water quality monitoring is being conducted in response to the requirements of the Clean Water Act (CWA) and the direction of the vital signs monitoring program. The CWA requires states to adopt standards for the protection of surface-water quality. Both Montana and Wyoming have established specific water-quality standards identifying what concentrations of chemical pollutants are allowable in their waters. Water-quality standards themselves consist of two parts: a specific desired use appropriate to the waterbody, termed a designated use, and a criterion that can be measured to establish whether the designated use is being achieved. A waterbody is considered to be impaired when water quality monitoring data reveal changes to natural conditions that exceed those allowed by state standards. The CWA also requires states to submit a listing (commonly referred to as the 303[d] list) of impaired waters to the Environmental Protection Agency (EPA) every other year.

The vital signs monitoring program views the monitoring of state identified impaired waters as fulfilling the fundamental requirement of Goal 1a4 of the National Park Service (NPS) Strategic Plan (NPS 2001), and partially fulfilling the requirements of the Government Performance and Results Act (GPRA) which mandates that federal agencies (federally funded programs) focus on "measurable or quantifiable" results for reporting to Congress. In contrast to several other vital signs components, the CWA provides one recognized means (by formal statute and state-developed numeric criteria and narrative standards) for the NPS to broadly measure improvement, or further degradation, of 303(d)-listed water resources and synthesize that information in reports to Congress (NPS 2003).

Four waterbodies in the Greater Yellowstone Network (GRYN) have been identified by the states of Montana and Wyoming (in response to the CWA) as being impaired and appear on their respective 303(d) lists. Causes for listing include: fecal coliforms, nitrogen, dewatering and metal contamination. The parameters to be monitored are dependent not only on the cause for listing, but also upon the specific criteria that each state uses to define the use categories or classes of its surface waters.

Monitoring Questions Addressed by the Protocol:

The development of measurable objectives is a critical element of any monitoring protocol. Regulatory monitoring (i.e., monitoring conducted under the provisions of the CWA) is intended to determine whether certain chemical or biological parameters meet state standards. The parameters chosen for monitoring are those found to be outside state standards and are the reasons for listing as 303(d) impaired by either the state of Montana or Wyoming. By answering the general question "Does parameter "X" exceed state standards?" the GRYN will:

1. Determine whether the overall goal of improved water quality is being achieved; and

2. Help gather information on the pollutants that exceed standards to assist the park and the state in designing specific pollution prevention or remediation programs through total maximum daily loads.

These objectives specifically cover streams that are currently listed by the state as 303(d). Montana and Wyoming update their list of impaired river and streams (303(d)) every two years. Bighorn Lake is scheduled to be assessed by the state of Montana in 2005. GRYN will keep appraised of state 303(d) status; if the status of streams in the network change and new streams are listed, additional objectives will need to be developed.

Specific monitoring objectives

Based on Wyoming standards for fecal coliforms (WY-DEQ 2001) (and anticipated standard for *Escherichia coli [E. coli]*), the regulatory monitoring objectives for the impaired portion of the Shoshone River are:

1a) Determine fecal coliform concentrations at the sampling location Shoshone River at Kane. Compare analytical results to the state standard: the geometric mean of 200 organisms per 100 milliliters based on a minimum of not less than 5 samples obtained during separate 24-hour periods for any 30-day period.

1b) Determine *E. coli* concentrations at the sampling location Shoshone River at Kane. Compare analytical results to the state standard: the geometric mean of 126 organisms per 100 mL based on a minimum of not less than 5 samples obtained during separate 24-hour periods for any 30-day period.

Based on Montana standards for nitrogen and the required documentation for "partially supporting" waters, the regulatory monitoring objective for the impaired portion of the Bighorn River are as follows:

2a) Determine nitrate concentrations at the sampling location Bighorn River near St. Xavier. Compare analytical results to the state standard: 10,000 µg/L as the geometric mean of monthly measurements.

2b) Determine the natural range of variability of nitrate concentrations at the sampling location Bighorn River near Xavier, based on monthly measurements.

2c) Determine the MT impairment score for macroinvertebrates (based on taxa richness, EPT richness, biotic index, % dominant taxon, % collectors, % EPT, Shannon diversity, % scrapers+shredders, #predator taxa and % multivoltine) at the sampling location bighorn River near St. Xavier. Compare to the state standard of between 0.75 – 1.00 for fully supporting waterbodies.

Sampling recommendations for Soda Butte Creek are based on a synoptic study conducted by Knauf and Williams (2004). Sampling of invertebrates, total and dissolved trace metals, and trace metals in sediments will address concerns about metal contamination in Soda Butte Creek. Metals targeted for analyses include arsenic, copper, iron and selenium. Samples will be

collected twice a year. The first sampling event will occur during snowmelt, when the hydrograph for Soda Butte Creek is on the ascending limb. This sampling time was chosen because it is the time when flushing from the surrounding areas will occur, mobilizing metals that could enter Soda Butte Creek. For total and dissolved metals, morning and evening sample collection will catch any diurnal variation that might occur. The second sampling event will occur during baseflow in order to determine any chronic conditions. Care should be made to sample close to the same date(s) each year so that trends in the data can be determined.

3a) Determine levels of dissolved and total metals at the sampling location Soda Butte Creek at the park boundary, both in the morning and evening at snowmelt and baseflow. Compare analytical results with state chronic/acute standards of 340/150µg/L for arsenic, 7.3/5.2 µg/L for copper, 1000/NA µg/L for iron, and 20/5 µg/L for selenium.

3b) Determine levels of metals in sediment at the sampling location Soda Butte Creek at the park boundary. Compare analytical results with the probable effect concentration (33 mg/kg for arsenic and 149 mg. kg for copper [EPA 2002]) at snowmelt and baseflow.

3c) Determine the diurnal variation of dissolved metals and total metals at the sampling location Soda Butte Creek at the park boundary, during snowmelt and baseflow.

3d) Determine the MT impairment score for macroinvertebrates (based on taxa richness, EPT richness, biotic index, % dominant taxon, % collectors, % EPT, Shannon diversity, % scrapers+shredders, #predator taxa and % multivoltine) at the sampling location Soda Butte Creek at the park boundary. Compare to the state standard of between 0.75 – 1.00 for fully supporting water bodies.

Table 1. Standards for total, dissolved and metals in sediments.

Parameter	**MT Aquatic Life Standard (µg/L) (MT-DEQ 2002)**		**Probable Effect Concentration (EPA 2002)**
	Chronic	Acute	
Arsenic	340	150	33 mg/kg
Copper	7.3@50 mg/L hardness	5.2@50 mg/L hardness	149 mg/kg
Iron	1000	n/a*	n/a*
Selenium	20	5	n/a*

*standard does not exist

Based on the Fish and Wildlife Service recommendation (1987) for minimum in-stream flow for Reese Creek, the regulatory monitoring objective for the impaired portion of Reese Creek is as follows:

4a) Measure discharge continuously at Reese Creek and compare with recommended minimum flows (0.037m^3/s between April 15 and October 15).

BASIC APPROACH:

This monitoring protocol targets specific objectives related to 303(d) listed water bodies in the network. The network expects that many of the standard operating procedures developed for this protocol will also be used in the integrated water quality monitoring protocol.

Existing protocols or methods that are incorporated into the protocol:
The monitoring protocol for regulatory water quality monitoring has adapted and incorporated protocols from the following:

American Public Health Association. 1998. Standard Methods for the Examination of Water and Wastewater. Twentieth Edition. American Public Health Association, Washington, D.C. 1268 pp.

Montana Department of Environmental Quality. 1995. Non-Point Source Water Quality Standard Operating Procedures. http://www.deq.state.mt.us/wqinfo/monitoring/SOP/sop.asp

Peck, D.V., J.M. Lazorchak, and D.J. Klemm (editors). Unpublished draft. *Environmental Monitoring and Assessment Program -Surface Waters: Western Pilot Study Field Operations Manual for Wadeable Streams.* EPA/XXX/X-XX/XXXX. U.S. Environmental Protection Agency, Washington, D.C.

Texas Commission on Environmental Quality. 2003. Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment and Tissue. RG 415. Also available on-line at http://www.tceq.state.tx.us/publications. 198 p.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at http://pubs.water.usgs.gov/twri9A

Wyoming Department of Environmental Quality. 1999. Manual of Standard Operating Procedures for Sample Collection and Analysis. Water Quality Division, Watershed Program. Cheyenne, Wyoming. August 1999 and revisions.

In addition, EPA standard methods for analysis and sample preservation will be used by the GRYN, unless state standards dictate an alternate procedure.

The complete protocol consists of the protocol narrative, several appendices (which include field forms, maps, references, etc.), and eleven standard operating procedures (SOPs) which are summarized below.

Summary of Standard Operating Procedures

Initial Site Establishment – SOP#1
This SOP describes the process for formally establishing water quality sampling stations. Procedures include establishing NPSTORET project and station files, selecting a suitable location for collecting water quality samples, establishing a preliminary profile of field measurements, obtaining station coordinates, photographic documentation, creating field folders, installing a staff gage and establishing a rating curve.

Pre-Season Activities – SOP#2

This SOP provides a dozen or so steps that should be taken to prepare for the field season. Specific tasks include reading the entire protocol, obtaining required training, reviewing checklists, updating reference materials, updating field folders, testing equipment and preparing equipment blanks.

Safety and Health – SOP#3

The "Safety and Health SOP" provides safety checklists and forms for GRYN and contract personnel who are involved with field activities. This SOP is meant to be used in conjunction with more comprehensive manuals (cf. Lane and Fay 1997) that provide details on regulations and recommendations that apply to specific locales and field conditions. In addition, technicians are instructed to contact local park safety officers for information regarding local problems and issues such as bear safety, avalanches, West Nile virus, Lyme's disease, and other location-specific issues.

Cleaning of Equipment for Water Quality Sampling – SOP#4

Standard procedures are described in this SOP for when, where and how to clean equipment and to collect equipment blanks and field blanks for quality control. Sections of this protocol have been adapted from Chapter A3 of the USGS National Field Manual (Wilde 2004). Also, equipment care after each stream visit is discussed, which includes general cleaning for biological contaminants including whirling disease spores.

Procedures for Collection of Required Field Parameters – SOP#5

This SOP focuses on the use of multi-parameter instruments and current velocity/flow meters for measuring the WRD required field parameters. Details include calibration of multi-parameter instruments, thermometers, thermistors and current velocity meters as well as the actual measurement procedures.

Procedures for Collection of Regulatory Parameters – SOP#6

Standard procedures for the collection of water quality samples for regulatory monitoring purposes in the GRYN are addressed in this protocol. This SOP describes sampling techniques such as preventing contamination, the use of disposable gloves, clean hands/dirty hands techniques, field rinsing of equipment, isokinetic sampling and filtration. Sample collection procedures for fecal coliforms, *E. coli*, nitrogen, total and dissolved metals, metals in sediment and two different procedures (one from Wyoming DEQ and one from Montana DEQ) for collection of benthic macroinvertebrates are described in detail. This SOP also provides instructions for sample preservation, labeling and packaging.

Quality Assurance/Quality Control Procedures – SOP#7

This SOP discusses aspects of the representativeness, comparability, completeness, precision, systematic error/bias and accuracy of the data to be collected for the regulatory water quality monitoring parameters in the GRYN. General data quality objectives (DQOs) for the GRYN are described. The use of quality control samples, such as blanks, duplicates and spikes is discussed with associated tables that illustrate the frequency, acceptable range and corrective actions for each QC sample. This SOP includes instructions for completing/maintaining instrument calibration log books, field log books and chain of custody forms. QA/QC procedures for data management, such as field data sheet review, electronic data entry, data archiving, data

verification, error correction procedures, data qualification codes and data validation are included in this protocol.

Data Management Procedures – SOP#8
This SOP outlines data stewardship responsibilities and lists specific instructions and references for managing data collected. The procedure focuses on the installation and configuration of NPSTORET (a standardized database application called the Water Quality Database Templates or NPSTORET) at network parks, data flow and submission of each park's master water quality data files to staff at NPS-WRD.

Data Analysis Procedures – SOP#9
This procedure provides guidelines for the analysis of the laboratory results from the regulatory water quality samples. The analyses of results from equipment blanks, descriptive statistics and trend analysis, calculating QA/QC and standard exceedances for fecal coliforms, E. coli, metals, macroinvertebrates, nitrate and discharge are described, as well as calculations for precision estimates.

Data Reporting Procedures – SOP#10
This procedure provides guidance for immediate reporting (i.e., when monitoring results show an exceedance of a state water quality standard) and for the preparation of annual reports. It includes a suggested report outline along with report review and distribution procedures. The information contained in this SOP was adapted for the GRYN from Peitz and Rowell (2004), Standard Operating Procedure #11, prepared for the Prairie Cluster Prototype Long-Term Ecological Monitoring Program.

Revising the Protocol – SOP#11
This SOP provides instructions for the use of the revision history log that lists all edits and amendments to a document since the original publication date. Information entered in the revision history log should be complete and concise. The table of changes in the narrative and each SOP tracks the original publication date and version, previous version date and number, date of revision, author(s) of revision, location of change by section and paragraph, description of change and the reason for change.

What is the basic methodological approach and sampling design?
Regulatory water quality monitoring for the GRYN will be conducted at fixed monitoring sites using an intermittent sampling scheme. Because state monitoring and assessment programs for water quality use this type of sampling design, it is important to continue this type of sampling to maintain data comparability. The sampling design follows the strategies described by the USGS National Water Quality Assessment (NAWQA) program (Shelton 1994) for basic and intensive fixed-site assessments. Basic fixed-site assessments characterize the spatial and temporal distribution of general water quality and constituent transport in relation to hydrologic conditions and contaminant sources. Intensive fixed site assessments characterize seasonal and short-term temporal variability of general water quality and constituent transport and determine the occurrence and seasonal patterns in the transport of contaminants (Shelton 1994).

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Development Schedule, Budget, and Expected Interim Products:
This protocol (O'Ney 2005) was completed and peer reviewed by NPS WRD personnel in 2005 and is available on the I&M website. Revisions (based on WRD comments) will be completed in early FY06. In June 2005 objectives 1-3 of this protocol were implemented. Implementation for objective #4 (Reese Creek) is planned for FY06. The network is presently populating the required fields of NPSTORET for the regulatory water quality monitoring project and associated stations. At present, the protocol is being implemented using park affiliated personnel. In FY06 the operational plans and budget will be combined with the integrated water quality

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Protocol Development Summary

Protocol: Streamflow

Parks Where Protocol will be Implemented: YELL, GRTE, BICA.

Justification/Issues being addressed: Streamflow is of such importance that the NPS Water Resources Division recognizes that " flow/discharge is a very important physical parameter of the water body that can strongly affect or show direct correlation to chemical parameters. For that reason, although not required, flow measurements are highly recommended" (Penoyer 2001, see also Irwin 2002). Streamflow at any point in time is an integration of the streamflow generation and routing mechanisms in a watershed. This integration also defines the water quality at that time, including land use activities, point source discharges and natural sources (NPS 1998). Thus streamflow measurement is an essential component of water quality monitoring.

The hydrology of rivers in the GYRN can change from direct human modification (e.g., impoundments, water abstraction) or via changes in climate (Meyer et al. 1999). Measurements of continuous discharge can help determine how water withdrawals and impoundments are influencing river and streamflow dynamics. Rivers can be altered hydrologically from dam operations (e.g., Snake River), which can in turn alter biotic assemblages (Stanford and Ward 1989). Water removal for irrigation can reduce instream flows and flood peaks in the summer, (e.g., Gros Ventre River, Bighorn River, Shoshone River, Spread Creek, Reese Creek) and may negatively impact fisheries populations (Mahoney 1987).

Climate change may alter stream hydrology (Poff 2002) which will affect all aspects of river ecosystem function (Meyer et al. 1999, Firth and Fisher 1992) ranging from food web interactions (Power et al. 1995) to nutrient cycling. Changes in baseflow characteristics may affect the following: balance of competitive, ruderal, and stress-tolerant organisms; creation of sites for plant colonization; structuring of aquatic ecosystems by abiotic vs. biotic factors; structuring of river channel morphology and physical habitat conditions; soil moisture stress in plants; dehydration in animals; anaerobic stress in plants; volume of nutrient exchanges between rivers and floodplains; duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments; distribution of plant communities in lakes, ponds, floodplains; duration of high flows for waste disposal, aeration of spawning beds in channel sediments. The timing of annual extreme water conditions (such as the date of maximum flow) may affect the following: compatibility with life cycles of organisms; predictability/avoidability of stress for organisms; access to special habitats during reproduction or to avoid predation; spawning cues for migratory fish; and evolution of life history strategies; behavioral mechanisms (The Nature Conservancy 2005).

Specific Monitoring Questions and Objectives Addressed by the Protocol: Specific monitoring objectives are being developed to answer the following broad question:

Are the magnitude, timing and duration of streamflow changing in the GRYN?

Objective 1.
Estimate trends in baseflow characteristics of rivers within or adjacent to the GRYN that are "permanently" gaged by the USGS.

Objective 2.
Estimate trends in the timing of annual extreme water conditions of rivers within or adjacent to the GRYN that are "permanently" gaged by the USGS.

Objective 3.
Compare annual hydrographs for the five most recent years of record of rivers within or adjacent to the GRYN that are "permanently" gaged by the USGS.

BASIC APPROACH:
This monitoring protocol will include the networks plans for gathering, storing, analyzing and reporting on streamflow in the GRYN. The GRYN will utilize the network of permanent streamflow (continuous discharge) gaging stations that are being monitored by the USGS National Stream Gaging Program. Currently streamflow is being monitored continuously by the USGS at the following locations:

Station_Name	USGS Station_ID	Period_of_Record
Madison River near West Yellowstone MT	06037500	1913-present
Yellowstone River at Yellowstone Lk Outlet YNP	06186500	1926-present
Soda Butte Cr nr Lamar Ranger Station YNP	06187950	1888-89; 1990-present
Lamar River nr Tower Falls Ranger Station YNP	06188000	1923-present
Yellowstone River at Corwin Springs MT	06190500	1889-1893; 1910-present
Gardner River near Mammoth YNP	06191000	1938-present
Firehole River near West Yellowstone MT	06036905	1983-1996 (discharge); 2002-present
Gibbon River at Madison Jct, YNP	06037100	2000-present
Boiling River at Mammoth, YNP	06190540	1988-1995; 2002-present
Soda Butte Cr at Park Bndry at Silver Gate	06187915	1999-present
Tantalus Creek at Norris junction, YNP	06039640	2004-present
Bighorn River at Kane, WY	06279500	1928-present
Bighorn River near St. Xavier, MT	06287000	1934-present
Shoshone River near Lovell, WY	06285100	1966-present
Snake River AB Jackson Lake t Flagg Ranch WY	13010065	1983 to present; prior to 1988 pub as 13010200
Snake River NR Moran WY	13011000	1903 to present
Pacific Creek at Moran WY	13011500	1906 to 1917; 1944 to 1975; 1978 to current year

Buffalo Fork AAB Lava Creek NR Moran WY	13011900	1965 to present
Gros Ventre River at Zenith WY	13015000	July-Sept. 1917 and 1918; October 1987 to present
Granite C AB Granite C Supplemental, NR Moose, WY	13016305	1995 to present
Snake River AT Moose, WY	13013650	1995 to present

Our primary goal is to connect park managers with available data by providing annual and synthesis reports on streamflow using these data.

The GRYN will analyze and interpret streamflow data through the use of the analysis program "Indicators of Hydrologic Alteration" or IHA. IHA is a software program that provides useful information for those trying to understand the hydrologic impacts of human activities. Over 1,000 water resource managers, hydrologists, ecologists, researchers and policy makers from around the world have used this program to assess how rivers, lakes and groundwater basins have been affected by human activities over time or to evaluate future water management scenarios. This program was developed by scientists at the Nature Conservancy to facilitate hydrologic analysis in an ecologically meaningful manner. This software program assesses 67 ecologically relevant statistics derived from daily hydrologic data. For instance, the IHA software can calculate the timing and maximum flow of each year's largest flood or lowest flows, then calculates the mean and variance of these values over some period of time. Comparative analysis can then help statistically describe how these patterns have changed for a particular river or lake due to abrupt impacts such as dam construction or more gradual trends associated with land- and water-use changes.

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Development Schedule, Budget, and Expected Interim Products:
A protocol narrative (5-10 pages) and associated SOP for using the IHA will be completed, peer-reviewed and implemented in FY06 for targeted watersheds in the GRYN. This protocol is expected to be brief and should be relatively inexpensive to prepare.

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Protocol Development Summary

Protocol: Whitebark pine

Parks Where Protocol will be Implemented: YELL and GRTE, with the possibility of BICA if this vital sign is extended to include limber pine. In addition, this protocol will be implemented on six national forests (Bridger-Teton, Custer, Shoshone, Gallatin, Beaverhead-Deerlodge and Caribou-Targhee).

Justification/Issues being addressed: Whitebark pine occurs in the subalpine zone of the Pacific Northwest, where it is adapted to a harsh environment, often consisting of poor soils, steep slopes, high winds and extreme cold temperatures. This long-lived species is well known for its diverse growth forms ranging from straight and narrow to multi-stemmed, stunted and gnarled krummholz. Although its inaccessibility and often gnarled growth forms render whitebark pine of low commercial value, it is high in ecological value.

Whitebark pine is often considered a "keystone" species of the subalpine zone (Tomback et al. 2001). Because whitebark pine can become established under conditions tolerated by few other trees, its presence can alter the microclimate such that it enables other species, such as subalpine fir, to follow (Tomback et al 1993). Its occurrence on wind-swept ridges serves as a snow fence, thus playing an important role in snow accumulation. But, perhaps its best-known role in these ecosystems is as a food source for a variety of wildlife species. Whitebark pine seeds are large and high in fat content, making them a valuable food source for more than 17 wildlife species (Kendall and Arno 1990). Whitebark pine seeds are an especially important food source for grizzly bears, which can find them stockpiled in large quantities cached by red squirrels in middens (Mattson et al. 1992). In the Greater Yellowstone Ecosystem (GYE), this food source is so important that annual cone production in the GYE is one of the major predictors of annual survival and reproduction of the bears (Mattson et al. 1992).

Whitebark pine stands have been decimated in areas of the Cascades and northern Rocky Mountains due to the introduction of an exotic fungus—white pine blister rust—as well as mountain pine beetles (with a possible interaction effect between these sources of mortality). Our objectives are intended to estimate the current status of whitebark pine relative to infection with white pine blister rust as well as to assess the vital rates that would enable us to determine the probability of whitebark pines persisting in the Greater Yellowstone Ecosystem.

Monitoring Questions Addressed by the Protocol:
Some of the monitoring questions that will be addressed by this protocol include:

- What is the extent of white pine blister rust infection of whitebark pine throughout the Greater Yellowstone Ecosystem and is the rate of infection increasing?
- What is the severity of existing infections of white pine blister rust on whitebark pine and is the severity increasing?
- What is the survival of mature whitebark pine trees infected with white pine blister rust throughout the Greater Yellowstone Ecosystem and are mortality rates increasing?

Specific Monitoring Objectives:

Objective 1. To estimate the proportion of whitebark pine trees within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests) infected with white pine blister rust, and to determine whether that proportion is changing over time.

***Justification/rationale for this objective*.--** White pine blister rust has devastated whitebark pine in other parts of the Northwest (Kendall and Keane 2001, Koteen 2002), and anecdotal evidence suggests that it may be escalating in the GYE (Koteen 2002, D. Tomback pers. comm.).

Objective 2. To determine the relative severity of white pine blister rust infection in trees > 1.4 m in height within stands of infected whitebark pine within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests). Severity is indicated by the number and location (trunk or branch) of blister rust cankers.

***Justification/rationale for this objective*.--** Determining the proportion of trees infected with white pine blister rust can be misleading without a further understanding of the magnitude of the infection. Trees that are infected at low levels may persist for a considerable time in the absence of new infections and continue to produce seeds (Tomback et al. 2001). Trees that are infected on or near the trunk of the tree also have a greater risk of mortality and loss of reproduction (Zeglan 2002).

Objective 3. To estimate survival of individual whitebark pine trees > 1.4 m in height within the Greater Yellowstone Ecosystem (GRTE, YELL and six national forests), explicitly taking into account the severity of infection with white pine blister rust (from objective 2).

***Justification/rationale for this objective*.--** Trees that are infected at low levels may persist for considerable time (i.e., decades) in the absence of new infections, depending on where the tree is infected (Tomback et al. 2001, Koteen 2002). Estimating survival will enable us to distinguish the occurrence and severity of white pine blister rust from the ecological effect of infestation (i.e., loss of whitebark pine). Therefore, we will be better able to determine the vulnerability of whitebark pine in the Greater Yellowstone Ecosystem directly, rather than relying on potentially controversial extrapolation from other regions.

BASIC APPROACH:

An existing protocol has been developed by the Whitebark Pine Ecosystem Foundation (Tomback et al. 2004), although modification was needed to meet GRYN objectives and I&M standards, particularly related to site selection. In the existing protocol, the use of probability sampling is only suggested as one alternative, because of a perception that such an approach will be cost prohibitive. Judgment sampling (also known as the "relevé" method) is proposed as a viable alternative, which is unacceptable for I&M Standards, as it suffers from a high probability of selection bias that can greatly diminish the reliability of the sampling effort (Cochran 1977, Levy and Lemeshow 1999, Olsen et al. 1999). We have been working with partner organizations (USGS, U.S. Forest Service, the Greater Yellowstone Coordinating Committee, and the Statistics Department of Montana State University) to make revisions that will meet NPS standards but will make use of those parts of the existing protocol that are acceptable.

The basic approach will be a two-stage cluster design with stands (polygons) of whitebark pine being the primary units and 10x50 m plots being the secondary units. Plots are permanently monumented for repeated visits and individual trees > 1.4 m in height are marked for estimating survival. An ongoing pilot effort funded by USFS includes subsampling within stands in order for us to evaluate within- and between–stand variability. This effort will guide the final refinement of our sampling design.

The revisit design will be a rotating panel with approximately a five-year interval between surveys for a given panel (exact interval to be determined based on preliminary analysis of the pilot effort).

Principal Investigators and NPS Lead:
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Development Schedule, Budget, and Expected Interim Products:

The primary monitoring objectives have been developed and adopted by our partners, although two additional objectives are still being considered. An existing protocol had been developed for monitoring whitebark pine, although some modifications were necessary to meet the specific needs of the GRYN and to meet I&M program standards. Field testing of these revised methods was initiated during FY04 using USFS money. Some problems were encountered during this initial effort and solutions proposed. We are currently field testing these refinements during our 2005 effort, again using USFS money. We anticipate an advanced field tested protocol to be completed by late fall 2005 for peer review. We anticipate full implementation by summer of 2006. This will be a collaborative effort among several agencies. Further, the necessary sample size would be obtained over several years via the revisit design, thus should not entail an unreasonable cost to the NPS. The final budget will depend on final details of the objectives and sampling design. However, based on preliminary efforts, we anticipate an annual budget for NPS of approximately $25,000, which will be matched by our partner organizations.

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Data and Information Management Plan

Version 1.0
September 2005

National Park Service
Greater Yellowstone Inventory and Monitoring Network

Bighorn Canyon National Recreation Area
Grand Teton National Park
John D. Rockefeller Jr. Memorial Parkway
Yellowstone National Park

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Executive Summary

Established in 2000 as one of 32 field offices in the NPS Natural Resource Inventory and Monitoring Program, the Greater Yellowstone Network (GRYN) provides coordination and services for the inventory and long term monitoring of selected natural resources in Bighorn Canyon National Recreation Area, Grand Teton National Park (including John D. Rockefeller Jr. Memorial Parkway), and Yellowstone National Park. As a component of the network's Vital Signs Monitoring Plan this data management plan outlines the strategy and guidelines for thorough, integrated, and coordinated resource information management activities to meet NPS-wide information requirements and park level inventory and monitoring information needs. The content of this plan includes overview descriptions, guiding principles, important concepts, and elements of the Service's evolving enterprise architecture for its natural resource line of business. Specific procedures and best practices not covered in this plan are found in the data management and other sections of the network's individual monitoring protocols.

About one-third of I&M program and network resources are devoted to generating, managing, and sharing data and information resources that are well planned, highly organized, easily accessible, completely documented, and scientifically credible. The purpose of emphasizing data management is to provide stable, long-term support for natural resource managers and decision makers in the NPS, as well as non-NPS partners, scientists, and other stakeholders.

The foundation for effective data management begins with specifying data stewardship roles and responsibilities for every aspect of program and project planning and operations. This plan lists several roles and associated responsibilities for data management that cover data producers through end users. Management level support for these responsibilities, particularly at parks, is required to meet I&M program goals. Park managers need to plan for and provide funds and time to adequately manage data and information resources generated by I&M program and other natural resource management activities. Managers at all levels also need to provide accountability for data management responsibilities as performance elements for all natural resource positions. Emphasis is placed on the collaborative nature of successful data stewardship, and the network promotes a teamwork approach to data management. Because it is essential to establish, communicate, and support data stewardship responsibilities for all staff at all stages of a project, chapter three discusses project workflow and data management issues and opportunities. A standard data lifecycle model helps demonstrate the relationship between park-level data collection for inventory and monitoring projects with NPS service-wide databases and data distribution services.

The network operates and maintains a NPS-compliant information technology infrastructure at offices currently located on the Montana State University campus in Bozeman. Hardware, software, security provisions, and local area network services are managed by GRYN staff with support from regional and park level technology service staff. The network maintains project-specific database applications and data sets designed and populated based on inventory study plans and specific monitoring objectives, often in partnership with non-NPS partners such as the US Geological Survey and the US Forest Service. The data stored in these local applications are transferred at appropriate intervals to NPS service-wide

databases and repositories including NPSpecies, NatureBib, NPSTORET, the NPS Natural Resource GIS Metadata and Data Clearinghouse, and the NPS Biodiversity Data Store.

The network necessarily focuses on collecting and managing data that are required to meet monitoring objectives specified in the vital sign monitoring protocols. GRYN also works with staff from network parks, the NPS regional and Washington offices, and other partner entities to identify, manage, and integrate legacy data from past monitoring efforts and relevant data sources from ongoing monitoring that are not based strictly on protocols generated by the NPS I&M program. Chapter five discusses the networks options for recording data in the field, its approach to database design and data discovery, acquisition, and entry, and the treatment of data from different organizational levels in the NPS.

An important data management goal discussed in chapter six is how to ensure that I&M projects produce data that meet quality requirements specified in vital sign monitoring protocols. The plan discusses ways to reduce errors when entering data, procedures for verifying and validating data, and methods to share information about data quality to promote the appropriate application and use of data resources. Another principal component of effective data management operations is data documentation, discussed in the context of network activities involving NPS metadata creation and distribution tools in chapter seven. Chapter eight follows with a brief discussion of the supporting role of data management for analysis and reporting.

GRYN is committed to making all available and relevant data easily accessible while providing for the appropriate level of protection for sensitive data resources. Procedures and solutions for making data available to park natural resource managers and decision makers, as well as other stakeholders and interested parties are presented in Chapter nine. In the final chapter the long term elements of data maintenance, storage, and archiving are addressed for electronic as well as physical (specimen) and hardcopy data and information resources.

Current and future GIS and information management strategies and solutions at each park represent valuable information about what works and what needs improvement in the realm of data management. Staff from the network and the parks will coordinate and integrate data management activities based on common tools, best practices and shared objectives. This plan is a key mechanism to help understand and address the relationships between park level information needs supported by park GIS and data management activities, and I&M program organization and standards for Network data management.

1. Introduction

In 1999 the National Park Service released its Natural Resource Challenge, an Action Plan for Preserving Natural Resources. The Action Plan focuses on ways to expand scientific research to inform the management of park resources, provide benchmarks and repositories of environmental information for local, regional, and global interests, and share knowledge with the scientific community, academic institutions, and the public. One component of the Action Plan involves the NPS Natural Resource Inventory and Monitoring (I&M) Program, which works to address standard natural resource inventories and long term status and trend monitoring for park-selected ecological indicators known as Vital Signs. To coordinate and provide services for the inventory and monitoring activities in four NPS units, the Greater Yellowstone Network (GRYN) was established in 2000 as one of 32 networks of parks in the I&M Program. Bighorn Canyon National Recreation Area, Grand Teton National Park, John D. Rockefeller Jr. Memorial Parkway (administered by Grand Teton NP), and Yellowstone National Park involve nearly 2.6 million acres in parts of Idaho, Montana, and Wyoming (Figure 1.1).

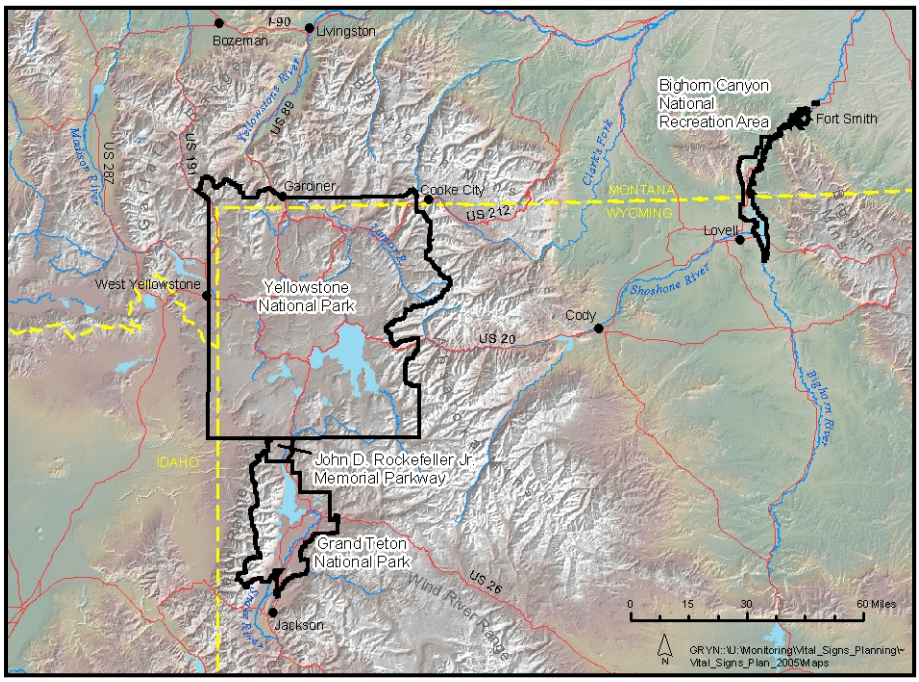


Figure 1.1. National Park Service Units served by the GRYN.

In a paper presented at the 2001 George Wright Society Conference, Abigail Miller of the National Park Service stated the need for a system-wide approach in the NPS to ensure that data meet national level standards for quality and availability. She set expectations for inventory and monitoring networks to strategically approach data collection and management activities that help meet park level information requirements as well as provide credible and useful data and information for landscape level and national efforts

This Data and Information Management Plan (the 'Plan') presents principles and guidelines that reflect the National Park Service Inventory and Monitoring Program's goal to ensure that investments made to acquire scientific data for park natural resources yield high quality data

and information assets that are organized, available, useful, compliant, and secure. To achieve these fundamental requirements, the Plan focuses on the following objectives:

- Provide data management services and guidance in support of the Inventory and Monitoring Program's goal to identify, catalog, organize, structure, archive, and make available relevant natural resource information;
- Initiate and invest in data management activities based on data and information needs defined in network monitoring protocols and inventory study plans;
- Integrate data management activities with all aspects and at all stages of network business;
- Specify data stewardship responsibilities for all personnel;
- Collaborate internally and externally to address data management issues with individuals at all organizational levels.

1.1 GRYN Organization

The network's coordinator, ecologist, and data manager are stationed in Bozeman, Montana. Temporary staff can be stationed in Bozeman and at the parks. Network business is guided locally by a Technical Committee of managers from the network parks, and approved by a Board of Directors made up by superintendents (or their representative) from each network park. Yellowstone National Park and Grand Teton National Park have active GIS and resource information management programs whose staff work with network personnel to identify and develop common strategies and policies for integrated data management. Resource specialists and managers at Bighorn Canyon National Recreation Area work with network staff to develop and implement data management practices that meet the information needs of the recreation area and the network.

1.2 Data and Information Synthesis

Natural resource **data** include collections of estimated, predicted, observed, and measured values or classifications for any element or event of an ecological system, including physical, chemical, biological, and human dimensions. The patterns and relationships among these data represent the **information** that provides meaning to people who wish to understand, manage, and use park resources. An important objective of the network's Vital Signs Monitoring Plan is to synthesize and deliver overall ecosystem status and trend information. Resulting products are based on data from multiple network Vital Sign monitoring protocols and other relevant data and information in various formats and conditions, from sources within and outside the National Park Service. The network manages all types, forms, and stages of data and information and their inherent relationships, provided that they support one or more of the following program elements:

- goals and objectives of the network's Vital Signs Monitoring Plan
- specific needs defined in approved Vital Sign monitoring protocols
- network inventory study plan objectives
- other specific natural resource management projects that network personnel and park staff agree to cooperate in developing and managing

1.3 Goals and Objectives for Managing Natural Resource Information Assets

The overall mission for GRYN data management is to provide and support data and information resources that are organized, useful, available, compliant, and secure. The

network's monitoring efforts and resource information management activities are expected to provide park managers with the scientific data they need to understand and manage park resources. Based on the strategic approach to data management from the Inventory and Monitoring Program, the goals of the network include the following:

- Identify the most critical data needs for parks and networks
- Develop partnerships with other land and resource management agencies, non-government entities, and public and private interests
- Collaborate internally and externally to help establish consistency among approaches and protocols
- Compare and share protocols and data sets locally and via the NPS I&M Protocol Database
- Use standard quantitative and qualitative measures to report on the condition and trends of natural resources

Primary objectives of natural resource data and information management include:

- Manage data and information as programmatic and service-wide resources
- Manage data acquisition to avoid duplication and unnecessary expense
- Store, manage, and maintain data in one or more central and accessible repositories
- Protect data from unauthorized or unplanned modifications
- Perform quality controls on data throughout its life cycle
- Share data and information appropriately with internal and external interests

1.4 Data Management Plan Scope and Revision Schedule

Data and information resources relevant to the network are those that result from or relate to the implementation of a formal network Vital Signs monitoring protocol, network Inventory Study Plan, or park and network approved project with well defined and thoroughly reviewed information needs. This plan covers ways in which the network manages all programmatic information assets, including hardcopy reports and field forms, electronic files, spatial and tabular data sets, image data from remote sensors and cameras, audio and video data, and ground-based images. The plan also discusses the network's involvement with the parks and conservatories in handling and managing physical specimens such as voucher evidence for records used in NPSpecies, the National Park Service's biological diversity database.

This plan, its appendices, and the data management section in each Vital Sign monitoring protocol require updates and regular maintenance by network staff. To provide access to data and information management principles and guidance, the network continuously maintains a web-based data and information management plan. Minor revisions and edits occur regularly and more substantial changes or additions occur as needed when relevant new information results from network business, NPS policy, or Inventory and Monitoring Program direction. A comprehensive review and update of the Data and Information Management Plan will occur every three years. Changes to the Plan are documented in the Revision History Log at the end of this document.

2. Data Stewardship Roles and Responsibilities

The benefits to natural resource managers, scientists, and the public from inventory and monitoring project results are substantially affected by the ability of the individuals working on the project, the network staff, and the National Park Service to keep track of data from the time they are gathered until and while they inform a decision making process. Managing data for multiple monitoring protocols and NPS inventories involves timeframes of several years and includes changes in information technology, turnover in staff, new scientific insights, and shifting priorities. This requires that every individual involved with the Greater Yellowstone network understand and perform data stewardship responsibilities in the production, analysis, management, and/or end use of the data (Table 2.1). As coordinator of these activities, the fundamental role of the network data manager is to understand program and project requirements, create and maintain data management infrastructure and standards, and educate, communicate, and work with all responsible individuals. In order to achieve the highest possible success in delivering useful and credible scientific information about park ecosystems, the Inventory and Monitoring Program expects each network to invest at least thirty percent of available resources (time, money, and expertise) in data management, analysis, and reporting. In addition to the overall data management roles and responsibilities presented here, each Vital Sign monitoring protocol and inventory study plan contains specific instructions for assignments and tasks that nest within a data stewardship framework.

Table 2.1. Categories of data stewardship involving all network personnel.

Stewardship Category	Related Activities	Principal jobs or positions
Note: Each position is listed in only one category according to overriding responsibilities. However, most positions contribute in each category.		
Production	Creating data or information from any original or derived source. This includes recording locations, images, measurements, and observations in the field, digitizing source maps, keying in data from a hardcopy source, converting existing data sources, image processing, and preparing and delivering informative products, such as summary tables, maps, charts, and reports.	Project Crew Member Project Crew Leader Data/GIS Specialist or Technician
Analysis	Using data to predict, qualify, and quantify ecosystem elements, structure, and function as part of the effort to understand these components, address monitoring objectives, and inform park and ecosystem management.	Network Ecologist Resource Specialist Statistician/Biometrician
Management	Preparing and executing policies, procedures, and activities that keep data and information resources organized, available, useful, compliant, and secure.	Network Data Manager Project Leader GIS Manager IT Specialist Database Manager National I&M Data Manager Curator

Stewardship Category	Related Activities	Principal jobs or positions
End Use	Informing the scope and direction of science information needs and activities. Providing the money and scheduling the time required for project leaders and staff to meet stated objectives for data quality and other data management objectives. Obtaining and applying available information to develop knowledge that contributes to understanding and managing park resources. Providing feedback for improvements in data content and quality.	Network Coordinator Park managers and superintendents Others

2.1 Definitions of Role and Responsibility

The network considers a role as a function or position (*e.g., Data Manager*) while a responsibility is a duty or obligation (*e.g., review data records*). Data stewardship is not treated as a role because it involves all project staff sharing the responsibilities for managing data and information resources. Using the term 'Data Steward' seems appropriate only when a list of specific responsibilities is associated with every role in a given project or program. Establishing a single project data steward role is avoided because an unmanageable burden (real or perceived) is placed on a single position/person, and others with data management responsibilities are more likely to under perform.

2.2 Primary Roles and Responsibilities for Data Management

An increasing demand for more detailed, higher quality data and information about natural resources and ecosystem functions requires a group of people working together to effectively steward data and information assets. The current and expected capacity, diversity, and rate of change in information technology make managing any large amount of data a greater task than any person can reasonably do alone. Knowledgeable individuals from scientific, administrative, and technological disciplines must work together to ensure that data are collected using appropriate methods, and that resulting data sets, reports, maps, models, and other derived products are well managed. Data sets and related products must be credible, representative, and available for current and future needs. A typical data set used for inventory and monitoring is handled, viewed, and stewarded by most or all of the people serving in the roles (jobs) listed in Table 2.2. These roles are listed 'from the ground up' to help demonstrate the hierarchy and overlap of responsibilities. For example, a project leader is ultimately responsible for the activities listed in the field level roles of crew leader and crew member, and the network coordinator ensures that the network data manager and ecologist achieve the required performance level. With one third of network resources devoted to overall data management, analysis, and reporting, the network intends to avoid cases in which a single position is assigned unattainable duties for multiple roles, resulting in a lack of attention to one or more aspects of the project. Meeting this goal requires awareness and support from park managers to plan for, fund, and provide performance level accountability for the resources required to adequately manage their park's data and information assets. Learning, understanding, and acting on the responsibilities listed for all categories of data stewardship will help prevent the critical aspects of data management from being overlooked or under-funded.

Table 2.2. Summary of Roles and Responsibilities

Role	Primary responsibilities related to data management
Project Crew Member	Record and verify measurements and observations based on project objectives and protocols. Document methods, procedures and anomalies.
Project Crew Leader	Supervise crew members to ensure their data collection and management obligations are met, including data verification and documentation.
Data/GIS Specialist or Technician	Perform assigned level of technical data management and/or GIS activities, including data entry, data conversion, and documentation. Work on overall data quality and stewardship with project leaders, resource specialists, and the Network data manager.
Information Technology/Systems Specialist	Provide and maintain an information systems and technology foundation to support data management.
Project Leader	Oversee and direct operations, including data management requirements, for one or more network projects. Maintain communication with project staff, Network Data Manager, and resource specialist regarding data management. Determine what others inside and outside the NPS are doing relative to the project, and establish a minimum set of standard data items to promote comparability with other efforts. **Note:** The Project Leader is often a resource specialist, in which case the associated responsibilities for data authority apply (see next role). A Project Leader without the required background to act as an authority for the data will consult with and involve the appropriate resource specialists.
Resource Specialist	Understand the objectives of the project, the resulting data, and their scientific and management relevance. Make decisions about data with regard to validity, utility, sensitivity, and availability. Describe, publish, release, and discuss the data and associated information products. **Note:** The Resource Specialist serving as a Project Leader is also responsible for the duties listed with that role.
GIS Manager	Support park management objectives. Coordinate and integrate local GIS and resource information management with network, regional, and national standards and guidelines.
Network Data Manager	Provide overall network planning, training, and operational support for the awareness, coordination, and integration of data and information management activities, including people, information needs, data, software, and hardware. Serve as Point of Contact for National Park Service database applications (NPSpecies) Coordinate internal and external data management activities, especially in collaboration with project leaders Ensure that metadata is created to meet NPS standards and published on an NSDI clearinghouse
Database Manager	Apply particular knowledge and abilities related to database software and associated application(s)
Curator	Oversee all aspects of the acquisition, documentation, preservation, and use of park collections
Statistician/Biometrician	Analyze data and present information

Role	Primary responsibilities related to data management
Network Ecologist	Ensure useful data are collected and managed by integrating natural resource science in network activities and products, including objective setting, sample design, data analysis, synthesis, and reporting
Network Coordinator	Ensure programmatic data and information management requirements are met as part of overall network business
I&M Data Manager (National Level)	Provide service-wide database design, support, and services, including receiving and processing to convert, store, and archive data in service-wide databases
Other End Users	These 'information consumers' include park managers and superintendents, researchers, staff from other agencies, and the public. End users are responsible for informing the scope and direction of science information needs and activities, applying data and derived products appropriately, and providing feedback for improvements. Park superintendents and program managers, in particular, are responsible for providing the money and scheduling the time required for project leaders and staff to meet stated data quality and other data management objectives.

2.3 Coordination with parks and others

The Natural Resource Challenge states that collaboration among the National Park Service, other public agencies, universities, and non-governmental organizations is necessary to effectively acquire, apply, and promulgate the scientific knowledge gained in parks. The Inventory and Monitoring Program encourages coordination among participants at all levels to help ensure that data collected by NPS staff, cooperators, researchers and others are entered, quality-checked, documented, analyzed, reported, archived, cataloged, and made available for management decision-making, research, and education. The network data manager works with national Inventory and Monitoring Program data management staff and regional resource information management personnel to maintain awareness and involvement in service-wide and regional databases and data management policy and guidance. The network data manager works locally with network personnel, park staff, and cooperators to promote and develop workable standards and procedures that result in integration and availability of data sets. Key contacts for the network data manager include park GIS and data managers and the project leaders for each monitoring or inventory project. Regular and productive communication among these personnel leads to common understanding and better synchronization of network and park data management activities. Park and network staff coordinate on resource information management using a variety of methods, including personal visits, phone calls, email, joint meetings and training sessions, as well as the meetings and work of the network's Technical Committee, Science Committee, and Board of Directors. The development of network planning materials, including inventory study plans and monitoring protocols, includes involvement and input from park scientists and resource information management staff. This data and information management plan, for example, is prepared with input and review from park GIS managers and others.

2.3.1 Network of Networks

The prototype monitoring parks and networks established a foundation of collaboration and coordination in network and park data management that continues to benefit the Inventory and Monitoring Program and data management in the National Park Service.

Data managers throughout the program regularly coordinate with each other and national program staff via annual meetings, conference calls, workgroups, a listserv, web sites, and informal communication. Data managers from several networks divided the workload and collaborated on developing their respective network Data Management Plans. This model of cooperation using available resources and strong communication is effective in the National Park Service and can be productively applied to most situations involving resource information management across and among the administrative units of the organization. The Greater Yellowstone Network maintains an active role in coordination between networks and parks to promote practical consistency among protocols, database designs, and data sets. GIS and data managers from network parks are asked to participate in program development and activities, take advantage of Inventory and Monitoring Program resources, and communicate with network and program staff to share information about progress and direction and address concerns.

2.3.2 External Coordination

The two largest network parks are partners in land and resource management within the Greater Yellowstone Ecosystem, which garners a high level of interest ranging from research and interpretation of the Ecosystem to dialogue about natural resource policy and management issues. This pervasive and intense interest bolsters the network's responsibility and the opportunity to participate in coordinated data management activities with external stakeholders. This involves establishing and maintaining awareness and communication regarding resource information management activities at other federal, state, and local government offices. For example, the Greater Yellowstone Coordinating Committee is an established group of federal land managers who have an interest in promoting high quality data and information management to support the work and products of their issue teams, subcommittees and the associated projects. The network uses and supports the functions of the Greater Yellowstone Coordinating Committee to maintain a role in ecosystem management based on credible data both inside and outside the parks. Another important commitment and opportunity for the network involves interagency collaboration on the development of Vital Sign monitoring protocols, which includes examining and producing solutions to make data useful among different agencies. Most or all network monitoring protocols benefit from coordination with inventory and monitoring interests in the National Park Service and from contributions made by external partners. A list of past and current contacts and contributors is maintained in the network's information system. Partnerships with organizations and agencies outside of the National Park Service are available for reference in the network Vital Signs Monitoring Plan.

2.4 Documentation is Key

If a single shared responsibility stands out in importance and value, it is to document data sets, the data source(s), and the methodology by which the data were collected or acquired. This establishes the basis for the appropriate use of the data in resulting analysis and products, both short term and long term. Network monitoring protocols contain key elements of data documentation. Network data records collected according to these protocols will include the name, date, and version of the associated protocol. Additional important guidance and reference for documentation and metadata are found in the Data Documentation chapter of this plan.

2.5 Project Stewardship

Since the data management aspects of every inventory or monitoring project normally require the expertise and involvement of several people over a period of months or years, it makes sense that one person is charged with keeping track of the objectives, requirements, and progress for each project. This project leader (or steward) is normally a resource management specialist with training and experience in the field of science related to the inventory or monitoring project and may have worked in the geographic area where the study occurs. A background like this prepares the project leader to oversee the field work, coordinate with GIS and data managers on information management needs, understand the project's objectives, and authorize the validity, utility, sensitivity, and availability of data resources. A project leader who lacks the background or expertise to act as an authority for the data will work with the appropriate resource specialists to account for those aspects of data stewardship. In order to ensure quality management of each project, including data management requirements, project leaders are assigned only those projects they can effectively oversee based on workload and other relevant factors determined by the network coordinator. Unless the project is short term (3 months or less) the project will have at least one alternate or backup project leader to provide continuity in case the principal project leader becomes temporarily or completely unavailable. Table 2.2 describes the primary responsibilities of a project leader, resource specialist, and network data manager that, when coordinated for a project, result in quality data and information products. Comprehensive responsibilities and assignments for these roles vary by project and are listed and described in detail with each Vital Sign monitoring protocol or other project study plan.

2.6 Data Stewardship

Keeping track of data from the time of acquisition until it is no longer useful is the shared responsibility of everyone involved with data as a producer, analyst, manager, or end user. This, in essence, is data stewardship. It is a principle of mutual accountability rather than a particular job for one individual. The importance of data stewardship must not be understated, and the degree of success with which it is used will have direct bearing on the quality and utility of products developed by the network. Data stewardship responsibilities for network and park level roles are listed in Appendix A, and are specified with more detail in individual monitoring protocols and study plans.

2.6.1 Awareness and Accountability

Successful data stewardship requires that people involved in network activities learn and understand the expectations for continuous data management, and are held accountable to perform the duties required to meet these expectations. This is equally important for network staff, park employees, and contractors or cooperators. All project participants receive training, briefings, materials, and additional regular communication about data stewardship from supervisors, project leaders, and data managers. The purpose is to promote the appropriate level of understanding about how their efforts relate to park and network management objectives, National Park Service and Department of Interior policies, and other federal government requirements. Other relevant context and linkages can also be discussed to help establish a sense of ownership and accountability among project staff. Inventory and Monitoring project leaders have a good understanding of resource information management issues and requirements and an awareness of the challenges and limitations associated with field data collection, including the use of GPS technology. This is achieved

through training, detailed and regular briefings, and accompanying field crews to perform data collection at reasonable intervals.

2.6.2 The Hub of Data Stewardship

Project leaders, data managers, and GIS specialists comprise the central data management team for inventory and monitoring projects. Each is responsible for certain aspects of project data, and all share responsibility for some overlapping tasks. Because of the collaborative nature of project data management, communication among project leaders, data managers and GIS specialists is essential to meeting program goals. The following section outlines the individual and shared responsibilities of each role.

Project leaders (stewards)

The project leader is accountable for data quality during all phases of the project, including collecting, entering, handling, reviewing, summarizing, and reporting data. Developing project documentation and metadata are crucial elements of the project leader's role. Specifically, the role of the project leader includes the following.

- Complete project documentation describing the who, what, where, when, why and how of a project.
- Develop, document and implement standard procedures for field data collection and data handling.
- Enact and supervise quality assurance and quality control measures for the project. Supervise and certify all field operations, including staff training, equipment calibration, species identification, and data collection. Supervise or perform data entry, verification and validation.
- Maintain concise explanatory documentation of all deviations from standard procedures.
- Ensure documentation of important details for each field data collection period.
- Maintain hard copies of data forms and send original data forms to archive on a regular basis.
- Work with program coordinators to identify analysis and reporting mechanisms and to establish a schedule for regular project milestones such as data collection periods, data processing target dates, and reporting deadlines.
- Produce regular summary reports and conduct periodic trend analysis of data, store the resulting reports, and make them available to users.
- Act as the main point of contact concerning data content.

The project leader will also work closely with the data manager to:

- Develop quality assurance and quality control procedures specific to project operations.
- Identify training needs for staff related to data management philosophy, database software use, quality control procedures, etc.
- Coordinate changes to the field data forms and the user interface for the project database.
- Fully document and maintain master data.
- Identify sensitive information that requires special consideration prior to distribution.
- Manage the archival process to ensure regular archival of project documentation, original field data, databases, reports and summaries, and other products from the project.

- Define how project data will be transformed from raw data into meaningful information and create data summary procedures to automate and standardize this process.
- Identify and prioritize legacy data for conversion; convert priority data sets to a modern format.
- Increase the interpretability and accessibility of existing natural resource information.

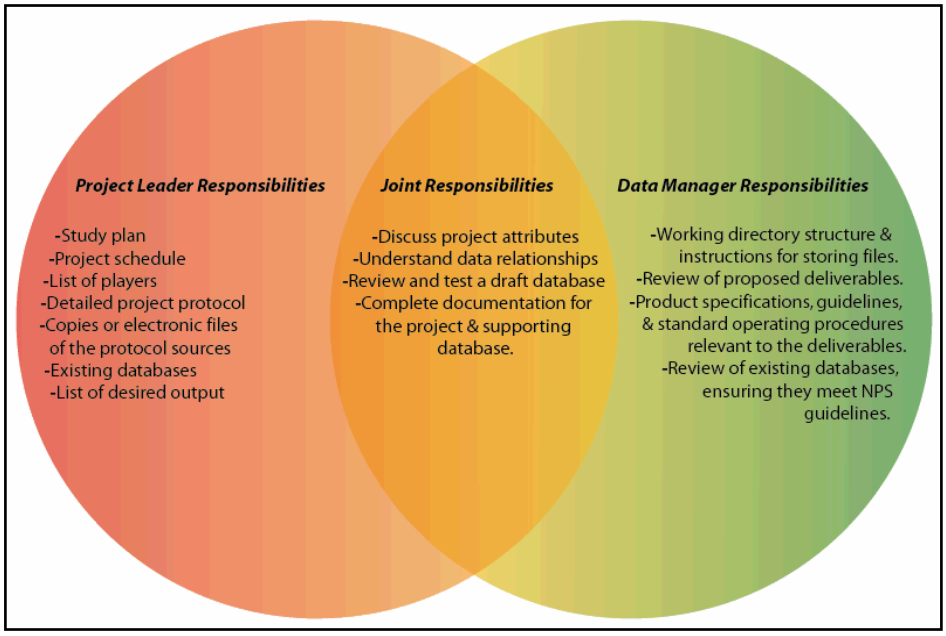


Figure 2.1. Joint Project and Data Management Responsibilities

Data managers

The data manager is responsible for ensuring the compatibility of project data with program standards, for designing the infrastructure for the project data, and for ensuring long-term data integrity, security, and availability. The data manager coordinates with the project leader throughout the project, as shown in Figure 2.1.

- Develop and maintain the infrastructure for metadata creation, project documentation, and project data management.
- Create and maintain project databases in accordance with best practices and current program standards.
- Provide training in the theory and practice of data management tailored to the needs of project personnel.
- Develop ways to improve the accessibility and transparency of digital data.
- Establish and implement procedures to protect sensitive data according to project needs.
- Collaborate with GIS specialists to integrate tabular data with geospatial data in a GIS system in a manner that meets project objectives.

Data managers will also work closely with the project leader to:

- Define the scope of the project data and create a data structure that meets project needs.
- Become familiar with how the data are collected, handled and used.

- Review quality control and quality assurance aspects of project protocols and standard procedure documentation.
- Identify elements that can be built into the database structure to facilitate quality control, such as required fields, range limits, pick lists and conditional validation rules.
- Create a user interface that streamlines the process of data entry, review, validation, and summarization that is consistent with the capabilities of the project staff.
- Develop automated database procedures to improve the efficiency of the data summarization and reporting process.
- Make sure that project documentation is complete, complies with metadata requirements, and enhances the interpretability and longevity of the project data.
- Ensure regular archival of project materials.
- Inform project staff of changes and advances in data management practices.

GIS specialists
The GIS specialists manage spatial data themes associated with network inventory and monitoring projects, as well as other spatial data related to the full range of park resources. They incorporate spatial data into the GIS. They also maintain standards for geographic data and are responsible for sharing and disseminating GIS data throughout the network.

The GIS specialists will work in collaboration with project leaders to:

- Determine the GIS data and analysis needs for the project.
- Develop procedures for field collection of spatial data including the use of GPS and other spatial data collection techniques.
- Display, analyze, and create maps from spatial data to meet project objectives.
- Properly document data in compliance with spatial metadata standards.

GIS specialists will also work directly with data managers to:

- Design databases and other applications for the network.
- Create relationships between GIS and non-spatial data and create database and GIS applications to facilitate the integration and analysis of both spatial and non-spatial data.
- Establish and implement procedures to protect sensitive spatial data according to project needs.
- Develop and maintain an infrastructure for metadata creation and maintenance.
- Ensure that project metadata are created and comply with national and agency standards.

3. Data Management Process and Work Flow

The network is involved with short-term and long-term projects that share many work flow characteristics and generate data sets and other products that must be managed and made available to current and future users. Short-term projects usually last from one to three years and include individual research projects, inventories, or pilot work done in preparation for long-term monitoring. Long-term projects include the network's vital sign monitoring projects and other multi-year research and monitoring projects performed by other agencies and cooperators. Successful project management is based in part on establishing and communicating data stewardship responsibilities for all staff at all stages of a project.

3.1 Project Work Flow

The five stages of a project shown in Figure 3.1 involve the roles and responsibilities for project and data management discussed in this section.

Planning and approval

The project leader and program administrator are responsible for defining the scope and objective(s) of the project, establishing funding sources, and obtaining permits and compliance clearances. The data manager contributes where appropriate as data processing and reporting schedules are set and budgets for data management activities are discussed and incorporated.

Design and testing

The project leader is responsible for adopting or developing and testing project methodology to meet project objectives. The project leader and data manager work together to establish appropriate data management procedures, develop the data design, and prepare a data dictionary, which comprehensively lists and describes the database fields and data value domains. The data manager develops a new database application or adapts an existing database to meet project requirements.

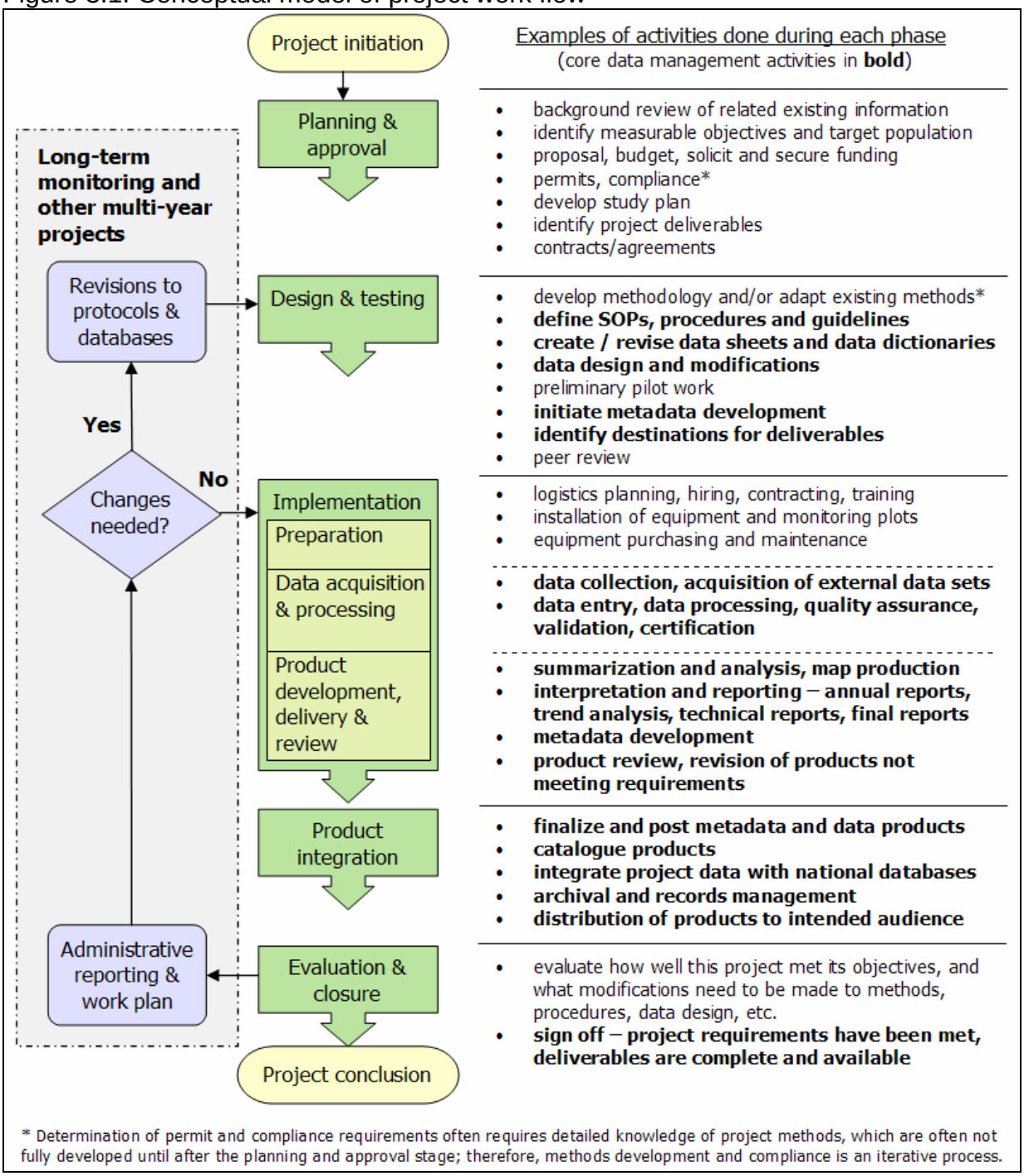
Implementation

During implementation data are acquired, processed, error-checked and documented. Reports, maps, GIS themes, and other products are developed and distributed. The project leader oversees all aspects of implementation, including logistics, contracting, training, and equipment procurement, data acquisition, report preparation and final delivery of products to resource managers. Data management staff provide training and support for database applications, GIS, GPS, and other data processing applications; facilitation of data summarization, validation and analysis; and assistance with the technical aspects of documentation and product development.

Product integration

The network maintains master copies and archives of all network-generated data on a local server. These are used to update NPS databases at appropriate intervals, e.g. annually updates to WRDSTORET for water quality data. Section 4.2.1 lists and describes the Service-wide databases used by the network for archival and distribution of data and information resources. The network also works with other partners to share and integrate results from network projects.

Figure 3.1. Conceptual model of project work flow



Evaluation and seasonal or final project wrap-up

For long-term monitoring and other cyclic projects, this phase occurs at the end of each field season as part of an annual review of the project. For non-cyclic projects, this phase represents the completion of the project. Upon season or project closure, project records are updated to reflect the status of the project and its associated deliverables in a network project tracking application. After products are catalogued and made available, program

administrators, project leaders, and data managers work together to assess how well the project met its objectives, and to determine what might be done to improve various aspects of the methodology, implementation, and formats of the resulting information. For monitoring protocols, careful documentation of all changes is required. Changes to methods and procedures are maintained in a tracking table associated with each document. Significant revisions, as defined in each protocol, may require additional peer review.

3.2 Data Life Cycle

Project data take on different forms and are maintained in different places as they are acquired, processed, documented, and archived. Figure 3.2 is a conceptual model that shows relationships between forms of data, databases, and data processes. Listed here are databases and forms of data:

- *Raw data* – Analog data recorded by hand on hard-copy forms and digital files from handheld computers, GPS receivers, telemetry data loggers, etc.
- *Working database* – A project-specific database for entering and processing data for the current season (or other logical period of time).
- *Certified data and metadata* – Completed data and documentation for short-term projects, or one season of completed data for long-term monitoring projects. Certification is a confirmation by the project leader that the data have passed all quality assurance requirements and are complete and ready for integration and distribution. Metadata records include the detailed information about project data needed for its proper use and interpretation (see Chapter 7).
- *Master database* – Project-specific database for storing the full project data set, used for viewing, summarizing, and analysis. Only used to store data that have passed all quality assurance steps.
- *Reports and data products* – Information that is derived from certified project data.
- *Edit log* – A means of tracking changes to certified data.
- *National databases and repositories* – Applications and repositories maintained at the national level, for the purpose of centralization, archival, and distribution among NPS units and with cooperators and the public.
- *Local archives and digital library* – Locally stored data, metadata and other products generated by projects.

The typical data process flow is described here and also shown in Figure 3.2:

1. *Acquire data* – For data recorded by hand in the field, data forms should be reviewed regularly (e.g., daily or weekly) for completeness and clarity in order to identify and resolve errors as close to their origin as possible.

2. *Archive raw data* – Copies of all raw data files are initially stored intact. Digital files are copied to the digital library section for the project; hard copy forms are either scanned and placed in the digital library, or are copied and placed in the archives. Archival or scanning of hard copy data forms may occur at the end of a season as a means of retaining all marks and edits made during the verification and validation steps. Once a project is completed or annual data results are validated and reported, original and intermediate data sets may be disposed in order to avoid unnecessary clutter in the information system. Disposing of data assets must be approved by at least the project

leader and the data manager based on established criteria for disposition that is documented in the data management procedures for the project.

3. *Data entry / import* – Analog data are entered manually, and digital data files are uploaded to the working database.

4. *Verification, processing and validation* – Verify accurate transcription of raw data and validate data using database queries to identify and resolve missing data values, out-of-range values, and logical errors.

5. *Documentation and certification* – Develop or update project metadata and certify the data set. Certification is a confirmation by the project leader that the data have passed all quality assurance requirements and are complete and documented. It also means that data and metadata are ready to be posted and delivered externally or used locally.

6. *Archive versioned data set* – Copies of the certified data and metadata are placed in the digital library. This can be accomplished by storing a compressed copy of the working database, or by exporting data to a more software-independent format (e.g., ASCII text; see Chapter 10).

7. *Post data and update national databases* – To make data available to others, certified data and metadata are posted to national repositories such as the NR-GIS Data Store and Biodiversity Data Store. In addition, national databases such as NPSpecies, NPSTORET, and NR-GIS Metadata Database are updated. Data and data products containing protected information are posted according to the guidelines and access levels outlines in chapter 9.

8. *Upload data* – Certified data are uploaded from the development database to the production database.

9. *Reporting and analysis* – Certified data are used to generate data products, analysis, and reports, including semi-automated annual summary reports for monitoring projects. Depending on project needs, data can be exported for analysis using other software applications and/or summarized within the database.

10. *Store products* – Reports and other data products are stored according to format and expected demand – either in the digital library, on off-line media, or in the document archives.

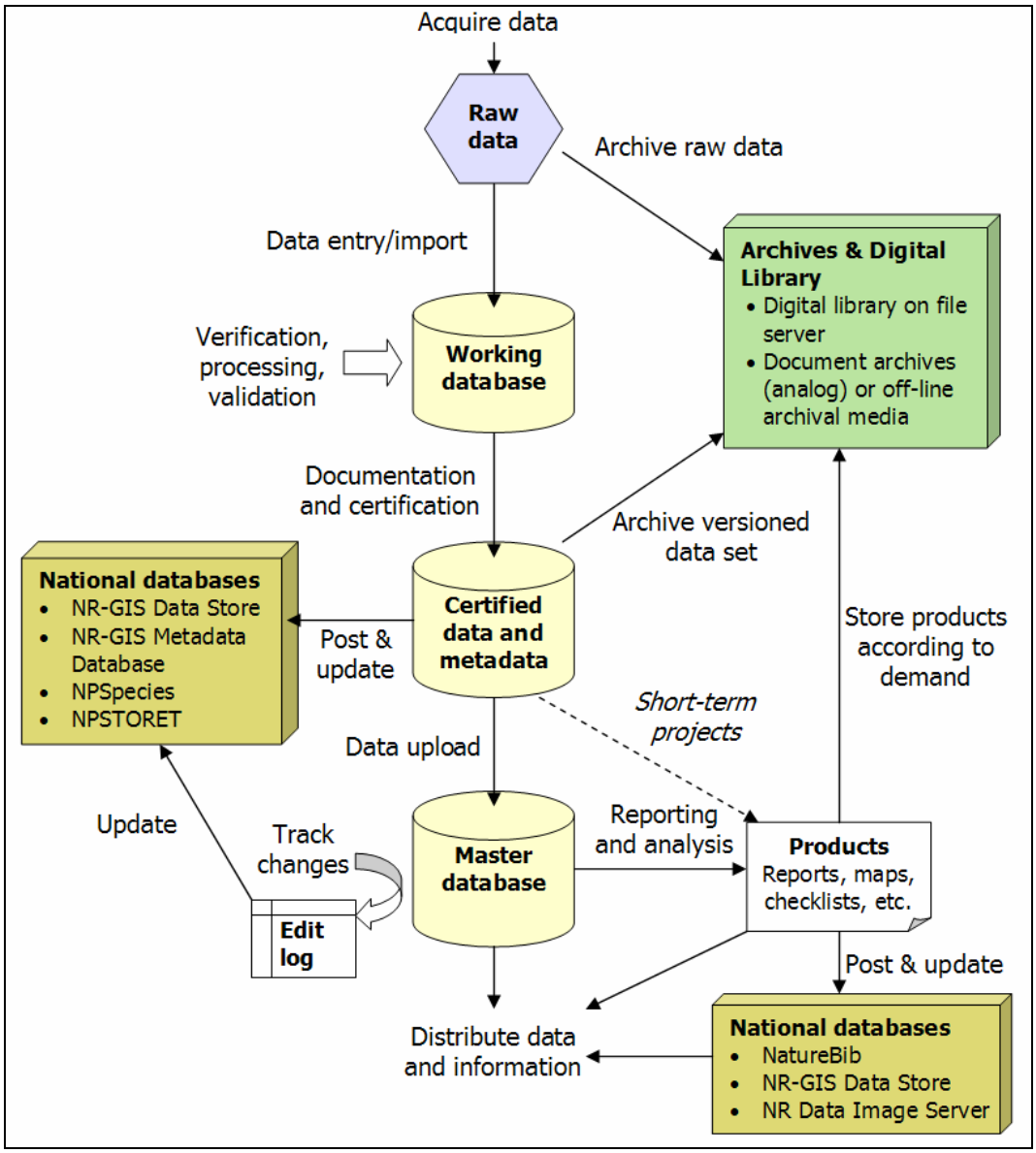
11. *Post products and update national databases* – To make products available to others, reports and other products are posted to national repositories such as NR-GIS Data Store or the NR Data Image Server. In addition, products are catalogued in NatureBib. Data products may not be posted if they contain protected information about the nature or location of rare, threatened or endangered species, or other natural resources of management concern (see Chapter 9).

12. *Distribute data and information* – Deliverables can be shared and distributed in a variety of ways - via the web-based national databases and repositories, by FTP or mailing in

response to specific requests, or by providing direct access to project records. Distribution is subject to legal requirements to protect information about sensitive resources (see Chapter 9).

13. *Track changes* – All subsequent changes to certified data are documented in an edit log, which accompanies project data and metadata upon distribution. Significant edits will trigger reposting of updated data and products to national databases and repositories.

Figure 3.2. Diagram of the typical project data life cycle.

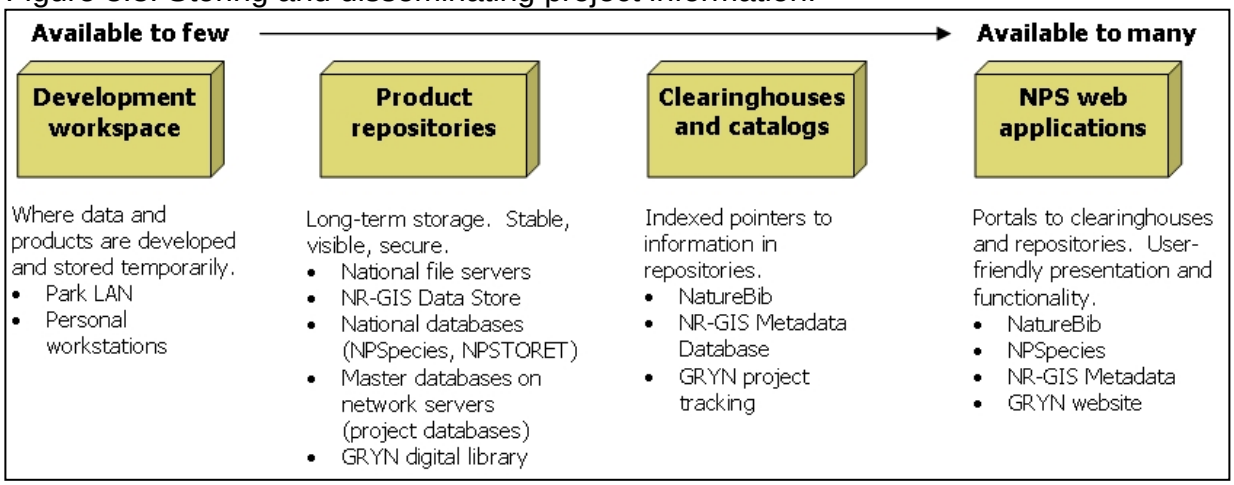


This data flow occurs iteratively (usually annually) for long-term monitoring projects and once for short-term projects. For projects spanning multiple years, decision points include whether or not a separate working database is desirable, and the extent to which product development and delivery is repeated year after year.

3.3 Integrating and Sharing Data Products

Final and seasonally certified project data and products need to be secured in long-term storage and made available. This requires using a variety of information systems such as product repositories, clearinghouses, and web applications. Each of these systems has a different purpose and function, as shown in Figure 3.3.

Figure 3.3. Storing and disseminating project information.



The specific repositories for most GRYN products are indicated in Table 3.1.

Table 3.1. Repositories for GRYN products.

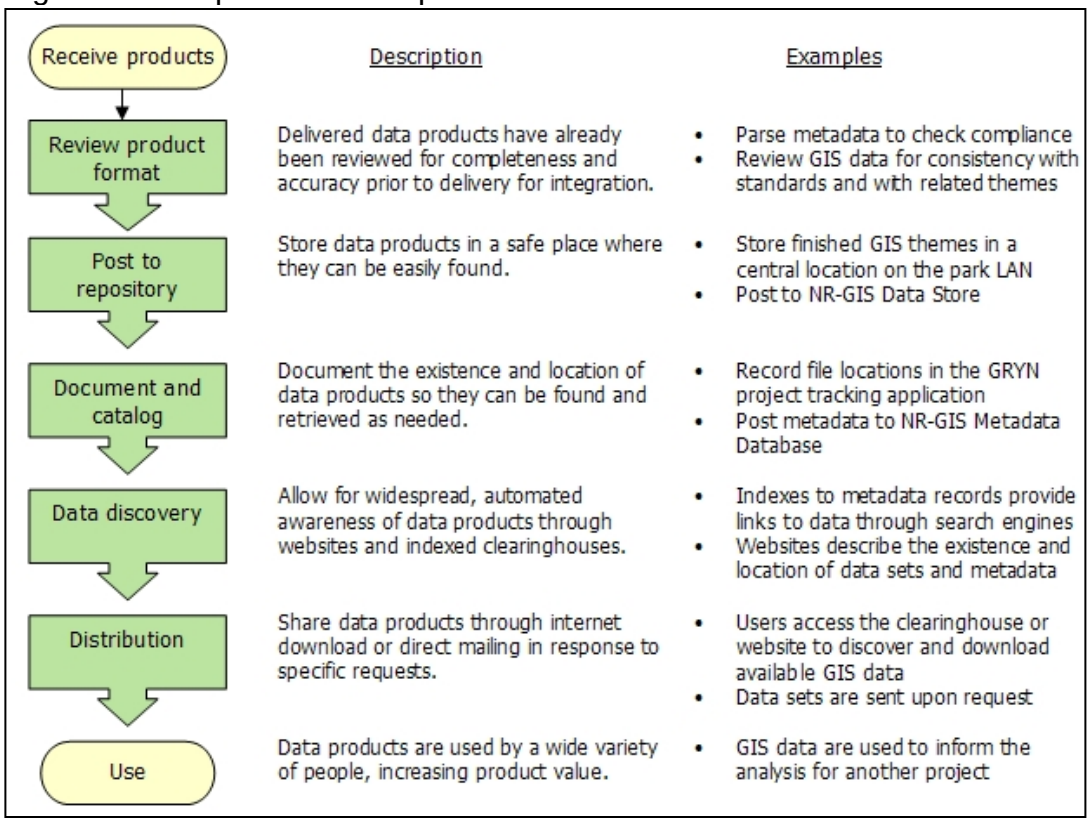
Item	Repository
Reports	GRYN digital library; posted to NR Data Image Server, linked and accessed through the catalogue record in NatureBib; Park collection (hard copy)
Digital data, metadata, and other products • Raw and processed data sets • Metadata, protocols, SOPs • Completed reports • Digital photographs	GRYN data servers, NR-GIS Data Store, Biodiversity Data Store, and other cooperators and agencies.
Project materials • Vouchers specimens, field data forms	GRYN and Park archives and collections, or another specified repository.
Administrative records	GRYN offices and/or park offices, park archives, National Archives

3.3.1 Data distribution

The process of product distribution involves several steps (Figure 3.4). In most cases the data manager or GIS specialist reviews products for conformance with format standards then transmits the products to the appropriate repository. All products are reviewed for completeness and accuracy by the appropriate resource specialist prior to delivery to the

data manager. Stored products are documented by posting metadata to the NPS clearinghouse and by updating records in the GRYN project tracking application. These metadata records provide contact and distribution information that help users obtain and use data sources and products.

Figure 3.4. Steps involved in product distribution.



Chapter Credits

This chapter was prepared by John Boetsch (NCCN) and adapted from concepts and material developed in collaboration with Dorothy Mortenson (SWAN), Velma Potash (CACO), Sara Stevens (NCBN), and Doug Wilder (CAKN). Special thanks to Dorothy Mortenson and Doug Wilder for significant contributions and ideas.

4. Data Management Infrastructure and Applications

The I&M Program relies on park, regional, and national IT personnel and resources to design and maintain a functional infrastructure to support I&M database and information system applications. This chapter briefly describes IT infrastructure and focuses on specific applications that are central to I&M network data management in a developing NPS Enterprise Architecture.

4.1 Network Computer Infrastructure

Due to the location of the GRYN offices separate from a park or other NPS office with conventional NPS computer network service, GRYN maintains a small client-server computer architecture that relies on disconnected data transfer to exchange information with the parks. The distributed hardware configuration shown in Figure 4.1 will suffice until a direct connection is established between park and network computers. The network manages common tables and high-value, long-term project databases within a system of revolving network attached storage devices to support a distributed, multi-user environment. There are four data servers that comprise the network infrastructure – one located at each of the three parks and one at the network's main office. These servers function as independent data nodes that can be accessed by park staff served by a local area network. They are also integrated in that common tables are replicated regularly among data nodes and network databases are replicated to each server.

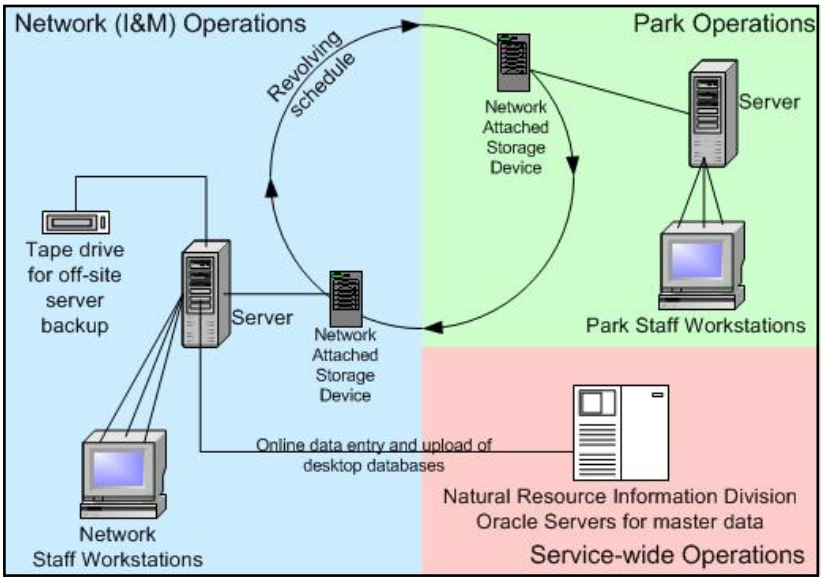


Figure 4.1. Network Computer Architecture

4.2 Network Information Management Systems

The network's information system strategy involves modular, standalone project databases that share design standards and use common data tables where possible, e.g. contacts and project personnel. Individual project databases are developed, maintained, and archived separately in Microsoft® Access and ESRI® GIS formats. Separate database applications allow greater flexibility in meeting the needs of each project but can be a barrier to synthesizing and consolidating data from related projects. Network and park data management and GIS staff work to develop resources, expertise, and institutional support for integrated and centralized databases that support park-level user requirements for natural resource management. Both the user requirements analyses and subsequent database development require a large initial investment followed by a long term commitment of resources to maintain, update, and support database applications. In order to be feasible,

investments made in complex interdisciplinary databases must be made with full participation from and understanding by park managers, scientists, and information technology staff. National level business requirements, such as summarizing and reporting core variables, must also be considered.

4.3 Information System infrastructure

The network stores data on national servers that host several master NPS applications, including NatureBib, NPSpecies, NR-GIS Metadata and Data Store. Centralized NPS repositories that include some of the network's data include the Biodiversity Data Store and the I&M Protocol Database. Public access sites to network data resources include current and planned portals to NatureBib, NPSpecies, NPSFocus, and the STORET National Data Warehouse.

Network and park data servers hold master network applications for data sets that are available locally for use by park and network natural resource specialists and managers. These include common tables, certified project data, a project tracking database, working data sets for NatureBib, NPSpecies, Dataset Catalog, and NPSTORET, digital libraries of developmental and production files and data sources, and downloads from national NPS or other data sources.

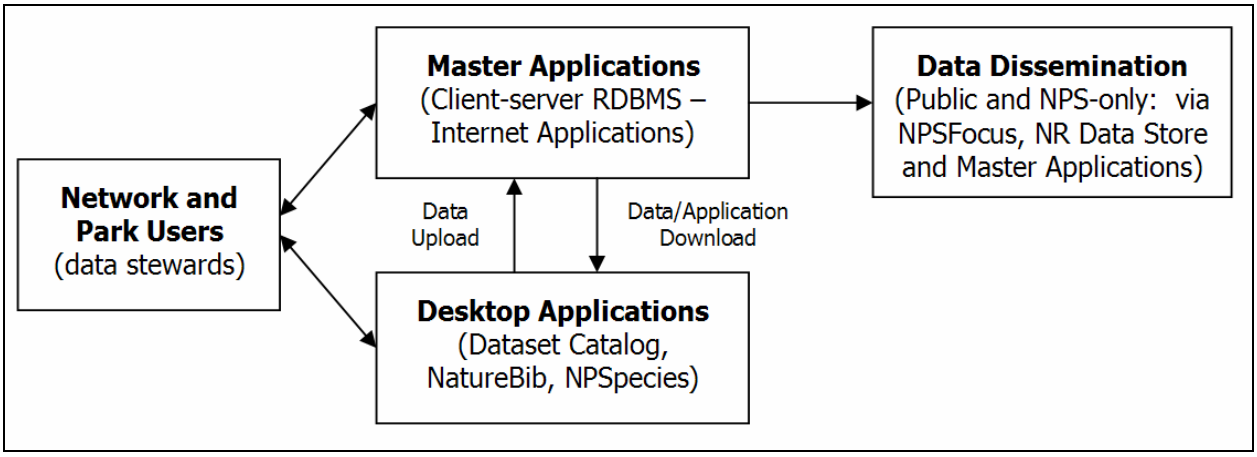
Each of the GRYN park servers and the network server uses a hierarchical folder and filing structure that meets the needs of local users. Files in development are commonly stored in separate folders from those used for production. The network's approach to folder and file management is explained in appendix B. Files for finished products are typically read-only. "Inbox" folders can be used as bins where users can save project-related files for processing and filing. Standards such as naming conventions and hierarchical filing are enforced within the production sections of the folder system. Although less stringent in other sections, these conventions are encouraged as good practice.

4.4 National Level I&M Database Applications

Integrating inventory and monitoring results at the network level involves national-level programmatic data and information management strategies that help provide consistent, long-term data and information sources for stewardship decisions, resource protection, and interpretation. The network maintains local access to all certified project data for use by park and network staff to help inform resource management and protection at parks. The network also provides data to the NPS Natural Resource Program Center (NRPC) and the I&M Program are involved in to centralized data archiving and distribution solutions developed by the NPS Natural Resource Program Center and the I&M Program. These databases and applications provide archive and accessibility for network data, and summary use by NPS and DOI managers and central office personnel to answer requests from Congress and for budget, program, and project planning.

To achieve an integrated information management system, three of the national-level data management applications (NatureBib, NPSpecies, and NR-GIS Metadata Database) utilize a distributed architecture (Figure 4.2) with master Oracle RDBMS applications available via web browser and desktop database applications for off-line data entry and access.

Figure 4.2. Model of the national-level application architecture.



NatureBib

NatureBib is the master database for bibliographic references that merges a number of previously separate NPS databases such as Whitetail Deer Management Bibliography (DeerBib), Geologic Resource Bibliography (GRBib), and others. It also contains citation data from independent databases like NPSpecies, Dataset Catalog, and NR-GIS Metadata Database. It currently focuses on natural resource references, but may eventually be linked to references on cultural resources and other park operations. As with NPSpecies and NR-GIS Metadata Database, it is possible to download data from the master web version into the Microsoft® Access desktop version that can be used locally on computers with limited internet connectivity *(http://www.nature.nps.gov/nrbib)*.

NPSpecies

NPSpecies is the master species database for the NPS. The database lists the species that occur in or near each park, and the physical or written evidence for the occurrence of the species (e.g., references, vouchers, and observations). Taxonomy and nomenclature are based on the interagency Integrated Taxonomic Information System (ITIS). The master version of NPSpecies for each park or network can be downloaded from the master website into an Microsoft® Access version of NPSpecies. The internet-based version is the master database, which can be accessed via password-protected logins administered by park, network and regional stewards assigned for each park and network. The master database requires certification of species lists by networks before any data will be available to the public. NPSpecies is linked to NatureBib for bibliographic references that provide written evidence of species occurrence in a park and will be linked to NR-GIS Metadata Database to document biological inventory products. The Microsoft® Access application and additional details can be found at the NPSpecies website *(http://science.nature.nps.gov/im/apps/npspp/index.htm).*

Dataset Catalog and NR-GIS Metadata Database

Dataset Catalog is a desktop metadata database application developed by the I&M Program to provide a tool that parks, networks, and cooperators can use to inventory and manage data set holdings. Although not designed as a comprehensive metadata tool, the Dataset Catalog is used for cataloging abbreviated metadata about a variety of digital and non-digital natural resource data sets. The Dataset Catalog helps parks and networks begin to meet

Executive Order 12906 mandating federal agencies to document all data collected after January 1995. It provides brief metadata and a comprehensive list about all resource data sets for use in data management, project planning, and more stringent metadata activities. As with other service-wide applications, the master metadata database (NR-GIS Metadata Database) is available through a website and will be linked to NPSpecies (the NPS species database) and NatureBib (the bibliographic database). It will be possible to download a version in Microsoft® Access format from the master website (*Dataset Catalog: http://science.nature.nps.gov/im/apps/datacat/index.htm and NR-GIS Metadata Database: http://science.nature.nps.gov/nrdata).*

NPSTORET

NPSTORET is the NPS desktop database designed to facilitate standardized park-level reporting for STORET, an interagency water quality database developed and supported by the Environmental Protection Agency's (EPA). STORET is an electronic warehouse for local, state, and federal water quality data collected in support of managing the nation's water resources under the Clean Water Act. STORET is used by NPS as a repository of physical, chemical, biological, and other monitoring data collected in and around national park units by park staff, contractors, and cooperators. The NPS Water Resource Division (WRD) operates WRD STORET and makes periodic uploads to the EPA STORET National Data Warehouse so that data collected by and for parks will be publicly accessible. NPS Director's Order 77 instructs the NPS to archive water quality data in STORET. Network staff and cooperators will use NPSTORET for data entry and management and to prepare data for upload to STORET by WRD staff (Figure 4.3). To support spatial analysis and functionality NPSTORET includes a field for the National Hydrography Dataset (NHD) reach code where water samples are collected. This allows sampling stations to be indexed to hydrographic features and analyzed with other resource layers in a GIS using a suite of hydrographic network and hydrologic tools. The Microsoft® Access application and additional details can be found at: *http://www.nature.nps.gov/water/infodata.htm*. Additional information on STORET can be found at: *http://www.epa.gov/storet*.

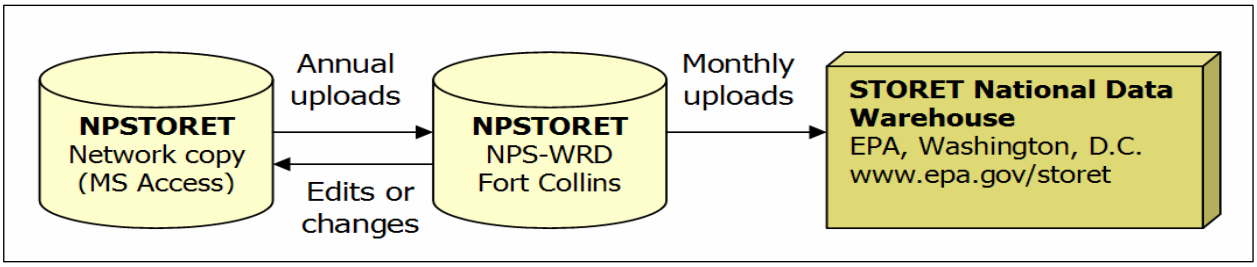


Figure 4.3. Water Quality Data Flow

Natural Resource Database Template

The Natural Resource Database Template (NRDT) is a flexible, relational database in Microsoft® Access for storing inventory and monitoring data (including raw data collected during field studies). This relational database can be used as a standalone database or in conjunction with the GIS software (e.g., ArcView™ or ArcGIS™) to enter, store, retrieve, and otherwise manage natural resource information. The template has a core database structure that can be modified and extended by different parks and networks depending on the components of their inventory and monitoring projects and the specific sampling protocols in use. NRDT is designed to support some standardization among monitoring protocols.

Approved monitoring protocols, including the databases that use the NRDT are available through a web-based protocol clearinghouse (see next item). A description of the Database Template application, a data dictionary, and example implementations are located on the NR Database Template website *(http://science.nature.nps.gov/im/apps/template/index.htm).*

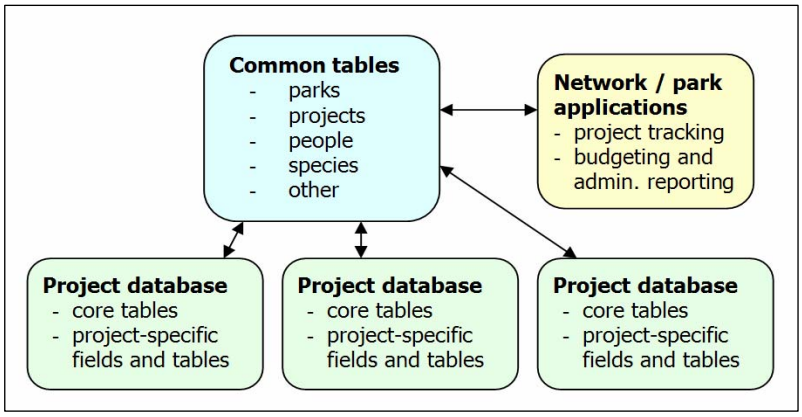
Natural Resource Monitoring Protocols Clearinghouse
The Natural Resource Monitoring Protocol Clearinghouse (i.e., Protocol Database) is a web-based clearinghouse of sampling protocols used in national parks to monitor the condition of selected natural resources. The clearinghouse provides a summary of each monitoring protocol and links to download full protocols and database designs. See the Protocol Database website for available protocols.
(*http://science.nature.nps.gov/im/monitor/protocoldb.cfm*).

NR-GIS Data Store
The NR-GIS Data Store is a key component of the data distribution strategy used by the I&M Program. The NR-GIS Data Store is a graphical search interface that links data set metadata to a searchable data server on which data sets are organized by NPS units, offices and programs. The interface allows customized public or protected searches of natural resource data sets, inventory products, and GIS data produced by the I&M and Natural Resource GIS programs. Each park or network is able to post and manage its data on the server. The NR-GIS Data Store will be integrated with the master NR-GIS Metadata Database application to streamline programmatic data documentation and distribution processes. The simple browse function of this server can be accessed at:
http://nrdata.nps.gov/.
See the NR-GIS Data Store website for further information
(*http://science.nature.nps.gov/nrdata*).

NPS Biodiversity Data Store
The Biodiversity Data Store (BDS) is a digital repository of documents, GIS maps, and data sets that contribute to the knowledge of biodiversity in National Park units, including species occurrence, distribution and abundance. The web site includes public and secure areas for searching and downloading data. The network will work to understand and manage the relationship between the BDS and the NPS GIS Data Store.

4.5 Project Database Standards

Figure 4.4. Common lookup tables and satellite databases



To promote compatibility among data sets that will be used in summary analysis and reporting across vital signs, network databases contain ***common lookup tables*** (Figure 4.4), ***core project tables*** standardized with regard to data types, field names, and domain ranges, and ***project-specific tables***. The network adapts or develops databases

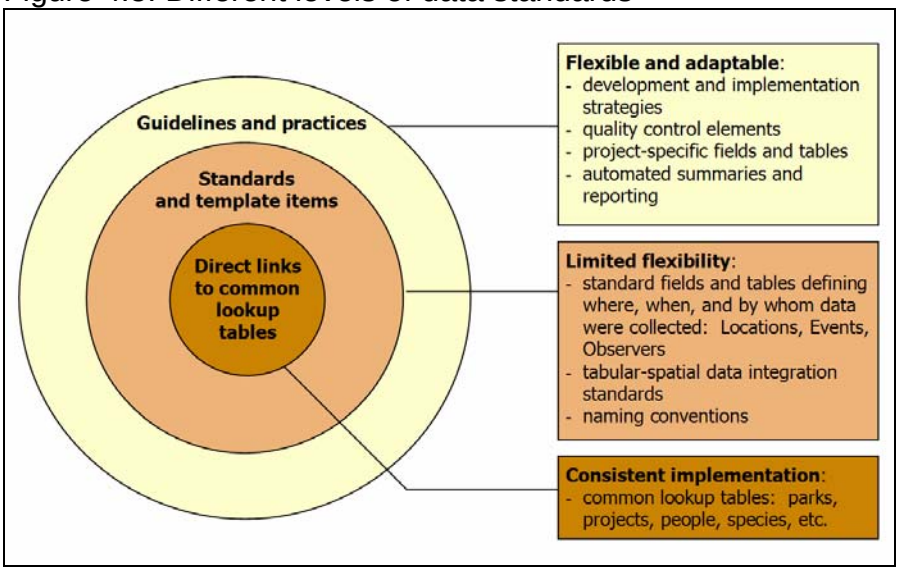
to be compatible with those maintained by other networks and cooperators managing similar data sets.

In the future a client-server database system may be developed at the network to associate common database components that are replicated among data nodes hosted at each network park. Individual project databases will continue to access these common tables.

4.5.1 Levels of data standards

Because common lookup tables are stored in one place and are referred to by multiple databases, they represent the highest level of data standard because they are implemented identically among data sets. The second level of standards is implied by core template fields and tables, which are standardized where possible, but project-specific objectives and needs could lead to varied implementations among projects. The third level of standards is applied most flexibly to accommodate the range of needs and possibilities for each project, yet always with compatibility and integrity in mind. Figure 4.5 presents the resulting variation in implementation of these differing levels as a "bull's eye", with the common lookup tables providing the most consistent implementation and hence the smallest range of variation.

Figure 4.5. Different levels of data standards



4.5.2 Project tracking application

To support program coordination and annual reporting, and to improve accountability for the products of natural resource inventory and monitoring efforts, the network will use a project tracking database. The primary functions of this application include:

1. Maintaining the list of projects – By maintaining a single list of natural resource data projects, it is much easier to quickly find project-related information (e.g., status, funding sources and amounts, objectives, contact information) and summarize that information for administrative reports.
2. Tracking product deliverables – For each project a comprehensive list is maintained of what deliverables are expected and when. Once they are delivered and posted or archived, this function shifts to being a finding aid for available products. Deliverables

are first specified at project initiation and information is updated at various project milestones (e.g., contracting, product delivery, archival).

3. Managing project codes – These are intelligent alphanumeric codes used to tie together digital information in various, minimally connected systems (e.g., RPRS, PMIS), along with analog materials that cannot otherwise be linked to an integrated information system. These codes are also used to link to data in databases and GIS themes, especially where information from multiple sources is stored together.

The master version of this application will be maintained at the network office and made available to each park. Project leaders, the network data manager, GIS staff, and the network coordinator share responsibility for the maintenance and availability of the project tracking data and reports. Each of these staff will be able to make certain changes to update information about project status, deliverable details, etc. Database views will be created to help project leaders keep on schedule, and to facilitate quick reporting on project status, accomplishments and delivered products.

<u>Chapter Credits</u>

This chapter was adapted from material prepared by John Boetsch (NCCN) and Patrick Flaherty (APHN). Section 4.2 - National Information Management Systems was adapted from material written by Lisa Nelson (WASO).

5. Data Acquisition and Processing

The network's peer reviewed and NPS-approved monitoring protocols list specific ecosystem parameters that are collected by observation, measurement, and/or prediction and stored as data. To be useful to park managers these data must be processed, analyzed, mapped, displayed, and reported not only as stand alone vital signs but in ways that demonstrate the dynamic connections among and between vital signs. Some of the vital signs selected by network parks are monitored using methods developed before the GRYN was established. Data from these past and continuing efforts contribute to scientific understanding and park stewardship regardless of their basis in local methods or peer-reviewed I&M protocols. The network engages natural resource professionals at all organizational levels to help determine the relevance to monitoring objectives for a variety of park and other data sources. Data that are certified by subject matter experts as valid, complete, and fully documented with FGDC and NPS spatial and biological metadata are processed to contribute to the network's inventory and monitoring objectives.

Table 5.1. Abbreviated Data Development Model

1. Identify issues and concerns
2. Define the purpose and need for data collection and analysis
3. Develop explicit monitoring objectives or inventory criteria (these are key questions addressing the issue or concern within the scope of the purpose and need)
4. List measurable, observable, and predictable variables associated with each key question
5. Formalize (document) information needs
6. Develop a Data Dictionary for field names, lists of values, quality factors, and metadata characteristics
7. Select or develop an appropriate sample design
8. Identify and assign explicit data stewardship roles and responsibilities
9. Write a complete monitoring protocol or inventory study plan
10. Design or adopt/adapt a database (including quality control elements)

1. Plan for data acquisition (**beginning of data life cycle)**
2. Collect data – field and office components
3. Process data (includes verification, transfer, addition of required attributes)
4. Store, organize, and secure data
5. Use, analyze, and report data
6. Maintain and serve data and derived products
7. Archive data (long term storage that may require media and/or platform transfer)
8. Dispose of data that are no longer needed, if appropriate (**end of data life cycle**)

Newly acquired vital sign data funded by the network involve the steps outlined in Table 5.1 and will meet the following requirements:

- Base data acquisition on documented and approved monitoring protocols
- Adhere to a data dictionary approved by the project leader and the network data manager
- Use common and/or existing data formats and field definitions to promote crosswalk and comparison with data from other times and places.
- Enter data in a database approved by the network data manager
- Provide data verification in the field and in the office by field crew members and the field crew leader
- Process the data with quality control features built in to a database application

5.1 Database Design

To promote data comparability among parks and networks GRYN draws on and extends the concepts and structure of the NPS Natural Resource Database Template and the NPS conventions for naming database objects. It is also important for GRYN to consider design elements that promote data comparability with other land and resource management entities in the Greater Yellowstone Ecosystem. Before starting a new database design from scratch the network will look to the following sources for existing designs and database objects:

- NPS Natural Resource Database Template
- I&M Protocol clearinghouse
- Other NPS I&M networks
- Cooperating agencies and entities
- Other parks
- Other agencies

In particular the network will review and associate, where appropriate, existing database and application design elements from the US Forest Service because their data structures store ecosystem parameters for administered lands surrounding Yellowstone National Park and Grand Teton National Park. Achieving some consistency in common data objects between the parks and the surrounding forests promotes ecosystem-based analysis and reporting.

5.2 Data Acquisition

New data collected by the network are from natural resources inventories or vital sign monitoring projects and collaborative efforts between the network and other regional programs or institutions. Data for these projects will be collected by I&M personnel, park staff, partners, and cooperators. Natural resource inventories help to identify the presence or occurrence, and status of park natural resources and represent an important component of park stewardship. A listing, description, and park status of standard NPS Natural Resource Inventories conducted by the Inventory and Monitoring Program are available online at http://science.nature.nps.gov/im/inventories.htm. Network-base inventory results are available via the GRYN web site (see title page for web address). Monitoring data are collected and processed according to requirements specified in peer reviewed and NPS-approved GRYN Vital Sign monitoring protocols. Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of a park's natural resources, known or hypothesized effects of stressors, or elements that have important human values. Information about the status and trend of vital signs contributes to the decision making processes used by park managers. Chapter III of the network's Vital Signs Monitoring Plan lists the vital signs and explains the selection process.

5.2.1 Data Discovery and Data Mining

Data discovery in the Greater Yellowstone Network refers to the process of searching out existing natural resource data and information that are useful to the I&M Program mission. Since 2000 GRYN has identified, catalogued, and entered thousands of data records and data sources in Dataset Catalog, NatureBib, and NPSpecies. The bulk of this effort occurred during the inventory phase of network development from 2000 through 2004 (GRYN 2000). These data discovery efforts primarily involved interviews with park natural resource specialists and targeted searches through hardcopy and electronic data sources stored at

park service units, other government offices, academic institutions, and collection facilities such as libraries, museums, and herbaria. Those efforts represent a different approach than more fundamental IT industry 'data mining' procedures that incorporate data input, data analysis, and results output using complex computer platforms and software applications for extracting knowledge from large volumes of data (US GAO 2004). The network does not intend to perform that type of data mining in the foreseeable future, but will continue to intentionally and incidentally identify and process relevant natural resource data sources related to GRYN parks and inventory and monitoring activities. A useful discussion and set of procedures for data mining activities that emphasizes a data catalog, bibliography, and metadata is available from the Klamath Network of the NPS I&M Program (Smith and Truitt, 2004). Additional background and guidelines for data mining in the NPS I&M Program are available on the npsweb: (http://www1.nrintra.nps.gov/im/datamgmt/DataMining/datamining.htm).

GRYN staff will find and review different sources for various types of data at the onset of new projects or during the development of new protocols as part of research for background information. Network staff use the following data sources via the internet and visits to local research or academic institutions, museums, and local parks.

Bibliographic/Literature
- National NPS Databases (e.g., NatureBib)
- Online literature databases (e.g., First Search or Biosis)
- Local document library
- Library catalogs (e.g., academic or research institutions)
- Park and other archives

Geographic Data
- Regional GIS Specialists
- Park GIS Specialists
- Federal and State Geographic data clearinghouses
- Local, state, and federal government offices

Biological/Natural Resources Data
- Automated National Catalog System (ANCS+)
- NPSpecies
- Voucher collections (museums, parks, universities)
- Network Parks
- Local, state, and federal government offices

Relevant information collected during a data discovery process is maintained at the network and/or at one or more network parks either electronically or in hard copy format depending on how it was collected. Geographic data sets collected during this process are documented with FGDC compliant metadata when possible and/or documented with brief metadata in Dataset Catalog.

4. **Dataset Catalog** – new data sets (spatial or non-spatial) are entered into Dataset Catalog.

- **Scientific citations** – The network uses the online and desktop versions of NatureBib.
- **NPSpecies** – Information relating to the biodiversity of network parks is entered into NPSpecies and linked to the available reference documents in NatureBib.
- **Reference Cabinets** – Hard copy materials are stored that relate to the network parks and the GRYN projects. All original data sheets, final reports, and contracts are stored in a fire proof cabinet and/or in more than one building as insurance against total loss. General references as well as those references linked to NPSpecies records in NatureBib are stored in file cabinets in the GRYN office.

Information collected during the data discovery process is likely to be ***legacy data***, which may be of high value to the network parks but differs in structure and intent from current NPS, I&M Program, or network data models, and/or is based on a different protocol with different objectives and methodology. Legacy data resources are primarily from inventory and monitoring efforts that originated before the NPS I&M Program. GRYN regards all legacy data sources as potentially useful. Network staff will coordinate with park staff to minimally document (e.g. in Dataset Catalog) those legacy data sources discovered incidentally during normal park and network business. Due to the volume of legacy data sources, particularly at YELL, investments in additional or extensive data discovery efforts must be reviewed and approved by project leaders and resource specialists to determine if candidate data sources can be documented as valid and related to the objectives of the vital signs monitoring program. If so, then legacy data may be converted using I&M funds to file formats compatible with the current standards. The network may scan hardcopy references and materials, saving them as PDF files in a digital library and transferring a copy to the NatureBib document center or NPS Biodiversity Data Store.

5.2.2 Field Studies

Biological inventories and monitoring projects are the most common examples of field studies conducted by the network. All NPS employees, volunteers, educational partners, contractors, etc. must conform to the National Park Service Geographic Information System Data Specification for Resource Mapping, Inventories, and Studies. (http://imgis.nps.gov/contract_specs.html) Following this guidance helps ensure that NPS investments result in usable GIS data in standard formats. The data manager is responsible for ensuring that data collection, data entry, verification, documentation, storage, and archiving for all field projects are consistent with the program and network standards. In addition to general operating procedures that define network-wide requirements, protocol specific standard operation procedures (SOP's) are developed for each protocol. The data manager works closely with the project leaders and network staff to develop these guidelines and methodologies for data collection, processing, and management. These activities range from specifying the proper design and use of hardcopy and electronic data entry forms to outlining calibration procedures for automated data loggers. Refer to the individual vital sign monitoring protocols for specific data management procedures. General NPS examples of protocol specific SOP's are available online at http://www1.nrintra.nps.gov/im/datamgmt/dmplanning.htm.

Field Data Acquisition Tools:

Since different protocols require unique data collection methods, the details about specific field data collection tools for individual projects are documented in each protocol's operating procedures. The network invests in technology based on the particular needs of each project rather than the allure of the latest, greatest gadgetry. The process to select equipment and methods will consider short term and long term cost, functionality, ease of use, user comfort levels, and support and training requirements. The network expects to use many of the general tools listed below.

Field Forms – this common method of recording field data is straightforward and inexpensive. Special attention must be paid to maximize clarity of written data values and minimize data form coding errors during the data recording process. Field forms require neat, legible handwriting and rigorous quality control. For some projects the network may transition from using hardcopy forms as the primary recording medium to electronic equipment, and continue to use field forms for backup when electronic equipment fails or is unavailable.

Field Computers – Collecting data in digital format in the field can increase data entry and processing efficiency and help reduce errors. Data can be directly transferred from the field computers to the office desktop computers to eliminate a data entry step. Data entry errors can be minimized by applying quality control functions in the electronic data entry forms. Field computers can complement hardcopy field notes, and hardcopy data sheets should always be available in case the electronic equipment is damaged, lost, out of power, or otherwise unavailable.

- **Handheld computers** (Personal Digital Assistants (PDA's), Portable Data Recorders (PDR's), etc.) **–** The small size and relative low cost of these devices make them worth considering for collecting field data. Those that are made for dusty, wet, and extreme temperature conditions or those that can be protected within a rugged container may be a good option for small field projects. However some may not have the battery, memory, or functional capacity for large data intensive field projects. Many rugged handheld computers are available with global positioning system (GPS) functions, as well as feature attribute data collection capacity. Most use Microsoft PocketPC or Palm operating systems which may require additional expertise and training in processing and programming to create the database structure for the handheld computer and transfer database content between computers.

- **Tablet PC's –** These have many of the same properties as laptop computers and provide the user with the convenience of a touch screen interface. They are bulkier, more expensive and harder to make rugged for field use than the handheld computers but are more powerful. Tablet PC's may be a better choice for field projects that are very data intensive. Because these units run Windows XP (Tablet Edition) the project database can usually be directly transferred from desktop units to field units without additional programming steps. The visibility of the computer screen in bright sunlight conditions is an important consideration for tablet PC's and handheld computers.

Automated Data Loggers – These are mainly used to collect physical environment data such as weather data or water quality parameter values. Data loggers require proper and

regular calibration and maintenance, so field crews must receive appropriate training, and standard operating procedures must include specific calibration and maintenance procedures. The resources required to set up, maintain, and manage automated data loggers should be carefully assessed and compared to alternative sampling techniques and equipment.

- **Permanently deployed devices –** Data from these devices must be retrieved and batteries changed on a regular basis. These intervals should be defined in the protocol and costs of visits and maintenance should be considered in the project budget.

- **Portable hand-held devices –** Deployed for sampling only during site visits, these are generally less expensive than units that are permanently deployed in the field.

Global Positioning System (GPS) Units – Two types of GPS units are typically used during field work to display and/or collect location information. The decision about which type to use depends on the requirements of the project related to the capabilities and limitations of the GPS equipment. See Appendix D for the GPS standard operating procedure.

- **Recreational GPS Units –** These are preferred mainly for all-purpose navigation rather than data collection because they store little or no attribute data and only general position information. Since most units do not record the accuracy of each position or feature, and the positions cannot be differentially corrected to improve the accuracy, recreational GPS units are not recommended for protocols or projects that require highly accurate location information. In some cases it is appropriate to use recreational GPS units to collect point features using position averaging to improve accuracy. Collecting line and area features with recreational GPS units is not recommended. Users are advised to record error estimates along with the coordinates.

- **Mapping GPS Receivers –** When used by well trained crew members, these receivers can collect highly accurate (sub-meter) location information, when using real time or post processed differential correction. Mapping grade receivers also support data entry forms for collecting feature attribute data that facilitates transfer to a GIS. Use of mapping grade units is encouraged for all line and area feature GPS data collection.

5.3 Data Entry

After data is recorded using the tools listed above, the following data entry procedures are necessary to maintain data flow and ensure data quality.

- Field crew members or other project staff will enter all data into a database approved by the project leader and network data manager.
- Project personnel will periodically transfer data files to the data manager. Individual protocols state the requirements for data transfer, backup, and archiving.
- The data manager maintains and updates the network's master copy of the database with data received from the field crews.

- All data is subject to quality assurance procedures. Chapter 6 discusses data verification and validation. Specific quality control activities are specified in each vital sign monitoring protocol.

Network data is stored and processed in local and national databases. Microsoft® Access databases and personal geodatabases are developed using the NPS Natural Resources Database Template. The flexibility of the NRDT allows customized local database applications to meet the needs and requirements of each project while using common tables for data values that repeat and are shared between projects (places, people, species, etc). Network database applications incorporate quality assurance mechanisms such as pick lists and validation rules. The network also processes its data using Service-wide data stores (listed in chapter 4) for centralized archival and distribution. The network keeps master data synchronized between local and Service-wide data stores.

5.4 Changes to Data Collection Procedures/Protocols

Changes to data collection procedures are made based on valid reasons for altering the methodologies. Most issues will be identified during the design and testing stages of the project and changes will be implemented prior to the collection of field data. The protocol development process includes attempting to identify and address any foreseeable issues that might occur with data acquisition and processing. Unforeseen issues may arise after data collection has begun which require changes to procedures or protocols. Significant changes to the protocols must be approved by the project leader, an I&M Program official at the Washington Office level, and the data manager. The I&M official must evaluate the proposed changes and determine if additional peer review is required before accepting the modifications.

Changes to protocols and associated data collection procedures may also occur as a result of scheduled program reviews. During the review, data are analyzed to determine if the current protocol is meeting stated objectives. If it is determined that the protocol has not achieved the desired results then recommended changes should be made.

5.5 Data Sources

A large percentage of data collected in network parks are collected by park personnel involved in projects initiated at the individual park level or by other NPS regional or national programs. The resulting data and associated products provide a great deal of information about park natural resources and are often relevant to the mission of the I&M Program.

5.5.1 Park Data

Network parks often use base funding or receive funding through other sources and programs to support park-level projects.

- **Park-based biological inventories** - network parks conducting their own park-based inventory projects generate data that can be used to supplement network-level inventories conducted by the I&M Program.
- **Park-based monitoring projects** - Park-level monitoring projects (such as vegetation and water quality) produce information that is valuable when developing network-level monitoring protocols.

- **Park and multi-park based projects** - other studies or projects conducted at the park or regional level that do not fall into one of the previous two categories (e.g., restoration projects).

5.5.2 Regional and National Programs

NPS regional and national programs support all of the parks within the network and also provide a good resource for natural resource information.

- **Air –** The NPS Air Resources Division (ARD) presents interpolated spatial and tabular air quality data for parks via the online Air Atlas: (http://www2.nature.nps.gov/air/). The NPS ARD compiles and analyzes air-related data from several national air monitoring networks, and performs broad-scale trend analyses relevant to GRYN air quality issues. The GRYN I&M Program will rely in part on these national scale monitoring networks to obtain trends for air-related vital signs.

- **EPMT -** Exotic Plant Management Teams (EPMT) collect and maintain data regarding the presence of exotic species in regional parks and the methods used to treat these species. This information is stored in the Alien Plant Control and Monitoring Database (APCAM) which is maintained by the EPMT data manager or EPMT liaison. http://www1.nrintra.nps.gov/BRMD/invasivespecies/exoticplants/index.htm

- **Fire Program –** data concerning the occurrence of fires within the network are maintained at the parks and regionally. National databases such as Fire-Pro, SACS and the soon-to-be implemented Fire Program Analysis (FPA) package (http://fpa.nifc.gov/) provide information regarding resources devoted to fires as well as fire occurrences. The NPS is also involved in efforts such as the Joint Fire Science Program (http://jfsp.nifc.gov/) that provides scientific information and support for fuel and fire management programs.

- **GIS –** The NPS OCIO GIS Division, the Natural Resource Program Center, and regional GIS staff provide guidance and assistance to network and park staff.

- **Water -** nearly all of the field data collected by the regional water resources program supports the water resources vital signs monitoring projects. The program also synthesizes, analyzes, and interprets water resources data collected by parks. The National Hydrography Dataset (NHD) is the NPS standard for spatial hydrography data. NPS Water Resource Division assists with water quality data management by providing NPSTORET and data transfer services for STORET.

- **Wildlife Management -** The NPS Wildlife Management Program is involved with coordinating long-term monitoring and assessment of wildlife populations.

5.5.3 Processing National Park Service Data

The I&M Program's current framework for natural resource information management (Figure 5.1) aims at achieving maximum return on investments made in data gathering, such that

relevant data and resulting information is available long term to multiple levels of the NPS organization (park, network, regional, national). The framework includes these elements:

- Provide spatial and attribute data standards and production methods for natural resource inventories
- Develop and support service-wide online natural resource database applications in Oracle RDBMS
- Provide desktop database applications that mirror master databases and promote standard data entry and organization
- Recommend a natural resource database template that allows local flexibility but also promotes design consistency for the purpose of sharing database designs and content
- Direct networks to hire data management staff and emphasize data management
- Mandate written network data management plans
- Require written data management procedures and responsibilities in inventory study plans and vital sign monitoring protocols

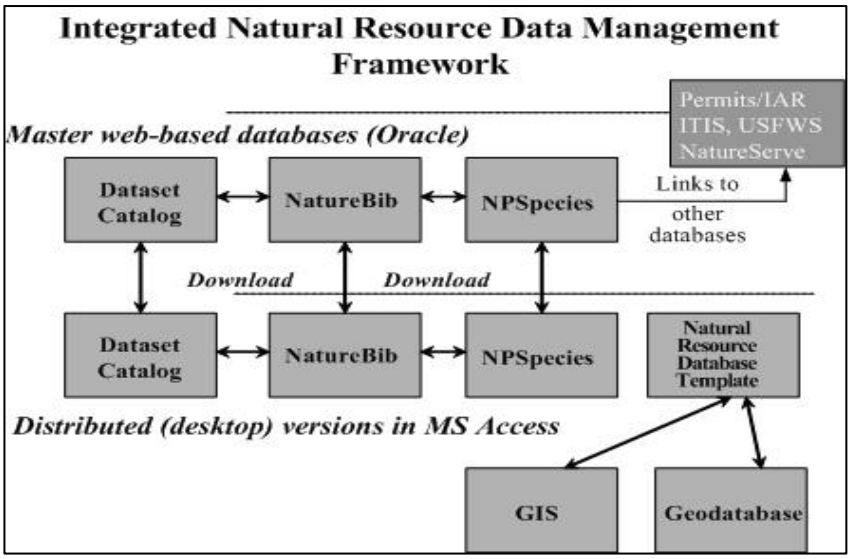


Figure 5.1. Natural Resource Data Management Framework

It is important that park, regional and network staff work closely together to ensure that information is maintained in a manner that promotes data sharing. Accordingly, the network data manager will:

- Coordinate with park and regional personnel to ensure that high quality data are available.
- Arrange for and/or provide training to park staff interested in learning to use NPSpecies, NatureBib, NPSTORET, and the Natural Resource Database Template.
- Ensure that information collected/maintained by the parks is entered into NPSpecies or NatureBib.
- Provide assistance with processing and storing voucher specimens collected in network parks.
- Assist with developing user requirements, database designs, and database application development based on the NPS Natural Resource Database Template and geodatabase.

Basic data processing steps include those listed here:

- Enter all new park biological inventory and monitroing data into NPSpecies (this is important for network-based and park-based biological inventories) and enter all associated references into NatureBib.
- Enter all park-based or regional reports and publications into the park library. Hard copies are stored in the appropriate file cabinets and electronic copies are archived in the proper directory on the park and network file server.
- Ensure that all GIS data is in the proper projection and accompanied by metadata that is complete and compliant with NPS format requirements.
- All data sets are entered into and tracked using Dataset Catalog.

5.5.4 External Data

Non-NPS and non-I&M data sources contribute to the development of the network's long term monitoring program. Certain vital signs may be addressed primarily by data that is collected and managed by non-NPS agencies or entities. For example, some vital sign parameters related to air quality, geology, and water can be referenced from existing non-NPS or non-I&M repositories and data stores. The agencies or organizations that collect these data have the expertise to conduct appropriate quality control procedures, and the capability to function as a repository and clearinghouse for the validated data. When necessary for analysis or summary reporting, the network acquires and processes off-site data according to the monitoring protocols. These "data snapshots" are archived by the network in cases where it may not be possible to repeat the same data acquisition and processing steps.

5.5.5 Processing External Data

Much of the data collected from external sources must undergo the following processing to meet the standards of the GRYN I&M Program.

- All GIS data obtained from other entities are stored in a format compatible with NPS information systems, has the correct spatial reference information, and has FGDC compliant metadata.
- All park-related biodiversity data obtained or received from other entities is entered into NPSpecies.
- Citations are entered into NatureBib for data taken from a report or published document.
- All reference materials obtained are kept in the network's library of electronic and/or hardcopy information resources.
- All data sets are entered into and tracked using Dataset Catalog.

Certain data sets will require more than the basic processing steps described above. The level of data processing required for external data sets such as those used in the vital signs monitoring program depends on the desired output. For example, if basic trends are of interest for air quality then relatively little processing is required. Where it meets the needs of the parks, the network will rely on trend analyses by other national programs. However, if more intensive analyses are needed, such as conducting in-depth analyses at a specific location rather than monitoring regional trends, the network will perform additional processing. In such cases, the specific protocols provide the necessary data processing requirements.

Remote sensing data sets such as satellite imagery or aerial photography will require varying levels of processing depending on how they are received and applied. Ideally, all spatial data sets will be acquired with existing geo-referencing and may only require geographic transformations to be compatible with NPS systems. Varying degrees of spatial and spectral processing may be necessary to adequately address stated inventory and monitoring objectives. The individual protocols outline the necessary processing steps.

Chapter Credits

This chapter was adapted from material prepared by Geoff Sanders (NCRN).

6. Data Quality Assurance

"Data need to meet national-level quality standards and need to be accessible to be used for wise and defensible decision-making at all levels. Data need to be able to be shared and aggregated with data from other parks and from adjacent lands to support landscape-level and national planning and decision-making." (Abigail B. Miller, National Park Service, 2001)

Importance of Quality Assurance/Quality Control (QA/QC)
Ecological data and related information resulting from GRYN resource inventory and monitoring efforts are a valuable resource worthy of preservation only if those data may be used with confidence. Analyses performed to detect trends or patterns in ecosystem processes and the condition of natural resources require data of documented quality. Data of inadequate quality can result in loss of sensitivity to subtle changes and incorrect interpretations and conclusions, and the potential for problems with data quality increases dramatically with the size and complexity of the data set (Chapal & Edwards 1994). Therefore, one important data management goal is to ensure that I&M projects produce data that meet quality requirements specified in monitoring protocols.

Documented methods to ensure data quality are critical to the preservation of data integrity. Established protocols for the identification and reduction of errors at all stages in the data lifecycle, including project planning, data collection, data entry, verification and validation, processing, and archiving, should be incorporated into the data management infrastructure and institutionalized.

While a data set containing zero errors is an ideal goal, such perfection is rarely achieved, and the cost of pursuing 100% accuracy may outweigh the benefit. Two parameters should be considered in setting a data quality goal: 1) the percent of entries that are incorrect (frequency of errors) and 2) the magnitude of the error (criticality of errors). For example, a two-digit numeric entry off by one decimal place is more likely to be a significant critical error than a six-digit numeric entry with the sixth digit off by one. In another case, one incorrect digit in a six-digit species number indicates a completely different species and is clearly significant. Error significance, therefore, is dependent on the type of data. The overall data quality goal should be a reasonable and attainable level of quality based on the intended use of the data and the potential consequences of making a wrong decision or interpretation.

6.1 NPS Mandate for Quality

Producers and users must know and document the quality of their data. This is especially important for sharing data and is the intent of several government directives. NPS Director's Order #11B: Ensuring Quality of Information Disseminated by the National Park Service was issued in 2002 to comply with these directives to ensure and maximize the quality of information disseminated by Federal agencies. The order defines ***'quality'*** as an encompassing term comprising objectivity, utility, and integrity; therefore 'quality' generally refers to all three of these elements. ***'Objectivity'*** includes two distinct elements: 1) presentation, whether disseminated information is being presented in an accurate, clear, complete, and unbiased manner within a proper context and 2) substance, a focus on ensuring accurate, usable, and reliable information. ***'Utility'*** refers to the usefulness of the

information to its intended users, from the perspectives of both the office and the public. ***'Integrity'*** refers to the security of information, e.g., protection from unauthorized access or revision to ensure that the information is not compromised through corruption or falsification. The order further specifies that information will be developed only from reliable data sources and that it will be accurate, timely, and representative of the most current information available. These standards apply not only to NPS-generated information, but also to information provided by other parties to the NPS if the NPS disseminates or relies upon this information.

High quality data and information are not only mandated by directives and orders, they are vital to the credibility and success of the I&M Program. According to Abby Miller (2001) of the Natural Resource Stewardship and Science Division, "data need to meet national-level quality standards and need to be accessible to be used for wise and defensible decision-making at all levels. Data need to be able to be shared and aggregated with data from other parks and from adjacent lands to support landscape-level and national planning and decision-making."

6.2 Definitions of Quality Assurance and Quality Control

Quality assurance procedures plan for quality in all stages of the data development process, while quality control procedures monitor or evaluate the resulting data products. Palmer (2003) defines quality assurance as "an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the consumer." He defines quality control as "the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer."

QA/QC mechanisms are designed to prevent data contamination, which occurs when a process or event other than the one of interest affects the value of a variable and introduces two fundamental types of errors into a data set. Errors of commission include those caused by data entry and transcription errors or malfunctioning equipment. They are common, fairly easy to identify, and can be effectively reduced upfront with appropriate QA mechanisms built into the data acquisition process, as well as QC procedures applied after the data have been acquired. Errors of omission often include insufficient documentation of legitimate data values, which could affect the interpretation of those values. These errors may be harder to detect and correct, but many of these errors should be revealed by rigorous QC procedures.

QA/QC procedures applied to ecological data include four activities ranging from simple to sophisticated, inexpensive to costly: 1) defining and enforcing standards for electronic formats, locally defined codes, measurement units, and metadata, 2) checking for unusual or unreasonable patterns in data, 3) checking for comparability of values between data sets, and 4) assessing overall data quality. Much QA/QC work is related to the first activity, which begins with data design and continues through acquisition, entry, metadata development, and archiving. The progression from raw data to verified data to validated data implies increasing confidence in the quality of the data through time (Figure 6.1).

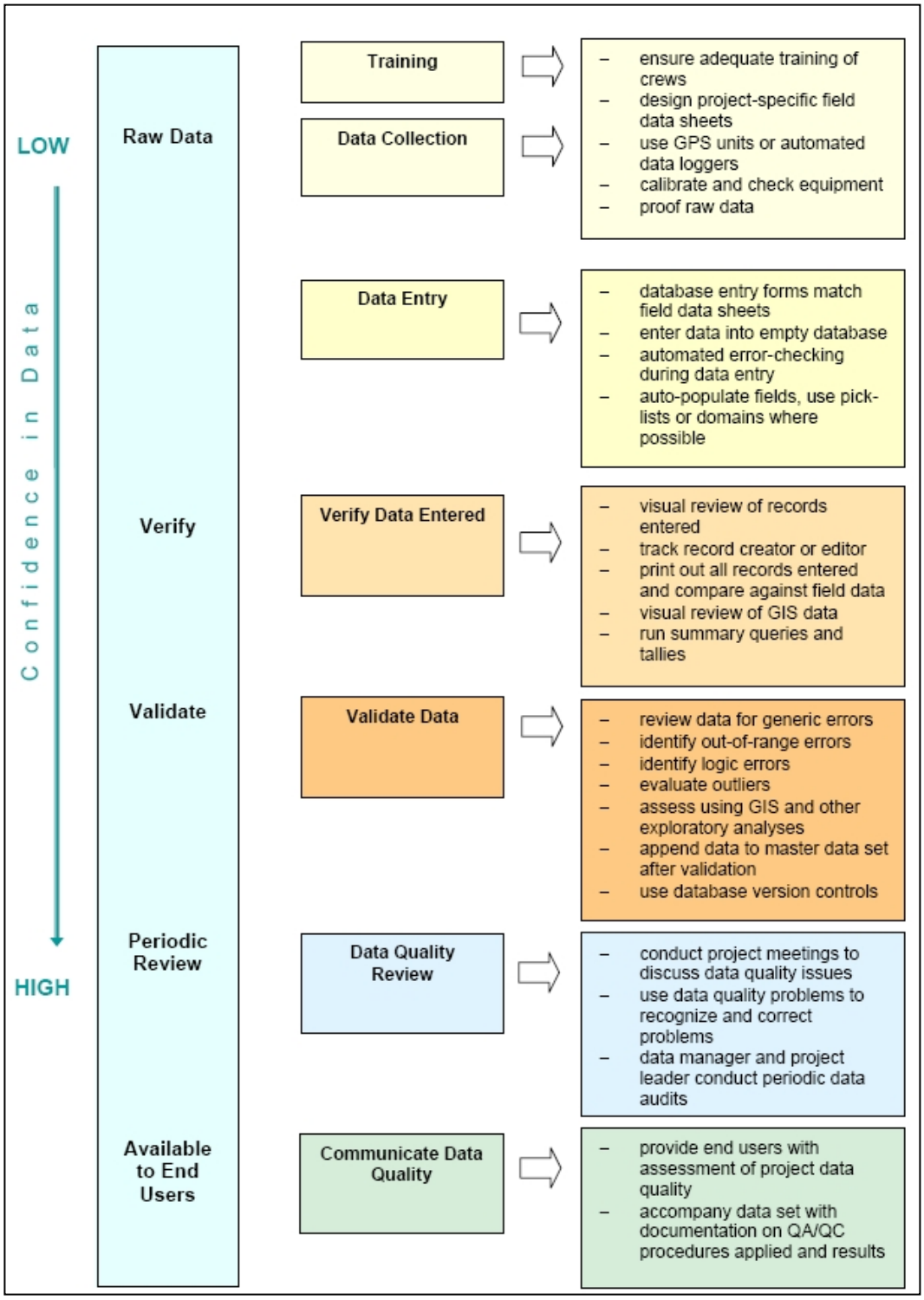


Figure 6.1. QA/QC controls applied at progressive stages of a project (Angel 2004).

6.3 Roles and Responsibilities for Quality Assurance

The importance of planning for quality in data and information before a project begins is critical. Quality assurance methods should be in place at the inception of a project and continue through all project stages to final archiving of the data set. All network employees

from the network coordinator to the data entry technicians, along with the data manager, should take responsibility for, and pride in, achieving a high level of data quality. People are the most important factor in the data quality process, and everyone plays a part in achieving high quality data products. All employees assigned to a project are responsible for the quality of the results generated from his or her task(s). The network coordinator and park managers must recognize the importance of data quality and support all appropriate efforts to achieve the highest possible quality in the data produced by network and park inventory and monitoring projects.

Project leaders must:
1) help prepare quality protocols and convey their importance to technicians and field crews,
2) ensure compliance with the protocols,
3) validate data after the verification process is complete, and
4) review and approve all final reports and information products.

The data manager is responsible for:
1) helping the project leader prepare protocols and SOPs to ensure data quality,
2) making project leaders, technicians, etc., aware of the established procedures and helping enforce adherence to them,
3) evaluating the quality of all data and information against NPS standards before distributing data outside the network, and
4) performing periodic data audits and quality control checks to monitor and improve data quality activities.

Technicians must follow established protocols for data collection, data entry, and verification established in the inventory and monitoring protocol data management SOPs.

6.4 Goals and Objectives for Quality Assurance

The overarching goal in establishing goals, objectives, and criteria for data quality is to ensure that a project produces data of the right type, quality, and quantity to meet the project objectives and the user's needs. Quality criteria should be set at a level proportionate to the project-specific objectives, and these criteria should indicate the level of quality acceptable for the final data product. The EPA (2003) defines data quality objectives as qualitative and quantitative statements that:

- clarify the intended use of the data,
- define the type of data needed to support the decision,
- identify the conditions under which the data are to be collected, and
- specify tolerable limits on the probability of making a decision error due to uncertainty in the data.

The most effective mechanism for ensuring that a project produces data of the right type, quality, and quantity is to provide procedures and guidelines to assist the investigator in accurate data collection, entry, and validation. Therefore, a comprehensive set of SOPs and data-collecting protocols for quality control, namely clear field methodologies, a well-trained field staff, well-organized field forms, and data entry applications with simple built-in validation controls are part of the network's data management approach.

Although specific QA/QC procedures will depend upon the individual vital signs being monitored and must be specified in the protocols for each monitoring vital sign, some general concepts apply to all network projects. The general QA/QC procedures presented in this plan were primarily adapted from the Draft Data Management Protocol (Tessler & Gregson 1997) and the ideas contained in Michener and Brunt (2000). These general guidelines will ensure that all data collected are checked for integrity before being integrated into monitoring program databases. Refer to SOPs and monitoring protocols for specific QA/QC procedures.

6.5 Data Collection

Careful, accurate recording of field observations in the data collection phase of a project will help reduce the incidence of invalid data in the resulting data set. Unlike a typographical error that occurs when a recorded observation is incorrectly transferred from a paper field form to a digital database, an incorrect entry in the field cannot be easily corrected. Therefore, attention to detail during data collection is crucial to overall data quality and will reduce the overall frequency and criticality of errors at subsequent stages in the data lifecycle.

Paper field notebooks and data forms are primary methods for recording ecological data. Paper has advantages in terms of longevity and ease of use, but requires careful handling and storage under some environmental conditions. Data processing options are limited until the data are transferred to digital format. As an alternative to paper, several options for electronic data collection in the field are now available, including handheld computers, automated data collection instruments, and audio recorders (see Chapter 5). Regardless of the collection method, data should be transferred from one form to another only once because each transfer has the potential to introduce additional errors into the data set. One transfer should result in fewer errors, provided that appropriate QA/QC measures are incorporated into the process.

Before the data collection phase of a project, the project leader, with assistance from the data manager provides the protocols/SOPs for data collection and storage. All field sheets and field data recording procedures must be reviewed and approved by the data manager and documented in the protocol SOPs. The project leader ensures that field crew members understand the procedures and closely follow them in the field. The data manager works with the project leader to provide necessary training. Field crew members are responsible for proofing raw data forms in the field, ensuring their readability and legibility, and verifying and explaining any unusual entries. They are expected to understand how to use the data collection forms, know how to take measurements, and follow the protocols.

6.5.1 Suggested Methods to reduce errors during field data collection

Use a formatted, project-specific data sheet as opposed to a field notebook. When electronic data collection devices are not used, data will be recorded on paper data forms. The use of acid-free paper prevents fading and subsequent data loss. Some circumstances require the use of paper and writing implements that can withstand moisture, dust, and other extreme environmental conditions.

Standardized data sheets that identify the parameters to be recorded and display the data for efficient computer entry (i.e., reflect the design of the data entry interface) will help ensure that all relevant information is recorded and subsequent data entry errors are minimized. Data sheets should contain as much basic preprinted project information as possible and sufficient space for recording relevant metadata such as date, collectors, weather conditions, etc. They should clearly specify all required information, using examples where needed to ensure that the proper data are recorded. Project personnel must follow these guidelines:

- All information added to the data sheet must be printed and clearly legible.
- If alterations to the data values are necessary, the original value should be crossed out with a single line and the new value written next to the original entry. Information should never be erased and old information should not be overwritten.
- Upon return from the field, copies of all original data sheets should be made and checked for legibility and completeness (i.e., no data cut off at the edges). The copies of the data sheets will be stored as specified in the protocol SOP, and the original data sheets will be used for data entry.

Use a handheld computer for data collection when applicable. The use of handheld computers minimizes the need for manual data entry from field forms and associated transcription and data entry errors. Specially designed database or computer programs may be required for handheld computers, and the user interface should be customized to meet project requirements. A customized data entry application has the advantage of incorporating on-the-spot QA/QC checks, so this data collection method provides a high level of data quality when combined with point-of-entry data quality checks. These portable units, however, are subject to environmental constraints such as heat, dust, and moisture. When handheld computers are used for data entry in the field, the data must be downloaded daily to avoid potential loss of information. Thus, if a handheld unit fails during data collection, only the current day's data are lost. Batteries should be checked prior to a data collection trip, and they should be charged at the end of every field day. The use of a memory card that will store the data in case of damage to the unit or battery failure is suggested. Finally, in case the unit becomes inoperable in the field, printed data sheets should always accompany field crews on data collection trips.

Use automated data loggers where appropriate. Instruments with their own data acquisition systems may be used to collect some types of data, such as water and air quality data. These devices can be calibrated and programmed to automatically record data and store them for later download directly to a computer, thereby eliminating the possibility for manual data entry errors. Data loggers are an efficient method for recording continuous sensor data, but routine inspections are necessary. Environmental constraints, as well as power (e.g., sufficient battery charge) and maintenance requirements, must be considered in the use of these instruments. Regular downloads are required since physical memory is usually limited, but the elimination of manual data entry reduces potential errors.

Use a handheld tape or digital audio recorder. Another alternative to paper field data forms is a handheld digital audio or micro cassette tape recorder. Recorded observations are subsequently transcribed to paper or directly entered into computer files. As with other technological solutions, there are drawbacks including battery and tape maintenance, low environmental tolerance, and risk of failure. However, if a single data collector is in the field,

audio recorders can provide an easily operated, high quality, efficient method of collecting data.

Consider calibration, maintenance, and minimum timing requirements of field equipment. Accurate field measurements are only possible if field equipment is regularly calibrated and maintained. Where appropriate, consult reference manuals for recommended calibration and maintenance procedures. Once in the field, allow sufficient time for field equipment (such as water quality probes and GPS units) to adjust to the environment so they will record accurate measurements. . Project personnel maintain records of equipment calibration and failures that accompany their field data.

Be organized and keep a log. Organization is the key to good data collection methods. Keeping a log of any decisions made and events that occurred will help clarify information and contribute to an accurate report.

Ensure that field crews receive proper training. Although protocols and SOPs are in place, they cannot guarantee that high quality data will be collected. Prior to routine data collection for a project, conduct training sessions to ensure that field personnel have a clear understanding of data collection procedures described in the SOPs. A training program may also include a process to certify that field staff understand and can perform the specified data collection procedures. The development of a training manual is advised for long-term monitoring data collection efforts and those that will involve a large number of field staff. Palmer and Landis (2002) provide an outline for a training manual and suggestions for planning training sessions.

Perform quantitative assessments of data quality. A quantitative assessment of data quality during data collection activities may be performed to determine if measurement protocols are being followed and quality objectives are being achieved. Repeating a measurement is the primary tool for performing quantitative assessments. Project leaders should periodically review the work of field technicians to ensure that their work does not drift from standards during the course of the field season. Quantitative assessments may be considered if staff and funding are available, and Palmer and Landis (2002) describe several approaches that may be employed.

6.6 Quality Assurance for Data Entry

Data entry is the initial set of operations where raw data from paper field forms are transcribed or typed into a computerized form linked to database tables. Spreadsheets may be used for data entry with approval from the project leader and data manager. When data are gathered or stored digitally in the field (e.g., on a data logger), data entry is the transfer of data (downloading) to a file in an office computer where they can be further manipulated.

Transferring data from field forms into the computer is a straightforward task. Nevertheless, concentration, close attention to detail, and an absence of distractions during data entry are important for reducing errors and maximizing quality. Without proper preparation and some established guidelines, the quality and integrity of the data will be in question. Data entry is best performed by a person who is familiar with the data and ideally takes place as soon as data collection is complete. The goal of data entry is the *transcription* of the data from paper records into the computer with 100% accuracy. However, since transcription errors are

virtually unavoidable during data entry, they will have to be corrected during the data verification process. Observing the data entry guidelines in the next section will help minimize verification work.

The data manager, in conjunction with the project leader, should provide training in the use of the database to all data entry technicians and any other users. The project leader will ensure that data entry technicians understand how to enter data and that they follow the protocols. Data entry technicians are responsible for becoming familiar with the field data forms and differences in handwriting. They must also be familiar with the database software, database structure, and any standard codes for data entry that have been developed. If the program or application used for entering the records is not familiar, the data entry technician should spend some time practicing before actually entering the data. They should know how to open the data entry form, create a new record, and exit the database properly. They must learn how to commit both a 'field' entry and a complete record entry and correct mistakes made while typing.

6.6.1 Suggested Methods to reduce errors during data entry

Enter or download data in a timely manner. All data should be entered or downloaded into the project database as soon as possible, preferably within one week. Do not delay data entry until all the project data have been collected. Downloaded data should be periodically stored on CD or other appropriate media and stored according to the protocol data management SOP.

Design efficient data entry forms and methods. A full-screen data entry form that mimics the field data forms can effectively reduce manual data entry errors due to the 1:1 correspondence of the attributes. A strategy to distinguish between validated data and newly entered data should be adopted. Data may be entered into an empty, fresh database table to avoid contaminating existing data and the new data appended to the master data only after formal verification, validation, and documentation. An alternate method is to include validation attributes that indicate which data have been checked and validated by the project leader in the database. Regardless of the strategy chosen, the process for validation must be clearly documented in the protocol data management SOP and built into the database design.

Build automated error checking features into the database. The most robust QA/QC measures for data entry will be built into the database design to perform automatic validation checks of data. Data entry forms reduce transcription errors through auto-filled fields, range limits, pick lists, and spelling checks; provide controlled access to the database (i.e., forms are set for data entry only, which prevents accidental deletion or alteration of existing data); and control the sequence of data entry (i.e., certain fields require an entry before more information can be entered). Controls warn the operator when errors are made and provide the opportunity for correction before the data are committed to a file.

- *Auto-filled fields.* Whenever possible, the data in a field should be auto-filled by the computer. For example, if a location ID is comprised of a park code, project code, and a unique number, those elements are automatically inserted into the location ID field, ensuring that the record always contains a unique identifier.

- *Range limits.* Where the appropriate values for a particular field span a finite range, the data entry program can check the entered value against the specified minimum and maximum values for that parameter. When a value is outside the accepted range, a warning message appears and asks the user to reenter a valid value. For some fields, values outside a specified 'normal' range may be acceptable. In this case, the warning message asks the user to verify the entry before continuing.
- *Pick lists.* The data entry application may also use pop-up pick lists for standardized text items where spelling errors can occur. For example, rather than typing in a species code or name (where a misspelling generates a new species in the database), the code or name is selected from a list of valid species codes or scientific names and automatically entered into the species field. A pick list may also be used when only certain entries are acceptable. Lists are not appropriate for all written fields but should be used when appropriate.
- *Unique constraints.* Duplicate and incorrect data entry can often be caught with the application of unique constraints on data entry fields. These constraints are particularly useful when importing data from other applications.

Provide a clean, organized work environment. Desktop space near the computer should be free of clutter and distractions that could cause the technician to lose their place. There should be enough space for two stacks of paper documents, one from which data are being entered and one from which data have been entered. A pad or notebook and some fine-point colored markers should also be available for making notes. The need for a clean workspace also applies to the verification and validation phases.

Have two data entry technicians available for data entry. Although not required, when one technician reads the data from the field data forms and another enters them into the computer, the work is often faster and results in a lower error rate. If only one person is available, he/she should work at a slower pace to avoid errors. Like many monotonous tasks, data entry can be done in a personal rhythm that eases the work for some people. Frequent rest periods (approximately every 20 minutes) also helps reduce data entry errors.

Perform initial and interval testing of data quality. To help ensure consistent, useful data is collected for a given monitoring objective it is important to test the data collection procedures and quality control methods soon after field work begins. A mandatory trial period (from one day to two weeks) follows thorough training for personnel involved in data collection. Data from the trial is measured against quality requirements. If the data meets the overall and protocol-specific requirements, then data collection will continue. If the data quality does not meet requirements, then personnel receive additional training and the trial is repeated followed by another quality test. If the data quality does not improve following the second trial, other aspects of the protocol will be examined for factors contributing to the difficulty of meeting data quality requirements.

6.7 Verification and Validation Procedures

Data quality is appraised by applying verification and validation procedures as part of the quality control process. These procedures are more successful when preceded by effective quality assurance practices. Performing both verification and validation of data is emphasized because verified data are not always valid data. ***Data verification*** checks that

the digitized data match the source data, whereas ***data validation*** checks that the data make sense. It is essential that all data are validated as truthful and do not misrepresent the circumstances and limitations of their collection. Failure to follow SOPs for data entry, validation, and verification will render a data set suspect. It is important to remember that only the data entry and verification stages can be done by someone who is not familiar with the kinds of errors sought during validation; validation requires in-depth knowledge about the data.

The project leader and data manager establish SOPs for verification and validation. The project leader will ensure that the SOPs are followed. The project leader or designee will validate the data after verification is complete. He/she is also responsible for reviewing all data products and reports before they are released outside the network. The data and project leaders will evaluate the results of verification and validation and determine any procedural or data form revisions that may be indicated by the results. Technicians will follow the SOPs for verification of data, make required changes, and document those changes.

Manual effort is generally required to get data into electronic format. Any typographical errors made will accumulate in the permanent database unless the data are verified and the errors detected. By implementing data verification procedures, these errors can be reduced, if not eliminated. Data verification immediately follows data entry and involves checking the accuracy of the computerized records against the original source, usually hard copy field records, and identifying and correcting any errors. When the computerized data are verified as accurately reflecting the original field data, the paper forms can be archived.

6.7.1 Suggested Methods for Data Verification

Data verification is most effective when performed immediately after data entry to check the accuracy of the computerized records against the original source, usually hard copy field records, and to identify and correct any errors. Once the computerized data is verified as accurately reflecting the original field data, the original paper forms are archived and further data processing is done on the computer. Each of the following methods has a direct correlation between effectiveness and effort. The methods to identify and eliminate the most errors can be very time consuming while the fastest (cheapest) methods will result in fewer error detections and corrections.

Visually review values and records at the time of data entry. The data entry technician verifies each record after it is input. The values recorded in the database are compared with the original values from the hard copy and any errors are corrected immediately. This method is the least complicated since no additional personnel or software is required. The reliability of this method depends wholly on the person keying data and is generally the least reliable of the data verification methods.

Visually review after data entry. All records are printed upon the completion of data entry. The values on the printout are compared with the original values from the hard copy. Errors are marked and corrected in a timely manner. When one technician performs this review, the reliability increases if someone other than the person keying data performs the review. As an alternative, two technicians may perform this review. One technician reads the original data sheets (the reader) and the second the same data on the printout (the checker).

Perform duplicate data entry. The data entry technician completes all data entry, as normal. Random records are selected (every **n**th record) and entered into an empty replica of the permanent database, preferably by someone other than the person keying the permanent data. A query that automatically compares the duplicate records from the two data sets and reports on any mismatches of data is run. Any disparities are manually reviewed and corrected if necessary. This method involves the overhead of retyping the selected records, as well as the creation of a comparison query (which requires additional effort, but is not time-consuming). This method becomes increasingly successful as the value of **n** decreases. This method is frequently used by professional data entry services.

Generate simple summary statistics. In addition to the above methods, summary information using the entered data can be calculated with statistical software. This is important because even when care is taken up to this point, a duplicate or omitted entry may have been overlooked. For example, the number of known constant elements, such as the number of sampling sites, plots per site, or dates per sample, can be viewed. The same question can be posed in different ways; differences in the answer provide clues to errors. The more checks devised to test the completeness of the data, the greater the confidence that the data are completely verified.

To minimize transcription errors during manual data entry, the network verifies 100% of records to their original source by NPS staff. In addition, 10% of records are reviewed a second time by the project leader, and the results of that comparison are reported with the data. If errors are found in the project leader's review, then the entire data set is verified again.

6.7.2 Data Validation

Data values correctly transcribed from the original field forms into a database are not automatically assumed to be accurate or logical. For example, a pH of 25.0 for a stream is suspect in the database and on the field form. The process of reviewing data for range and logic errors is *validation*. It can be done during data verification *only* if the operator has comprehensive knowledge about the subject matter to which the data relates. More often, validation is a separate operation carried out *after* verification by a natural resource specialist to identify generic and specific errors in particular data types. Validation efforts are often facilitated by database entry controls that inform the user when a value entered is out of a previously defined expected or normal range of continuous values or list of discrete values. For resource specialists not familiar with the database, the data manager can produce hardcopy summary reports and lists for review during the validation phase. Corrections or deletions of logical or range errors in a data set require notations in the original paper field records about how and why the data were changed. Modifications of the field data should be clear and concise while preserving the original data entries or notes (i.e., no erasing!). Validation efforts should also include a check for the completeness of a data set since field sheets or other sources of data could easily be overlooked.

General step-by-step instructions are not possible for data validation because each data set has unique measurement ranges, sampling precision, and accuracy. Nonetheless, validation is a critically important step in the certification of the data. Invalid data commonly consist of slightly misspelled species names or site codes, the wrong date, or out-of-range

errors in parameters with well defined limits (e.g., elevation). But more interesting and often puzzling errors are detected as unreasonable metrics (e.g., stream temperature of 70°C) or impossible associations (e.g., a tree 2 feet in diameter and only 3 feet high). These types of erroneous data are called *logic errors* because using them produces illogical (and incorrect) results. The discovery of logic errors has direct, positive consequences for data quality and provides important feedback to the methods and data forms used in the field. Histograms, line plots, and basic statistics can reveal possible logic and range errors.

6.7.3 Suggested Methods for Data Validation

The following general methods may be used to validate data. Specific procedures for data validation depend upon the vital sign being monitored and will be included in the monitoring protocols.

Data entry application programming. Certain components of data validation are built into data entry forms. The simplest validation during data entry is range checking, such as ensuring that a user attempting to enter a pH of 20.0 gets a warning and the opportunity to enter a correct value between 1.0 and 14.0 (or better yet, within a narrow range appropriate to the study area). Not all fields, however, have appropriate ranges that are known in advance, so knowledge of what are reasonable data and a separate, interactive validation stage are important.

Edwards (2000) suggests the use of 'illegal data' filters, which check a specified list of variable value constraints on the master data set (or on an update to be added to the master) and create an output data set. This output data set includes an entry for each violation, along with identifying information and an explanation of the violation. They illustrate the structure of such a program, written in the SAS® programming language.

A caveat should be interjected regarding the operative word 'illegal'. Even though a value above or below a given threshold has never before been observed and the possibility that it could occur seems impossible, such an observation is not always an illegal data point. Edwards (2000) points out that one of the most famous data QA/QC blunders to date occurred when NASA's computer programs deleted satellite observations of ozone concentrations that were below a specified level, seriously delaying the discovery of the ozone hole over the South Pole.

Outlier Detection. According to Edwards (2000), "the term outlier is not (and should not be) formally defined. An outlier is simply an unusually extreme value for a variable, given the statistical model in use." Any data set will undoubtedly contain some extreme values, so the meaning of 'unusually extreme' is subjective. The challenge in detecting outliers is in deciding how unusual a value must be before it can (with confidence) be considered 'unusually' unusual.

Data quality assurance procedures should not aim to **eliminate** outliers. Extreme values naturally occur in many ecological phenomena; eliminating these values simply because they are extreme is equivalent to pretending the phenomenon is 'well-behaved' when it is not. Eliminating data contamination is a better way to explain this quality assurance goal. If contamination is not detected during data collection, it is usually only be detected later if an outlying data value results. When an outlier is detected, attempts should be made to

determine if some contamination is responsible and to resolve the issue by making appropriate changes and documenting the changes.

Database, graphic, and statistical tools can be used for ad-hoc queries and displays of the data to detect outliers. Some of these outlying values may appear unusual but prove to be valid after confirmation. Noting correct but unusual values in documentation of the data set saves other users from checking the same values.

Other exploratory data analyses. (Palmer and Landis 2002) suggest that in some cases, calculations for assessments of precision, bias, representativeness, completeness, and comparability may be applicable and that for certain types of measurements, evaluation of a detection limit may also be warranted (the authors provide examples of procedures that may be applicable). Normal probability plots, Grubb's test, and simple and multiple linear regression techniques may also be used (Edwards, 2000; the author provides SAS® and Splus® code for constructing normal probability plots and examples of output showing normal and non-normal distributions).

Examples of Validation Errors (Tessler & Gregson 1997)

Wrong Date. A simple typo during data entry creates a logical set of data for a day, month, or year in which samples were never taken. This can become puzzling if the data are sorted by date – thus moving the entry away from its true neighbors. If sorting creates the appearance of missing data where a record should have been, the apparently appropriate corrective action might actually *create* duplicate records in the file rather than fix the ones that were wrong – leaving the original problem unresolved. Even when left in the original order, however, date errors may go undetected because checkers can sometimes see what the readers say – especially when the month and day are the items of focus and an incorrect year digit is not examined. A summary analysis counting the total records in the data set will also be correct. A check of the number of dates or samples per year will often detect an erroneous year by revealing too many samples or a year that does not belong, whereas the rest of the data records reveal where the correction is needed. Identifying site code errors, etc. is a similar process for incorrect values not identified during verification.

Cryptic Duplicates. An example is a contracted vegetation monitoring program. The contractor supplies a field sheet containing species codes, names, and counts in each sample which are to be entered into the computer. Cryptic duplicates occur in the data files when a single sample contains two entries for the same species – the contractor didn't realize he already had a line for that species when doing the counts and added another line later in the table. The data verification process correctly confirms the separate entries but does not recognize that they should be pooled for that sample. Summary counts of the number of species for that sample also show the same number as lines of original data – apparently correct. However, using a *count distinct* query, a count of the number of unique species in the sample is one less than the line count. Returning to the original data form and comparing each line with the others for that sample eventually reveals the error of duplication, and the data file is corrected by pooling the abundance values into the first record of that species and then deleting the second. The original printed data table (the original form) is then also corrected. Here, two different methods of making counts of the same item (species per sample) were used and compared to find the discrepancy. In

Microsoft Access, cryptic duplicates can be eliminated with the proper use of unique primary keys.

Wild Temperatures. Temperatures can show wild variations and yet be completely verifiable and valid. For example, some older data (or the occasional spurious recent record) may have been taken in Fahrenheit rather than Celsius. The difference in the recorded number(s) is large. This is actually a protocol problem and not a data question, but if quality control procedures during data collection were lax, these types of errors are often found only during data validation or (more annoyingly) data analysis. Routinely producing a box-plot or histogram of numerical data reveals drastic outliers, and when the original data forms are consulted, true outliers vs. errors in measurement scale or units become apparent, as does the correction for the files (i.e., convert the measurement to the appropriate units).

Foxes that Change Sexes or Get Younger. As an example, let's use vertebrate monitoring and capture and tagging of foxes each year. The program manager discovered that some of these re-captured measured foxes were changing sex or getting younger. Foxes don't change sexes or get younger. Some serious detective work revealed that inexperienced observers were not able to accurately gauge the age and sex of the foxes. Queries can be run to find these discrepancies. Unfortunately, sometimes these discrepancies cannot be fixed by editing the data files and may result in data of poor quality which may not be usable for their original purpose.

Trees that shrink. The vegetation monitoring program in Shenandoah National Park includes remeasuring trees in permanent plots every five years. In one survey, the project manager discovered that some of the remeasured trees were getting smaller—recent DBHs (diameters at breast height) were less than the original measurements 5 years earlier. Tree trunks of live trees do not get smaller. Some serious detective work revealed that the data were entered accurately (verifiable), but seemingly slight-to-moderate differences in the accuracy and exact methodology by current vs. previous crews. A search-and-compare program was written to parse the data and identify and scale the differences between trees, revealing the extent of the damaged data. Unfortunately, this problem could not be fixed by editing the data files. Rather, it revealed a previous protocol problem that resulted in data of poor quality and data that are useless for the original purpose.

6.8 Version Control

Version control is the process of documenting the temporal integrity of files as they are being changed or updated. Change includes any alteration in the structure or content of the files, and such changes should not be made without the ability to undo mistakes caused by incorrect manipulation of the data. Data progresses through various lifecycle stages, and whenever a set of changes is complete, the user should save the file with a unique name. Version control is simple insurance for maintaining data integrity, and using good version control should be routine for all data handlers.

Prior to any major changes to a file, a copy should be stored with the appropriate version number that allows the tracking of changes over time. With proper controls and communication, versioning ensures that only the most current version is used in any analysis.

The data manager determines the version control method that will be used, and other network personnel are responsible for accurately designating versions for any files upon which they have worked. Staff is encouraged to design and use software tools that assist in file management. For example, databases can be created that include fields to record revision history on the file. Backup routines can be built into the databases that allow for automatic file renaming and archiving. Important program files can be catalogued in a simple index or more formally tracked and archived using professionally developed version control software. Refer to Appendix B for additional information on file management and storage.

Version Control Options

Dates. Using a date provides logical version control. The date is usually formatted as YYYYMMDD or YYMMDD, where DD is optional (depending on the frequency of changes). One drawback to this method is that dates may be hard to read, thus causing confusion for users who may open the wrong version of a file.

Sequential numbers. Versioning of archived data sets is handled by adding a number to the file name, e.g., 001 or V1.0 for the first version. Each additional version is assigned a sequentially higher number. Documenting the date that a file becomes a new version is strongly recommended if this method is used. For example, backup copies of the same database with different raw data are placed in a backup subdirectory with the YYYYMMDD date tagged on the end. Frequent users of the data must be aware of the version control method so they can identify the most recent version.

Version control software. To avoid the work of differentiating multiple versions of documents by appending modifying characters to the file name, version control software is an option. Such software applications track changes made to a document, add comments related to the different document iterations, and retrieve the document at any recorded stage of development. These applications are available in either desktop or online formats.

The following list summarizes some of the issues version control software should address:

- Track documents as they change during the course of the developmental and editorial phases of document/report creation.
- Prevent conflicts between multiple collaborators by prohibiting multiple edits to the same file at the same time.
- Provide the ability to recover previous versions of documents.
- Evaluate the document creation process by tracking who changes a file, when they make the change, and what changes they make.
- Reduce storage requirements by eliminating multiple copies of complete documents.

6.9 Data Quality Review and Communication

QA/QC review is required prior to communicating/disseminating data and information. Only data and information that adhere to NPS quality standards will be released.

Director's Order #11B states that all information (e.g., brochures, research and statistical reports, policy and regulatory information, and general reference information) distributed by

the NPS (including information obtained from sources outside of the NPS) must be accurate, reliable and timely in nature. Therefore, the network must evaluate and identify the types of information it will disseminate that will be subject to the guidelines. Information disseminated to the public must be approved by the appropriate reviewing officials and programs. Documentation of the QA/QC standards used in producing the information and that substantiate the quality of the information must be formally documented Furthermore, mechanisms must be in place for receiving and addressing comments/complaints pertaining to the quality of data.

Data are distributed to the public through the GRYN I&M web page, national web sites such as the Biodiversity Data Store and the Natural Resource/GIS Data Store, and public access databases such as NPSpecies and NatureBib. Any information distributed through any of these mechanisms must undergo internal QA/QC procedures and be approved for release.

Data Quality Review Methods

The network will establish guidelines and protocols to ensure compliance with DO #11B. These protocols will document both internal and external review procedures for data and information disseminated outside the network, as well as a process for processing feedback about data quality.

Edwards (2000) suggests the initiation of quality circles, regular meetings of project leaders, the data manager, and data management personnel for discussing data quality problems and issues. These meetings promote teamwork attitudes while focusing brainpower on data quality issues. Participants become more aware of quality issues and learn to anticipate problems. Moreover, all participants develop a greater appreciation of the importance of their role in data quality and the entire monitoring effort.

Value of Feedback from QA/QC Procedures

Quality assurance procedures may need revision to improve the quality level if random checks reveal an unacceptable level of data quality. Quality checks should not be performed with the sole objective of eliminating errors; the results may also prove useful in improving the overall process. For example, if the month and day are repeatedly reversed in a date field, the data entry technicians may require retraining about the month/day entry order. If retraining is unsuccessful in reducing the error's occurrence, the computer program may need to be rewritten so that month and day are entered separately, field length limits are enforced, or a pick list is created. In this manner, the validation process will serve as a means of improving quality as well as controlling the lack of quality.

Sometimes, modification of field data forms to avoid common mistakes is necessary. With knowledge of validation errors and exploratory data results in hand, the field data forms as the source of the logic errors can be reevaluated. Often minor changes, small annotations, or adding check boxes to a field form remove ambiguity about what to enter on the form. In fact, any time the same type of validation error occurs repeatedly in different data sets, the field form – not the field crew – is usually at fault. Repeated errors found during validation can also mean that protocols or field training are at fault, which can then be recognized and corrected.

Monitoring Conformance to Plans and Standards

Data managers may elect to use periodic data audits and quality control checks as mechanisms to actively participate in the oversight and improvement of data quality activities. Data managers must verify that staff is operating in conformance with the data quality procedures specified in this plan and the protocol specific data management plans. The data manager should track and facilitate the correction of any deficiencies. These quality checks promote a cyclic process of continuous feedback and improvement of the both the data and quality planning process. The cyclic process of quality planning, data collection, data validation and acting on problems is the foundation for the quality assurance philosophies of quality gurus Dr. William Edwards Demming and Dr. Joseph Juran.

Periodic checks by the data manager to see if network staff are adhering to the data quality procedures established in the Data Management Plan and protocols SOPS may include verification of the following:

- Data collection and reporting requirements are being met.
- Data collection and reporting procedures are being followed.
- Verification and validation procedures are being followed.
- Data file structures and maintenance is clear, accurate and according to plan.
- Revision control of program documents and field sheets is adequate.
- Calibration and maintenance procedures are being followed.
- Seasonal and temporary staff have been trained in data management practice.
- Metadata collection and construction for the program is complete.
- Data is being archived and catalogued appropriately for long term storage.

The results of quality assessments should be documented and reported to the project staff and the network coordinator. The project leader and coordinator are responsible for ensuring that non-conformities in data management practices are corrected.

Communicating Data Quality

Data documentation and metadata will be used to notify end users, project leaders, and network management of data quality. A descriptive document for each data set/database will provide information on the specific QA/QC procedures applied and the results of the review. Descriptive documents or formal FGDC-compliant metadata will document quality for spatial and non-spatial data files posted on the Internet.

Every monitoring project requires standard quality control procedures like those listed in table 6.1. In addition to these customary activities, many projects involve unique or specialized quality control measures such as properly calibrating a particular brand and model of equipment used in monitoring.

Table 6.1. Checklist of fundamental quality control activities for a project (Brunt 2000)

Quality control checks	Data Management Phase			
	Design	Acquisition	Metadata	Archive
Check that data sheets represent project design criteria	X			
Check that measurement units are defined on the data sheet	X			
Check that field/attribute names meet NPS & project standards	X			
Check that date, site, and coded values meet NPS & project standards	X			
Check that descriptions of attribute names are provided	X			
Check that data are complete		X		
Check that data entry procedures were followed		X		
Check that data include time, location, and collector(s) full name		X	X	X
Check that measurement data are within the specified range		X		
Check that data values or codes are represented correctly		X		
Check that data are formatted correctly for further use		X	X	X
Check that data table design reflects project design criteria		X	X	X
Check that values for each attribute are used consistently		X	X	X
Check that errors and corrections are recorded		X	X	X
Check that metadata are present			X	X
Check metadata for content (accuracy and completeness)			X	X
Check that data dictionary is present and accurate	X		X	X
Check that measurement units are consistent		X	X	X
Check (again) that data and metadata are complete				X

Chapter Credits

This chapter was adapted from material prepared by Debbie Angel (SODN).

7. Data Documentation

7.1 Purpose of Metadata

Data documentation is information about the content, quality, condition, and other characteristics of a data set so that it may be used and qualified based on its original purpose and limitations. Structured metadata also provide the means to catalog data sets for discovery and distribution on a computer network to a broad range of potential users. In addition to data set documentation, the network will use feature level metadata to document characteristics about each data record associated with a vital sign monitoring protocol. Feature level metadata will include the name, date, source, and version of the monitoring protocol, and FGDC standard attributes for Process Description, Horizontal Positional Accuracy Report, and Process Date. Other feature level metadata characteristics may be added to some data sets.

Many data sets seem to take on lives of their own, with different copies and versions on multiple hard drives, servers, and other storage media. Some data sets remain hidden in digital formats or in seldom used file drawers. Once these data are discovered, a potential user may have little or no information about a data set's quality, content, or process methodologies. Such ambiguity can result in lost productivity when the user must invest time tracking down information, or can render a data set useless because answers to critical questions about the data cannot be found. For these reasons, the planning and implementation of inventory and monitoring projects includes requirements and procedures to provide documentation for all project data. The following mandates and policies exist to guide network staff in developing data documentation strategies.

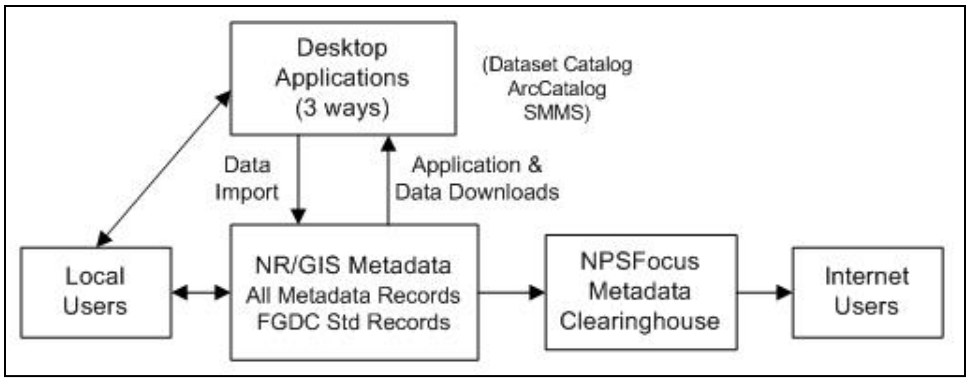
- Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure," signed by President Clinton in 1994, mandates federal agencies to "...document all new geospatial data it collects or produces, either directly or indirectly..." using the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM). In addition, EO 12906 directs agencies to plan for legacy data documentation and provide metadata and data to the public.
- The FGDC Biological Data Profile contains all the elements of the CSDGM and includes additional elements for describing biological data sets. Metadata created in compliance with the Biological Data Profile can be added to the National Biological Information Infrastructure (NBII) Clearinghouse. Although not a requirement, completion of the Biological Data Profile is recommended for biological data sets.
- All GIS data layers must be documented with applicable FGDC and NPS metadata standards. The NPS GIS Committee requires all GIS data layers be described with FGDC standards and the NPS Metadata Profile.
- While there are numerous tools available for developing metadata, the NPS Integrated Metadata System Plan is limited to three recommended desktop applications: Dataset Catalog, ArcCatalog™, and Spatial Metadata Management System (SMMS™).

7.2 NPS Integrated Metadata System Plan and Tools

The NPS Integrated Metadata System Plan represented in figure 7.1 recommends three desktop applications for collecting metadata. The following briefly describes each of these

tools and their potential utility for developing metadata. A fourth tool, the Metadata Parser (mp) is also discussed.

Figure 7.1. NPS Integrated Metadata System Plan



From 12/7/2004 visit to http://science.nature.nps.gov/im/datamgmt/metaplan.htm

Dataset Catalog: Dataset Catalog is a Microsoft® Access database application for cataloging basic metadata on geospatial and biological data sets pertaining to park(s) and networks. It provides a way to inventory, organize, and maintain information about local data set holdings. While Dataset Catalog is not intended to store complete FGDC metadata records, its value for parks and networks is to compile a single list of local data resources along with many of the metadata elements required to meet the mandates of EO 12906. Using the current version of Dataset Catalog (version 2) users can export records as FGDC-format text files for import and further processing using other metadata tools. Dataset Catalog Version 2.1 (in development) will include a function to export records in Extensible Markup Language (XML) that can be imported directly by ArcCatalog™. As the I&M Program recommends, the GRYN catalogs all relevant data sets at I&M parks and the network using Dataset Catalog.

Spatial Metadata Management System: SMMS™ is a commercial software application by Intergraph© for creating and publishing metadata that complies with FGDC requirements. The NPS Integrated Metadata System Plan recommends SMMS™ for FGDC Biological Profile and other geospatial metadata creation. Since the GRYN does not have a license for SMMS™, the network intends to use an NPS-customized ArcCatalog™ metadata extension currently in development.

ArcCatalog™: ArcCatalog™ is a management tool for GIS files contained within the ArcGIS™ Desktop suite of applications.

> "Geographical metadata consists of properties and documentation. Properties are derived from the data source, while documentation is entered by a person. By default, ArcCatalog™ automatically creates and updates metadata, which is stored as well-formed XML data in a file alongside the data or within a geodatabase. Metadata for a folder can also consist of a well-formed HTML file describing its contents." (ESRI®. 2004. ArcCatalog™ Help)

With ArcCatalog™, users can browse, manage, create, and organize tabular and GIS data. In addition, ArcCatalog™ comes with support for several metadata standards that allow one to create, edit, and view information about the data. It includes editors for entering metadata text, a storage schema, and property sheets to view the data. With ArcCatalog™ users can view GIS data holdings, preview geographic information, view and edit metadata, work with tables, and define the schema structure for GIS data layers. Metadata within ArcCatalog™ is stored exclusively as Extensible Markup Language (XML) files. The NPS Integrated Metadata System Plan recommends ArcCatalog™ for gathering GIS-integrated geospatial metadata. The network uses the NPS Metadata ArcCatalog™ Extension developed by NPS Midwest Region GIS Technical Support Center which fixes several ArcGIS™ 8 metadata errors and provides added functionality to properly document NPS data sets. NPS GIS is also developing Biological Profile editing capability and NPS Profile support for the ArcCatalog™ extension.

Metadata Parser: The MetaParser (mp) program is used by the network to validate metadata records by checking the syntax against the FGDC Content Standard for Digital Geospatial Metadata and to generate compliant output files for posting to clearinghouses. It generates a textual report indicating errors in the metadata, primarily in the structure, but also in the values of some of the scalar elements where values are restricted by the standard.

7.3 Metadata Process and Workflow

The general procedures involved with the lifecycle of metadata include identifying which existing and planned data sets require documentation, compiling data characteristics, cataloging, preparing FGDC metadata records, posting the metadata records, and maintaining the records. An overview of these procedures is presented in this section.

Step 1. Identify Data Sets
The scope of data resources requiring metadata for the I&M Program is limited primarily to natural resource themes. Therefore, the network is not concerned with identifying and documenting all data sets for cultural, facility, law enforcement, and other park operations and values. This does not preclude the use of these data by the network for reporting, mapping, etc. Whether natural resource data are acquired as a result of implementing an I&M vital sign monitoring protocol, from existing or future park protocols, or from those of non-NPS sources such as other federal agencies, the value of the data for network parks is determined by professional resource specialists who examine the data and its metadata for relevance to local information needs. For existing data sets determined to be useful and new data sets that are designed to be useful, the next step is to gather information about the data.

Step 2. Compile Metadata Elements
Existing data sets may lack complete metadata and the originator may no longer be available for consultation. In cases where comprehensive documentation is not available, the supporting information relating to a data set is assembled in order to keep track of as much background as possible. Existing data from non-NPS sources may require contacts to request available metadata and/or conduct a metadata interview.

For new projects, metadata development begins up front, with documentation requirements specified in project plans, contracts, and agreements. In addition to written requirements, project leaders, cooperators, and other participants should receive verbal briefings about metadata responsibilities and expectations. Metadata for data sets acquired according to a vital sign protocol will include the protocol name, date, version, and source, along with the protocol's justification statement and specific monitoring objective(s) 'purpose' section of the metadata record. This ensures a link among the complete monitoring protocol documentation, the metadata record, and the data set via the protocol name and version at the record/feature level in the database. The network data manager works principally with project leaders to ensure metadata requirements are met. Complete metadata is required by the network as criteria for completing a project.

Step 3. Create Dataset Catalog Record
The network enters Dataset Catalog records for data sets identified in step one, including both geospatial and non-spatial data sets. Benefits of cataloging brief metadata records include the following:

- provides brief metadata for park and network data holdings in a searchable, centralized location
- helps to organize, identify, and prioritize data sets for which formal FGDC metadata will be developed
- records the status of metadata documentation for a particular data set (i.e., planned, in work, complete)
- supports exporting records for import into the online NR-GIS Metadata System or to continue with additional processing steps based on data type, source, and importance.

Once data sets are cataloged, they can be prioritized for further documentation according to their current and expected level of use or distribution. For example, data sets frequently requested outside the NPS will be fully documented, and those data sets not in use due to vintage or format are considered adequately tracked and documented in Dataset Catalog and the metadata records are available for future processing. All locally published GIS layers will be documented with applicable FGDC and NPS metadata standards.

Step 4. Prepare the Complete Metadata Record
The network plans to use ArcCatalog™ and NPS extensions as the primary tool to create and maintain data set documentation according to FGDC and NPS standards.

In order to correctly process, apply, and interpret raw data contained in the rows and columns of a tabular data files, these must be accompanied by a descriptive document that includes the following information about the project and the data:

- List and description of contents data set content
- Description of the project
- Location of the project study plan and work plan
- Project leader's name and contact information
- Principal investigator's name and contact information
- Data set contact's name and contact information

- Description of the database model (entity-relationship diagram and data dictionary)
- Sensitive data issues, if any
- Description of data verification/validation methods and results
- Additional comments and documentation as needed to inform, as completely as possible, those not involved in the project who will process and apply the data.

Step 5. Make Information Available
Complete metadata and associated data will be submitted to the internet-based NR-GIS Metadata and Data Store as the primary distribution mechanism for sharing information on data holdings with park resource managers, researchers, and others. This system integrates metadata search functions, data downloading, and metadata maintenance. Basic metadata is also available to network parks via reporting functions in Dataset Catalog, including customized queries and reports. Non-sensitive NR-GIS Metadata records are routinely posted to NPS Focus.

Step 6. Maintain metadata records
Like any data set, it takes planning and effort to keep metadata records current. The network intends to schedule annual review of metadata records and to update and synchronize Dataset Catalog and ArcCatalog™ records with the NR-GIS Metadata database.

Chapter Credits
This chapter was adapted from material prepared by Theresa Leibfreid (CUPN).

8. Data Management Support for Analysis and Reporting

Providing meaningful results from data summary and analysis is a cornerstone of the I&M Program and characterizes the network's data management mission to provide useful information for managers and scientists. The Data Analysis and Reporting chapter (VII) of the Vital Signs Monitoring Plan contains the background and overall approach to data analysis and reporting by the network. The associated data management objective is to provide valid data in formats that support scheduled and ad hoc display, query, analysis, summary, and reporting of data to meet local, regional, and national requirements. Routine and scheduled data summary and analysis requirements and procedures are identified in each vital sign monitoring protocol. The following sections discuss data management activities related to using GIS and database application software for data summary and analysis, and to prepare data for analysis using statistical software applications.

8.1 Periodic and Annual Reporting

The network data manager will work with the network ecologist, project leaders, and others involved in data analysis to specify and design or adapt database objects, fields, and values to support the formats and functions necessary for analysis using statistical software applications, e.g., SAS®, R, and S. A list of common vital sign monitoring reports and venues and their purpose, frequency, and intended audience is shown in chapter 7 in the GRYN Vital Signs Monitoring Plan. Some basic summary and reporting functions required by a vital sign monitoring protocol can be developed within Microsoft® Access database applications where data are stored. Examples include descriptive statistics (mean, standard deviation, sample size). The network ecologist and others will use existing and custom data conversion and export functions in Microsoft® Access to prepare data sets for import into other software applications. Spatial analysis and maps will be produced by network and/or park affiliate staff. Ad hoc queries and reports will be handled on a case by case basis due to their dynamic nature.

The network will enhance its web site over time to deliver reports and provide supplemental background data and information. In the future this may include web-based internet map services and functions for user-controlled queries and summaries of network data. The web-site offers easy access to park managers for up-to-date information generated by the network and other related programs.

8.2 Long-term Trends Analysis and Reporting

Most long term data analysis will involve statistical software applications to perform the three primary types of analyses described in Chapter VII of the network Vital Sign Monitoring Plan: parameter estimation, hypothesis testing and model selection. Data formats required by statistical software often involve arrays of binary or discrete values that represent one or more parameters. Data analysts and the network data manager will identify and develop the data conversion routines necessary to generate these formats for analysis.

GIS functions can also contribute to understanding long term status and trends of vital signs and ecosystems. The network will provide geographic data display, summary, and mapping services for scheduled reports and other requests. Methods may be developed for using GIS to visualize time-series data, perform geostatistical, functions, and do spatial network

analysis with hydrography, transportation, and other linear features. Tabular and spatial results can be shared in reports and made available on the network's web site and via internet map services.

9. Data Distribution

9.1 National Park Service Policy on Data Ownership

The National Park Service defines conditions for the ownership and sharing of collections, data, and results from survey and research funded by the United States government. All cooperative and interagency agreements, as well as contracts, should include clear provisions for data ownership and sharing as defined by the National Park Service:

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

The Office of Management and Budget (OMB) ensures that grants and cooperative agreements are managed properly. Federal funding must be disbursed in accordance with applicable laws and regulations. OMB circulars establish some degree of standardization government-wide to achieve consistency and uniformity in the development and administration of grants and cooperative agreements. Specifically, OMB Circular A-110 establishes property standards within cooperative agreements with higher institutions and non-profit organizations. Section 36 of Circular A-110, “Intangible Property” describes the following administrative requirements pertinent to data and ownership:

> (a) The recipient (academic institution or non-profit organization receiving federal monies for natural resource inventory and/or monitoring) may copyright any work that is subject to copyright and was developed, or for which ownership was purchased, under an award. The Federal awarding agency(ies) (in this case the National Park Service) reserve a royalty-free, nonexclusive and irrevocable right to reproduce, publish, or otherwise use the work for Federal purposes, and to authorize others to do so.
>
> Section 36 also states:
>
> (c) The Federal Government has the right to:
>
> > (1) obtain, reproduce, publish or otherwise use the data first produced under an award
> >
> > (2) authorize others to receive, reproduce, publish, or otherwise use such data for Federal purposes
>
> (d) (1) In addition, in response to a Freedom of Information Act (FOIA) request for research data relating to published research findings produced under an award that were

used by the Federal Government in developing an agency action that has the force and effect of law, the Federal awarding agency shall request, and the recipient shall provide, within a reasonable time, the research data so that they can be made available to the public through the procedures established under the FOIA (5 U.S.C. 552(a)(4)(A)).

(2) The following definitions apply for purposes of paragraph (d) of this section:

(i) Research data is defined as the recorded factual material commonly accepted in the scientific community as necessary to validate research findings, but not any of the following: preliminary analyses, drafts of scientific papers, plans for future research, peer reviews, or communications with colleagues. This "recorded" material excludes physical objects (e.g., laboratory samples)…

(ii) Published is defined as either when:

(A) Research findings are published in a peer-reviewed scientific or technical journal; or

(B) A Federal agency publicly and officially cites the research findings in support of an agency action that has the force and effect of law.

(iii) Used by the Federal Government in developing an agency action that has the force and effect of law is defined as when an agency publicly and officially cites the research findings in support of an agency action that has the force and effect of law.

9.2 Establishing Data Ownership Guidelines

The network has established guidelines for the ownership of data and other research information. To ensure that proper ownership, format, and development of network products is maintained, all cooperative or interagency work must be conducted as part of a signed collaborative agreement. Every cooperative or interagency agreement or contract involving the network must include OMB Circular A-110 cited under the Reports and Deliverables Section of all agreements and contracts. The following shows appropriate language to use when citing Circular A-110:

> "As the performing organization of this agreement, <*institution or organization name*> shall follow the procedures and policies set forth in Office of Management and Budget (OMB) Circular A-110. (http://www.whitehouse.gov/omb/circulars/a110/a110.html)"

Every cooperative or interagency agreement or contract must include a list of deliverables and products clearly defined within each agreement or contract. Details on formatting and media types that will be required for final submission must be included. Agreements and contracts must list all products expected to result from the project. These include, but are not limited to, field notebooks, photographs (hardcopy and digital), specimens, raw data, and reports.

The following statement must be included in the Reports and Deliverables section of all GRYN agreements and contracts:

> "All reports and deliverables must follow the most recent version of the GRYN Product Specifications."

Investigators should also provide a schedule of deliverables that includes sufficient time for NPS review of draft deliverables before scheduled final submissions.

9.3 Data Distribution

One of the most important goals of the Inventory and Monitoring Program is to integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.

To accomplish this goal, the network uses procedures to ensure that relevant natural resource data collected by NPS staff, cooperators, researchers and the public are entered, quality-checked, analyzed, documented, cataloged, archived, and made available for management decision-making, research, and education. Providing well-documented data in a timely manner to park managers is important to the success of the program. The network will make certain that:

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

To accomplish this, the network uses a variety of distribution methods that allow information collected and developed as part of the program to be widely available to park staff and the public.

9.3.1 Data Distribution Mechanisms

Network staff will coordinate with park staffs to help prevent unnecessary duplication of metadata and data that are posted to internal and external clearinghouses. This will help preserve storage space on the clearinghouse server(s) and prevent confusion among users about duplicate or similar data sets. For distinct but similar data sets the metadata record must include text explaining the differences.

The primary distribution of the network's inventory and monitoring data will occur on the internet. This approach makes data and information available to a broad community of users and does not require a local system to receive and process multiple data requests. As part of the NPS I&M Program, the following web-based applications and repositories (Table 9.1) have been developed to store park natural resource information:

- NatureBib–a master web database housing natural resource bibliographic citations for I&M Program parks (NatureBib web site)

- NPSpecies–a master web-based database to store, manage and disseminate scientific information on the biodiversity of all organisms in all National Park units (NPSpecies web site)

- Biodiversity Data Store–a digital archive of document, GIS data set and non-GIS data set files that document the presence/absence, distribution and/or abundance of any taxa in National Park Service units (Biodiversity Service Center web site)

- Natural Resource and GIS Metadata and Data Store-online repository for metadata and associated data products. NR/GIS Metadata System is a component of the Natural Resource and GIS Data Store (NPS NR-GIS Metadata and Data Store web site prototype).

- GRYN Website–provides detailed information about the I&M network and its activities. Metadata, data sets, and related products such as summary reports for all network-funded inventory and monitoring products will be available via the web site. Park-funded and non-NPS-sourced materials related to the vital signs monitoring program will be linked via the network website where possible.

Table 9.1. Online Database Applications and Related Data Types.

Web Application Name	Data types available at site
NPSpecies	Data on Park Biodiversity (species information)
NatureBib	Park Related Scientific Citations
Biodiversity Data Store	The raw or processed data and products associated with Inventory and Monitoring projects that are stored in NPSpecies.
NR-GIS Metadata and Data Store	Metadata and GIS data sets with no biological component
GRYN Website	Reports and metadata for all Inventory and Monitoring Data produced by the network.

Currently, the NR-GIS Metadata and Data Store and the Biodiversity Data Store are under development. Until procedures and further guidance become available for the use of these two repositories, the network may also disseminate data via the network website. When both Service-wide repositories are completely operational, the network will upload all applicable data and information to each of those sites as needed.

Storing network metadata and data sets in the data stores listed above enables searching via the integrated metadata and image management system and search gateway called NPS Focus. NPSFocus is a Digital Library and Research Station that complies with an international standard protocol (ISO 23950:Z39.50 (http://www.loc.gov/z3950/agency/)) for computer-to-computer information retrieval. This makes NPSFocus a compliant node with the National Spatial Data Infrastructure (NSDI). The system is under development using Blue Angel Enterprise software for metadata management and the LizardTech© Express Server

for image management. One stop searching is currently available for ten NPS and two non-NPS databases in the NPS Focus prototype. NPSFocus is an Intranet version only, and a future public version is planned.

9.4 Data Classification: protected vs. public

All data and associated information resulting from I&M activities must be assessed by network staff to identify sensitive content so that the appropriate level of access can be granted to potential users of the data. This includes, but is not limited to, materials such as reports, metadata, raw and processed spatial and non-spatial data, and maps.

The Federal Geographic Data Committee's Homeland Security Working Group has published an interim version of the "Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns." The Guidelines include procedures to help identify sensitive information content in geospatial data sets and helps data producers provide appropriate access to the data while protecting sensitive contents.

The Freedom of Information Act, 5 U.S.C. § 552, referred to as FOIA, stipulates that the United States Government, including the National Park Service, must provide access to data and information of interest to the public. FOIA, as amended in 1996 to provide guidance for electronic information distribution, applies to records that are owned or controlled by a federal agency, regardless of whether or not the federal government created the records. FOIA establishes a right for any person to access federal agency records that are not protected from disclosure by exemptions. Under the terms of FOIA, agencies must make non-protected records available for inspection and copying in public reading rooms and/or online. Protected records are provided in response to requests through a specified process. The Department of the Interior's revised FOIA regulations and the Department's Freedom of Information Act Handbook can be accessed at http://www.doi.gov/foia/ for further information. The Northeast Coastal and Barrier Network prepared a summary discussion of FOIA issues related to the Inventory and Monitoring Program and its networks (Appendix C)

In some cases, public access to data can be restricted. Under the NPS Director's Order #66 (draft), and four resource confidentiality laws (the National Parks Omnibus Management Act (16 U.S.C. 5937), the National Historic Preservation Act (16 U.S.C. 470w-3), the Federal Cave Resources Protection Act (16 U.S.C. 4304) and the Archaeological Resources Protection Act (16 U.S.C. 470hh)), the National Park Service is directed to protect information about the nature and location of sensitive park resources. Through these regulations, information that could result in harm to natural resources can be classified as 'protected' or 'sensitive' and withheld from public release (National Parks Omnibus Management Act (NPOMA)).

The following guidance for determining whether information should be protected is suggested in the draft Director's Order #66 (the final guidance may be contained in the Reference Manual 66):

- Has harm, theft, or destruction occurred to a similar resource on federal, state, or private lands?

- Has harm, theft, or destruction occurred to other types of resources of similar commercial value, cultural importance, rarity, or threatened or endangered status on federal, state, or private lands?
- Is information about locations of the park resource in the park specific enough so that the park resource is likely to be found at these locations at predictable times now or in the future?
- Would information about the nature of the park resource that is otherwise not of concern permit determining locations of the resource if the information were available in conjunction with other specific types or classes of information?
- Even where relatively out-dated, is there information that would reveal locations or characteristics of the park resource such that the information could be used to find the park resource as it exists now or is likely to exist in the future?
- Does NPS have the capacity to protect the park resource if the public knows its specific location?

Natural Resource information that is sensitive or protected requires the:

- Identification of potentially sensitive resources
- Compilation of all records relating to those resources
- Determination of what data must not be released to the public
- Management and archival of those records to prevent their unintentional release

Classification of sensitive I&M data will be the responsibility of the GRYN staff, the park superintendents, and investigators working on individual projects. network staff will classify sensitive data on a case by case, project by project, basis. They will work closely with investigators for each project to ensure that potentially sensitive park resources are identified, and that information about these resources is tracked throughout the project.

The network staff is also responsible for communicating all potentially sensitive resources to project leaders and principal investigator(s) working on each project. The investigators, whether network staff or partners, will develop procedures to flag all potentially sensitive resources in all products that come from the project, including documents, maps, images, databases, and metadata. When submitting products and results, investigators should specifically identify all records and other references pertaining to potentially sensitive resources. One method for flagging sensitive information is designing fields in database objects and using data entry procedures for tracking sensitive records. Partners should not release any information in a public forum before consulting with network staff to ensure that the information is not classified as sensitive or protected.

For example, information may be withheld regarding the nature and/or specific locations of the following resources recognized as ‘sensitive’ by the National Park Service. According to NPOMA, if the NPS determines that disclosure of information would be harmful, information may be withheld concerning the nature and specific location of:

- Endangered, threatened, rare or commercially valuable National Park System Resources (species and habitats)
- Mineral or paleontological objects

- Objects of cultural patrimony
- Significant caves

Information already in the public domain can, in general, be released to the public. For example, the media reports in detail the return of condors to the Grand Canyon. If an individual requests site-specific information about where the condors have been seen, general description of geographic areas can be released. However, the locations of specific nest sites cannot be released.

9.5 Access Restrictions on Sensitive Data

Network personnel are responsible for managing access to sensitive data handled by the program. All potentially sensitive park resources will be identified and investigators working on network projects will be informed that:

- All data and associated information must be made available for review by network staff prior to release in any format
- Any information classified as protected should not be released in any format except as approved in advance by the National Park Service

For each project dealing with known or potentially sensitive resources, the network staff provides a complete list of all references to potentially sensitive park resources in each park to the park superintendent for review. Each superintendent then determines which information should be protected.

The network coordinator, project leader, or data manager identifies all potentially sensitive park resources to the principal investigator for each project. Reciprocally, the principal investigators for each project must identify any known references to potentially sensitive park resources.

When preparing to upload information into any network database, the network staff ensures that all protected information is properly identified and marked. The network staff must ensure that all references to protected information are removed or obscured in reports, publications, maps, and other public material.

Network staff will:

- remove any sensitive information from public versions of documents or other media
- isolate sensitive from non-sensitive data
- determine the appropriate measures for withholding sensitive data

The main distribution applications and repositories developed by the I&M Program, (see section 9.3.1) are maintained on both secure and public servers, and all records that are marked ‘sensitive’ during uploading will be available only to appropriate NPS personnel on the secure servers. Procedures for assigning a sensitivity level to specific records when uploading to both the NPSpecies and NatureBib databases are discussed in the GRYN NPSpecies and the NatureBib Data User Manuals (unfinished appendices) as well as at the following websites:

- http://science.nature.nps.gov/im/apps/npspp/index.htm

5. http://www.nature.nps.gov/nrbib/index.htm

Thus, access to data on sensitive park resources can be limited to network staff or project partners. However, limits to how these data are subsequently released must also be clearly defined. It is crucial that the network staff institute quality control and quality assurance measures to ensure that the person doing the uploading of records into the online applications is familiar with the procedures for identifying and entering protected information.

9.6 NPS Inventory and Monitoring Data Availability

According to FOIA (specifically the 1996 amendments), all information routinely requested must be made available to the public via reading rooms and/or the internet. Network project data will be available to the public at one or more internet locations:

- The GRYN web site
- Public servers for the NPSpecies and NatureBib databases
- Public server for the Biodiversity Data Store
- Public server for the NR/GIS Data Store

The network will regularly provide updated information about inventories and monitoring projects, including annual reports and detailed project reports through the network web site. Information on species in the National Parks, including all records generated through the Inventory and Monitoring Program, will be stored and accessible in the NPSpecies database. Bibliographic citations that refer to National Park System natural resources will stored and accessible through the NatureBib database. Documents, maps, and data sets containing resource information from all sources, and their associated metadata, will be accessible through the Biodiversity Data Store and/or NR/GIS Data Store. Each of these databases/repositories offer both a secure server and a public server, and the public can access all information in these databases except those records marked as ‘sensitive.’

Both raw and processed data resulting from the network’s inventory and monitoring projects will be fully documented with FGDC compliant metadata and made available to the public via the network’s website. The metadata for all data sets will be made accessible to the public as soon as they are provided and verified by the principal investigator(s) or project leaders.

Data sets for short-term inventory studies will be provided to the public via the GRYN website not more than two years following the year the data were collected or following publication of the investigator’s results (whichever comes first). Data sets for long-term monitoring studies will be provided to the public when the data is sufficient to support trend analyses reported by the network. The network’s Vital Signs Monitoring Plan and the network web site contain further scheduling details. Before data are posted, a park representative and the investigator or project leader will verify the final data set and metadata if necessary.

GRYN staff will notify investigators prior to making data sets available to the public. This will allow each investigator the opportunity to submit a written request to postpone or further restrict access to the data set by the public. Network staff will review the request to determine whether a data set can or should remain restricted to public access.

Geospatial data records from GIS are a priority electronic records format identified by the US National Archives and Records Administration (NARA) and by partner agencies as part of the Electronic Records Management (ERM) initiative, one of 24 E-Gov initiatives under the President's Management Agenda. A major goal of this initiative is to provide the tools for agencies to access electronic records for as long as required and to transfer permanent electronic records to NARA for preservation and future use by government and citizens. The requirements in this guidance are effective April 15, 2004. The network will incorporate these guidelines into data management operations. http://www.archives.gov/records-mgmt/initiatives/digital-geospatial-data-records.html

9.7 Data Access and Request Procedures

Online Access

The network does not intend to track downloads of data or reports from the network website or other data stores like the Biodiversity Data Store and NR GIS and Metadata Data Store. The network web site will contain a statement about use and appropriate citation of data in resulting publications and a request that users acknowledge the National Park Service Inventory and Monitoring Program.

Offline Requests

For data and information not available online, non-NPS individuals or entities can submit a written request to the network, preferably by email. Requests should include the name of the person or entity, their contact information, the export file format and transfer method, the date delivery is requested, and a description of the content and/or geographic extent of the data. An optional description can be included about the expected use of the data. The purpose of gathering this information in writing is to understand the request for complete and appropriate response by the network, and to document interest in the program and its results by maintaining a list of those who receive network data and products. In many cases the network data manager will follow up by phone with the requesting individual to clarify the information once the written request is received.

9.8 Data Quality Feedback

The GRYN will accept feedback from NPS staff, cooperators and the public on data and information gathered as part of the network's I&M Program. The purpose is to identify, communicate, and resolve errors or concerns about data content and quality. Users can notify network staff by email, phone, or in person. Network staff will investigate and resolve issues and concerns brought to their attention and follow up with the user and other affected individuals to communicate the resolution.

Chapter Credits

This chapter was adapted from material prepared by Sara Stevens (CUPN) and edited by Gary Entsminger (Partner).

10. Data Maintenance, Storage and Archiving

This chapter describes procedures for the long-term management and maintenance of digital data, documents, and objects that result from GRYN projects and activities. The overall goals of these procedures are:

- to preserve information over time
- to ensure that information can be easily obtained, shared, and properly interpreted by a broad range of users.

Effective long-term data maintenance is inseparable from proper data documentation, and an essential part of any archive is accompanying explanatory materials (Olson and McCord 1998). This chapter will refer to, and in some cases elaborate on, metadata standards and data set documentation procedures that are more fully explained in Chapter VII (Data Documentation) of this plan.

10.1 Digital Data Maintenance

In general, digital data maintained over the long term will be one of two types: short-term data sets for which data collection and modification have been completed (i.e. inventory projects), and long-term monitoring data sets for which data acquisition and entry will continue indefinitely.

Technological obsolescence is a significant cause of information loss, and data can quickly become inaccessible to users if stored in out-of-date software programs, on outmoded media, or in legacy data formats. Maintaining digital files involves managing for the dynamic infrastructure of associated hardware, software, file formats, and storage media. Major changes in hardware can be expected every 1-2 years, and in software every 1-5 years (Vogt-O'Connor 2000). As software and hardware evolve, data sets must be consistently migrated to new platforms, or they must be saved in formats that are independent of specific platforms or software (e.g., ASCII delimited files).

Data sets for which data entry or updates are still occurring will be stored in a structured file system for active projects on the GRYN server. A file system for completed projects will hold data and information resources that are no longer expected to change.

10.1.1 Short-term data sets

For finalized short-term data sets created or managed by GRYN, a set of American Standard Code for Information Interchange (ASCII) tab-delimited or comma-delimited text files will be created for each data table comprising the data set. These files will be accompanied by a readme.txt file that explains the contents of each file, file relationships, field definitions, and useful queries in sql format. Because delimited ASCII files can be imported by virtually all known database and spreadsheet software applications, the ASCII files serve as a format independent, cross-platform archive of the native version of the data set. All finalized files will be stored on the GRYN server in the appropriate project's archive folder.

In addition to creating ASCII files, the network will update data sets stored in previous versions of Microsoft® Access, so that no data set is more than two versions behind the

current version of Microsoft® Access used by GRYN. To the extent possible, preexisting functionality of data entry forms and reports will be maintained. However, the priority will be to ensure basic table and relationship integrity.

10.1.2 Long-term monitoring data sets

Long-term monitoring data sets require regular updates and conversion to current database formats. All active or long-term databases will conform to the current NPS and I&M software version standards. Monitoring projects have variable long-term data archiving requirements that include those listed here.

- Original data sets are normally stored in perpetuity as a basis for processing and deriving new values. This can be accomplished both by preserving values in original data fields throughout the life of a database object, and by archiving complete database objects.
- Substantial changes in database design or content due to evolving monitoring protocols may require complete data sets to be archived, with new data stored in different database structures and/or formats. If necessary for comparing new and legacy data sets, a process to relate between the two should be developed as part of the transition.
- Some project methods require preservation of interim data sets (data “milestones”) over the long term.

Data sets or subsets destined for long-term archiving will be saved, whenever possible, in their native formats in addition to ASCII delimited text files. Data archiving requirements for ongoing projects will be spelled out in the data management SOPs for each monitoring project.

10.2 Quality control for converted data

All ASCII files created from databases will undergo quality control activities or functions to ensure that the number of records and fields correspond to the source data set, and that conversion has not created errors or data loss. A second reviewer (preferably a program scientist) will evaluate the ASCII files and documentation to verify that tables, fields, and object relationships are adequately explained and documented for users not familiar with the program.

Databases that are converted from one version of database software to an upgraded version will require additional QC, particularly when the database applications are actively used for data entry or analysis. Forms, queries, reports, and data entry will be thoroughly tested during upgrades.

Version control

Documentation of version updates and associated details will be part of the archive metadata record, and revision information and history will be included in tables within the database files. File names of the archived revisions will clearly indicate the revision number or date.

Spatial data

Spatial data sets are maintained in formats that remain compatible with the current version of ArcGIS™. The network will work towards converting existing GIS formats to the personal

geodatabase format. The network will investigate using the Spatial Data Transfer Standard (SDTS) to archive GIS data in a software or platform-independent format. Both uncorrected and corrected GPS data (e.g., Trimble .ssf and .cor files) will be archived in their native format in addition to the corresponding GIS files that are created. Remote sensing data, including satellite images, are stored in their native format and in processed formats for use in image processing and GIS applications.

Digital Still Images
The network expects that most images acquired with handheld cameras will be still images in digital Joint Photographic Experts Group (JPEG) format. Network staff and cooperators are encouraged to use digital camera resolution and quality settings that produce images with adequate quality at a reasonable file size. Project crew members normally collect more images than necessary for documenting a project. The project leader should select and submit only those images necessary to complement the other project data. The data manager will review images for quality and file size and may process the images to meet specifications. Digital images are stored and named according to the instructions in each monitoring protocol.

10.3 Storage and Archiving Procedures for Digital Data
Digital data need to be stored in a repository that ensures both security and ready access to the data in perpetuity. GRYN will maintain a RAID (redundant array of independent disks) server for data storage, combined with a schedule of full, incremental, and differential backups using Network Attached Storage (NAS) devices for on-site backup and magnetic tape for off-site backup.

10.4 Directory structure for individual projects
The organization and naming of folders and files should be concise, descriptive, and clear to users unfamiliar with a specific project. Because the amount and type of material varies with each project, a high level standardized folder structure organizes several of the following common project elements:

- administrative documents such as agreements, correspondence, research permits
- programmatic documents including protocols, procedures, supporting documents
- interim data sets or “milestones”
- data sets distinguished by status: original, in-work, published, and archived
- conceptual or statistical models used for data interpretation
- final reports
- ‘readme’ files - includes an explanation of directory contents, project metadata (including a Dataset Catalog report), and version documentation.

Files are stored in a hierarchical folder structure that provides context to the information system. Folder structures are kept as flat as possible while providing for adequate classification. The network uses the folder and file naming and version tracking conventions in Appendix B.

Once final data and reports have been submitted, approved, and archived, draft and intermediate products should be reviewed and deleted if appropriate.

10.5 Backup procedures for digital data

The risk of data loss exists from a variety of sources including catastrophic events (e.g., fire, flood), user error, hardware failure, software failure or corruption, and security breaches or vandalism. Network staff perform regular backups of data and arrange for off-site storage of backup sets to safeguard data resources.

Data stored on the GRYN server receives weekly normal backups and nightly differential backups using a Network Attached Storage device. A set of four revolving quarterly full backups on magnetic tape are stored off-site to preserve all digital information resources for one full year. All backups are performed and monitored by the network data manager. The data manager tests backup files at random by performing intermittent restore operations. All backups are run with "verify," which compares source files against the backup files and detects any discrepancy in file size or other errors. Magnetic tape media is replaced every two years to prevent data loss due to deterioration.

Backups of data that reside on the desktop computers of network staff are the responsibility of each staff member. Network staff is reminded regularly to copy working files onto the network server or local backup device. The data manager works with network staff and cooperators to develop and perform regular backups of network data resources.

10.6 Data and network security

Access to files on the network server requires successful completion of all required security awareness and IT training for both I&M staff and network partners. Folders containing completed or protected project data may be designated as read-only for certain staff, as determined by the network coordinator. This helps ensure that changes to files are authorized by appropriate staff and communicated to the data manager when updates to associated documentation or other activities must accompany the change. It also deters inadvertent copying, moving, or deleting of files and folders.

10.7 Storage and Archiving Procedures For Documents and Physical Objects

This section applies to documents such as final reports prepared by staff or contractors, program administrative documents, contracts and agreements, memoranda of agreement, and other documents related to GRYN administration, activities, and projects. This section also applies to physical items such as natural history specimens, photographs, and audio tapes. In most instances these documents and objects are essential companions to the digital data described in the previous sections.

Direction for managing many of these materials (as well as digital materials) is provided in NPS Director's Order 19: Records Management (2001) and its appendix, NPS Records Disposition Schedule (NPS-19 Appendix B, revised 5-2003). NPS-19 states that all records of natural and cultural resources and their management are considered mission-critical records, that is, necessary for fulfillment of the NPS mission. NPS-19 further states:

> Mission critical records are permanent records that will eventually become archival records. They should receive the highest priority in records management activities and resources and should receive archival care as soon as practical in the life of the record.

Section N of NPS-19 Appendix B, which provides guidelines on natural resource-related records (including, specifically, the results of Inventory and Monitoring programs), indicates that all natural resource records are considered "permanent," that is, are to be transferred to the National Archives when 30 years old. It also indicates that non-archival copies of natural resource-related materials are "...potentially important for the ongoing management of NPS resources" and should not, in any instance, be destroyed.

10.7.1 Documents

All paper documents managed or produced by the GRYN will be housed in one of three locations:

1. GRYN central files, Bozeman, MT.
Central files contain project files, administrative documents, and non-record copies of documents that are archived at an off-site facility (see item 2, below). Examples include: meeting minutes, correspondence, memoranda of understanding, contracts and agreements, research permits, interim and selected final reports produced by the program or under its auspices. GRYN will use acid-free paper and folders for all permanent records in the central files. In addition to maintaining these paper records, GRYN will maintain electronic versions, when possible, on the GRYN server. The central files are maintained by the GRYN administrative clerk, under the guidance of the data manager and network coordinator.

2. Western Archeological and Conservation Center (WACC)
[repository subject to change]. WACC provides temperature and humidity-controlled facilities, a professional archival staff, and meets all museum standards set by NPS. This repository will be used for original documents and associated materials produced by the network (e.g., photographs, field notes, permits) that are a high priority to maintain under archival conditions. Examples include: original inventory reports and accompanying slides and maps; original vegetation mapping reports; GRYN Phase 1, 2 and 3 reports. Copies of these reports will be maintained in the GRYN central files, and all will have an electronic equivalent (e.g., PDF) for distribution or reproduction.

For all materials submitted to WACC, GRYN will provide essential cataloging information such as the scope of content, project purpose, and range of years, to facilitate ANCS+ record creation and accession. GRYN will also ensure that materials are presented using archival-quality materials (acid-free paper and folders, polypropylene or polyethylene slide pages).

Many GRYN reports and documents encompass data from multiple parks, which makes it challenging to accession archival copies into a specific network park museum. In these instances WACC will prepare associated ANCS+ records that reference all parks included in a report or document, and will prepare finding aids to help potential users locate the materials.

3. Network parks' central files and/or museums.
High-quality copies of park-related documents resulting from GRYN projects, along with electronic versions, will be provided to park resource management staff. Parks may choose to accession these materials into their museums, incorporate them into their central files, or

house them in their resource management library. GRYN will not directly manage documents at the park level but will work with park resource managers and curators to bridge network and park level document management requirements.

10.7.2 Specimens

The network assists with planning for monitoring projects that includes budgeting for specimen preparation and records processing and cataloging. Specimens collected under the auspices of GRYN will be provided to the network park in which they were collected for curation, or to a repository approved by a park (where the specimens are considered on loan). GRYN will provide park curators with necessary data for cataloging each specimen. This data will be in comma-delimited format (.csv) for automated uploading into ANCS+. Data provided to non-NPS curators will be in an appropriate format for each institution.

10.7.3 Photographs

Due to concern among some archivists that the accelerating rate of technological change threatens documentary heritage in the information age (Cox 2000), GRYN accepts and processes 35mm slides (preferably Kodachrome or Ektachrome), which have a proven long-term stability (Wilhelm and Brower 1993), and 4x6 color prints. Original photographs are a high priority for placing in archival storage conditions.

Slides are labeled using indelible pigment ink, or using laser-printed archival-quality slide labels. Slide labels will include: a unique ID, project name, photographer name, photo date, a brief identification of contents (e.g., species name, plot ID), and geographic location (UTM coordinates or a description). All slides are stored in polypropylene slide sleeves at the GRYN office until transferred to WACC. In addition, all slides are scanned and saved digitally as Tagged Image File Format (TIFF) files, and these are used as the primary means of distributing and reproducing the images.

Photographs are stored in individual polypropylene sleeves and within archival boxes. Each photo is labeled on the back, using archival-quality labels that are either laser-printed or hand-labeled with the same information elements required for slides. If a contractor is submitting photographs, corresponding TIFF files must also be submitted.

Every image, regardless of format, has an entry into the GRYN Photo Database where attributes such as electronic file name, keywords, project, photo description, photographer, date, and location are catalogued. All digital image files and the associated photo database are stored on the GRYN server.

10.8 Role of curators in storage and archiving procedures

Curators for parks within GRYN and from other NPS collection facilities are a valuable source of expertise, advice, and guidance on archiving and curatorial issues, and they have a role in almost every project undertaken by the network. Project leaders should involve park curators when projects are in the planning stage to ensure that all aspects of specimen curation and document archiving are considered, and that any associated expenses are included in project budgets.

Chapter Credits
This chapter was adapted from material prepared by Margaret Beer (NCPN).

Change Procedures and Revision History Log

This following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this document should promptly notify the GRYN data manager and/or program coordinator about recommended and required changes. The GRYN data manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the footer of the document file.

Write down edits and versioning in the Revision History Log table for the GRYN Data and Information Management Plan. Version numbers increase incrementally by hundredths (e.g. version 1.01, version 1.02, …etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 …).

Post new versions on the GRYN web site and communicate the update to all known individuals with a previous version of the Plan.

Revision History Log:

Original Publication Name, Version and Date: Data and Information Management Plan - Greater Yellowstone Inventory and Monitoring Network, Version 1.0, September 30, 2005				
Date and number of Previous Version	Date of Revision	Author(s) of Revision (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change
Add rows as needed for each change or set of changes tied to an updated version number				

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Appendix A: Roles, Responsibilities, and Awareness Levels for Data Management

This table is an expanded version of Table 2.2 – Summary of Roles and Responsibilities in the Data and Information Management Plan. This representative list of data stewardship roles, responsibilities, and awareness levels can be applied and extended by anyone involved with the NPS Greater Yellowstone Inventory & Monitoring Network. For example, the listed elements can help to brief and debrief project staff and crew members, and inform training plans, work plans, recruitment efforts, contract specifications, and other data management aspects of network operations.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Project Crew Member	Collect, record, and verify data	Obtain training in data management for the project. Read and follow project protocols, study plans, and relevant NPS guidance. Communicate with Crew Leader, Project Leader, and Data Manager. Record and verify observed or measured data values. Schedule and perform regular data transfer and backup. Review, verify, and correct field data. Assist with data and procedural documentation, especially deviations from the protocol or study plan.	Aware of specific protocol and related subject(s) for the project. Aware of related protocols and projects.
Project Crew Leader	Supervise crew	Obtain training in data management for the project. Ensure crew members receive data management training and briefings. Conduct debriefing sessions; summarize and communicate the results to the project leader. Read and follow all protocol, project, and relevant Network-level guidelines. Communicate with Crew Members, Project Leader, and Data Manager. Ensure data are regularly transferred, backed up, verified, and entered into the appropriate NPS database(s). Assist with data and procedural documentation.	Aware of specific protocol and related subject(s) for the project. Aware of related protocols and projects. Aware of Network activities, NPS I&M Program generally.
Data/GIS Specialist or Technician	Process and manage data	Obtain briefings about projects and related data to understand the geospatial and technical requirements and relevance. Communicate with other participants in the project to the extent necessary to accomplish assigned tasks. Perform assigned level of technical data management and/or GIS activities, including data entry, data conversion, and documentation. Work on overall data quality and stewardship with Project Leaders, Resource Specialists, and the Network Data Manager.	Aware of Network activities, NPS I&M Program generally. Aware of data management relationships between parks and the network.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Information Technology/ Systems Specialist	Provide IT/IS support	Provide and maintain an information systems and technology foundation to support data management. Advise project participants about capabilities of hardware and software resources to support project and program objectives. Work with Database Manager to resolve hardware and software issues relating to database functions and availability.	Aware of NPS I&M Program generally. Aware of database tools and applications used by the I&M program.
Project Leader	Oversee and direct project operations	Ensure Crew Leader receives pertinent training and briefings. Prepare debriefing plans and materials for field crews; participate in selected debriefing sessions. Communicate with Crew Leader, Data Manager, and I&M Network Coordinator. Complete project documentation describing the who, what, where, when, why and how of a project. Develop, document and implement standard procedures for field data collection and data handling. Enact and supervise quality assurance and quality control measures for the project. Supervise and certify all field operations, including staff training, equipment calibration, species identification, and data collection. Supervise or perform data entry, verification and validation. Maintain concise explanatory documentation of all deviations from standard procedures. Ensure documentation of important details of each field data collection period. Maintain hard copies of data forms and send original data forms to archive on a regular basis. Work with program coordinators to identify analysis and reporting mechanisms, and to establish a schedule for regular project milestones such as data collection periods, data processing target dates, and reporting deadlines. Produce regular summary reports and conduct periodic trend analysis of data, store the resulting reports, and make them available to users. Act as the main point of contact concerning data content. **The project leader works closely with the data manager to:** Develop quality assurance and quality control procedures specific to project operations. Identify training needs for staff related to data	Aware of specific protocol and related subject(s) for the project. Aware of related protocols and projects. Aware of Network activities, NPS I&M Program generally. Aware of park resource information management and GIS Plans and capabilities. Aware of other related projects external to NPS.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Project Leader (continued)	Oversee and direct project operations	management philosophy, database software use, quality control procedures, etc. Coordinate changes to the field data forms and the user interface for the project database. Fully document and maintain master data. Identify sensitive information that requires special consideration prior to distribution. Manage the archival process to ensure regular archival of project documentation, original field data, databases, reports and summaries, and other products from the project. Define how project data will be transformed from raw data into meaningful information and create data summary procedures to automate and standardize this process. Identify and prioritize legacy data for conversion; convert priority data sets to a modern format. Increase the interpretability and accessibility of existing natural resource information. **Note:** The Project Leader is often a resource specialist, in which case the associated responsibilities for data authority apply (see resource specialist role). A Project Leader without the required background to act as an authority for the data will consult with and involve the appropriate Resource Specialists.	
Resource Specialist	Understand the project and make decisions about the data	Understand the objectives of the project, the resulting data, and their scientific and management relevance. Guide development of an Information Needs Assessment based on the objectives of the project. Make decisions about data with regard to validity, utility, sensitivity, and availability. Describe, publish, release, and discuss the data and associated information products. **Note:** The Resource Specialist serving as a Project Leader is also responsible for the duties listed with that role.	Aware of specific protocol and related subject(s) for the project. Aware of related protocols and projects. Aware of Network activities, NPS I&M Program generally. Aware of park resource information management and GIS Plans and capabilities. Aware of other related projects external to NPS.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
GIS Manager	Support park management objectives with GIS and resource information management	Coordinate and integrate local GIS and resource information management with Network, Regional, and National standards and guidelines. **The GIS specialists will work in collaboration with project leaders to:** Determine the GIS data and analysis needs for the project. Develop procedures for field collection of spatial data including the use of GPS and other spatial data collection techniques. Display, analyze, and create maps from spatial data to meet project objectives. Properly document data in compliance with spatial metadata standards. **GIS specialists will also work directly with data managers to:** Design databases and other applications for the network. Create relationships between GIS and non-spatial data and create database and GIS applications to facilitate the integration and analysis of both spatial and non-spatial data. Establish and implement procedures to protect sensitive spatial data according to project needs. Develop and maintain an infrastructure for metadata creation and maintenance. Ensure that project metadata are created and comply with national and agency standards.	Aware of Network activities, NPS I&M Program generally. Aware of data management relationships between parks and the network. Aware of associations between park resource issues and park/network I&M objectives.
Network Data Manager	Ensure inventory and monitoring data are organized, useful, compliant, safe, and available	Assist in developing and implementing procedures to ensure that I&M data collected by NPS staff, cooperators, researchers and others are entered, quality-checked, analyzed, reported, archived, documented, cataloged, and made available to others for management decision-making, research, and education. Provide guidance and support, to the extent possible, to extend Network standards and procedures to studies and data funded by park base and other funding sources to promote integration and availability of datasets. Provide overall Network planning, training, and operational support for the awareness, coordination, integration of data and information management activities, including people, information needs, data, software, and hardware. Serve as Point of Contact for National Park Service database applications (NPSpecies, NatureBib, Dataset Catalog)	Aware of specific protocol and related subject(s) for all network projects. Aware of related protocols and projects. Aware of park resource information management and GIS Plans and capabilities. Aware of other related projects external to NPS.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Network Data Manager (continued)	Ensure inventory and monitoring data are organized, useful, compliant, safe, and available	Coordinate internal and external data management activities. Assign and enforce data stewardship responsibilities. Review and approve all data acquisition plans, hardcopy and electronic field forms, and data dictionaries. Participate in development of Information Needs Assessments. Communicate with Crew Leader, Project Leader, I&M Network Coordinator, and Park GIS/Data Management office. Develop and maintain overall Network and individual Vital Sign data management operating guidelines and relationship to national standards and procedures. Develop and maintain the infrastructure for metadata creation, project documentation, and project data management. Create and maintain project databases in accordance with best practices and current program standards. Provide training in the theory and practice of data management tailored to the needs of project personnel. Develop ways to improve the accessibility and transparency of digital data. Establish and implement procedures to protect sensitive data according to project needs. Collaborate with GIS Specialists to integrate tabular data with geospatial data in a GIS system in a manner that meets project objectives. **Data managers will also work closely with the project leader to:** Define the scope of the project data and create a data structure that meets project needs. Become familiar with how the data are collected, handled, and used. Review quality control and quality assurance aspects of project protocols and standard procedure documentation. Identify elements that can be built into the database structure to facilitate quality control, such as required fields, range limits, pick lists and conditional validation rules. Create a user interface that streamlines the process of data entry, review, validation, and summarization that is consistent with the capabilities of the project staff.	

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Network Data Manager (continued)	Ensure inventory and monitoring data are organized, useful, compliant, safe, and available	Develop automated database procedures to improve the efficiency of the data summarization and reporting process. Make sure that project documentation is complete, complies with metadata requirements, and enhances the interpretability and longevity of the project data. Ensure regular archival of project materials. Inform project staff of changes and advances in data management practices. Additional examples of the duties and responsibilities of the network data managers are listed in the I&M Program Vision and Organizational Framework document "Network Data Manager Overview of Responsibilities". **NOTE:** Data Managers with Prototype Monitoring Programs have the same basic duties and responsibilities as the network data managers but also are responsible for mentoring and training others and developing and testing new approaches to data analysis, synthesis, and reporting of monitoring results.	
Database Manager	Know and use databases and applications	Install, maintain, and support specific database software applications and NPS database applications. Work with Information Technology Specialists to resolve hardware and software issues.	Aware of NPS I&M Program generally. Aware of database tools and applications used by the I&M program. Aware of IT functions and capabilities at the park and network.
Curator	Oversee all aspects of the acquisition, documentation, preservation, and use of park collections	Know park natural resource collections Conduct accessioning, cataloging, legal, and other documentation of collections Manage collections databases Recognize objects needing conservation treatment Recommend and refer treatment to the appropriate facility Work with Network Data Manager to acquire and process data related to natural resource collections	Aware of NPS Museology Aware of database tools and applications used by the I&M program.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
Statistician or Biometrician	Analyze data and present information	Work with the Network Ecologist to analyze and report data according to established protocols. Work with the Network Data Manager to acquire and process raw data from databases and store derived data and information after analysis	Aware of capabilities, limitations, and applicability of statistical software applications Aware of database tools and applications used by the I&M program.
Network Ecologist	Integrate science in network activities	Ensure useful data are collected and managed by integrating natural resource science in network activities and products, including objective setting, sample design, data analysis, synthesis, and reporting. Assist with development and modification of monitoring protocols and inventory study plans. Work with the Network Data Manager to incorporate data management in monitoring protocols. Participate in the development of Information Needs Assessments based on the objectives of the project. Guide and/or perform statistical and other analyses of network data. Contribute to the synthesis and reporting of data and information. Provide guidance and support, to the extent possible, to extend Network standards and procedures to studies and data funded by park base and other funding sources to promote integration and availability of datasets.	Aware of park resource information management and GIS Plans and capabilities. Aware of database tools and applications used by the I&M program. Aware of Data Stewardship principles.
Network Coordinator	Coordinate all network activities	Ensure programmatic data and information management requirements are met as part of overall Network business. Communicate with Network staff, park staff at all levels, and other appropriate audiences to support and emphasize data management as a critical aspect of network business Work with Network Data Manager regarding data management policy and guidelines, budget, staffing, and training. Hold Network staff accountable for responsibilities involving data management.	Aware of database tools and applications used by the I&M program. Aware of Data Stewardship principles.

Role	Programmatic Responsibility	Data Stewardship Responsibilities	Recommended Awareness Level
I&M Data Manager (National Level)	Provide service-wide database availability and support	Provide services to receive, convert, store, and archive data in service-wide databases. Work with Network Data Manager to resolve local issues involving the access and use of inventory and monitoring databases. Provide training where possible. Design and maintain standardized, master databases for Servicewide planning, decision-making, and accountability (e.g., NPSpecies, NatureBib, Dataset Catalog, Database Template, GIS tools). Collaborate with networks to help develop overall data management vision and approach, and continual improvement of specific tools. Coordinate establishment of standards for naming conventions and content of data management plans and monitoring protocols. Promote collaboration and integration with other divisions and programs including the GIS community, fire program, air resources, water resources, geologic resources, etc. Facilitate coordination and collaboration among the parks and networks by providing examples of good database designs with flexibility to allow adjustments for different situations.	Aware of network contacts
Other End Users	Use and apply Network services and products	These 'information consumers' include park managers and superintendents, researchers, staff from other agencies, and the public. End users at all levels are generally responsible for providing necessary and requested feedback, review, and comments on various products in order to sustain and promote continuous improvement of network operations and services. End users are responsible for the appropriate use and application of data and derived products, e.g. by reading metadata. Administrative unit managers and program managers, in particular, are responsible for providing the money and scheduling the time required for project leaders and staff to meet stated data quality and other data management objectives.	Varies with each end user. Awareness is an outcome of end use. Awareness of the resources (time, expertise, and funding) required to develop and maintain an effective data and information management system that meets the business needs of the end user(s).

Appendix B: GRYN Folder and File Naming Conventions

Files are stored in a hierarchical folder structure that provides context to the information system. Folder structures are kept as flat as possible while providing for adequate classification of common project elements. The organization and naming of folders and files are concise and descriptive to promote understanding by users unfamiliar with specific projects and administrative functions.

Folder Structure

Computer drive letters G, I, and U are shared locations of hard drives or disk partitions on the GRYN file server. As corporate information resources these drives and their contents meet National Park Service Security standards for confidentiality, integrity, and availability. Controls exist for physical and electronic access to the file server and backup of all corporate and user data occurs daily, weekly, and quarterly. Quarterly backup media is stored off-site.

G:\ (data drive)

The data drive (G:) is GRYN's corporate library for GIS data, NPS Natural resource Databases, and NPS Service-wide Databases. Data sources are stored in various spatial data formats, including ESRI shapefile, coverage, geodatabase, and image file formats. The directory structure organizes the data primarily by spatial extent such as park-wide, network-wide, and statewide. Within a directory like "yell" (for Yellowstone) the data are organized in folders named by resource type or discipline, for example "climate", "fire", and "water".

The "Natural_Resource_databases" folder contains a variety of files in Microsoft Access format based on the National Park Service's Natural Resource Database Template (NRDT). GRYN staff members are investigating the long-term utility of the NRDT versus developing data sources strictly as ESRI geodatabases, or using a combination of geodatabase and NRDT.

The "Servicewide_databases" folder holds desktop versions of standard database applications developed for the entire Park Service. These include NPSpecies, NatureBib, Dataset Catalog, and NPSTORET. Some of these databases have counterpart online interfaces to NPS corporate master databases that reside on servers at the national I&M Program Office in Fort Collins, Colorado. Users must be aware of and account for the synchrony between local desktop or file server copies and master corporate databases. This is an issue when updating and using the database because users must ensure that changes to local data are communicated to the corporate database, and that the local copy of the data represents the complete content of the corporate database.

Top-level folders of the G:\ ('data') drive:

bica	national
Documentation	Natural_Resource_databases
grte	Servicewide_databases
gryn	Toolsets
ID	WY
MT	yell

Replicas of GRYN corporate datasets on local computers are stored in explicit locations on the local hard drive that indicate a copy of a master information resource. For example, GRYN corporate data stored on the workgroup file server's G: drive is stored locally at C:\NPS_Corporate_Data\G_Drive_Replica\

U:\ (User drive)
The user drive (U:) holds I&M staff workspaces and corporate files representing the business of the I&M Network. Each GRYN staff member with login access to the local computer network (IMWORKGROUP) is assigned a top-level folder named with their user name. User workspaces support daily operations to assemble and manipulate files and documents, prepare drafts and sections of documents, etc. The U: drive also contains folders and files specific to the business of the program, such as "Admin", "Inventory", and "Monitoring".

Top-level folders of the U:\ drive:

Admin	Monitoring
Data_Info_Management	Program_Web_Portal
General_Library	Users
Inventory	

Managing data and information resources across computer networks
Some GRYN personnel are not directly connected to the GRYN computer workgroup which is supported by a US Geological Survey Local Area Network. This prevents access to GRYN's shared disk drives. This is due to staff using non-NPS computer hardware or because these staff are located at offices served by a different Local Area Network. Staff working off-network and those without access to network drives must be aware of GRYN corporate folder structure and should follow the GRYN guidelines for file naming and storage. Using the following GRYN directory structure and naming convention on desktop and laptop computers facilitates information exchange.

The convention for local disks includes the following:

C:\NPS_Corporate_Data\G_Drive_Replica\

C:\NPS_Corporate_Data\I_Drive_Replica\

C:\NPS_Corporate_Data\U_Drive_Replica\

C:\NPS_Working_Data\

C:\NPS_Install_Files\

Local users should build the basic structure listed above and need to replicate and synchronize only those folders and subfolders relevant to the work they contribute for the GRYN Program. For example, an off-network employee working on the arid seeps and

springs Vital Sign will work in the following local directory:
C:\NPS_Corporate_Data\U_Drive_Replica\Monitoring\Vital_Signs\Arid_Seep_Spring\
Subfolders under Arid_Seep_Spring should follow the corporate Vital Sign subfolders listed below. It is not necessary for this user to build the other vital sign folders and subfolders on the local computer. If users choose not to replicate the corporate structure on the local machine, they must communicate their local file management design and explicitly define how it relates to the GRYN corporate structure. This can be submitted in writing or verbally communicated to the GRYN data manager.

Information transfer can occur by several methods, depending on the circumstances. All off-network personnel can use e-mail to exchange files. Small files (less than 500KB) can be directly attached to an email message. Larger files or collections of files should be compressed to a target size of 3MB or less. Larger compressed files should be transferred using other methods, including physical transfer of files on USB storage devices and optical disk media (DVD or CD), or file transfer protocol (ftp). Those personnel using NPS laptop computer hardware can also transfer large volumes of information by physically connecting the laptop to a site on the USGS Local Area Network that serves GRYN. Those not using NPS hardware are prohibited by Department Of Interior security policy from directly accessing the USGS LAN.

The data manager assists users to reconcile and synchronize the contents of the corporate files on the file server and the replicas on desktop and laptop computers.

To gain access to GRYN information resources, off-network users request CD or DVD media containing copies of GRYN files, or connect NPS-property computers to the network temporarily to transfer files.

Synchronization of files between staff computers and the GRYN file server should occur frequently in order to maintain a current corporate library that is available to all GRYN staff, other NPS employees and for including in backup and security procedures. Synchronization is strongly recommended on a monthly basis or more frequently.

Vital Signs Information Management

The U:\Monitoring directory and its subfolders represent the strategic planning at GRYN to develop a consistent, simple, and comprehensive file management model that directly supports development of products like the Network Monitoring Plan and individual Vital Sign Monitoring Plan and Protocol documents, as well as web-interfaces targeted to a variety of audiences.

The structured design of folders, file naming convention, and file content format allow for functional development and maintenance of information resources as manageable components. The design provides for easy assembly of information products, both hardcopy and web-based. These products may be compiled manually at first, but will later be automatically generated based on content tags and markup language.

Information sources are named and filed according to this convention. Filing information sources in shared locations and using descriptive file name are important steps to develop a useful corporate information system. In cases where users are acquiring several files from another source, it is appropriate to file them in the best location and follow up as soon as possible with file naming that follows the GRYN convention.

Versioning and Change Procedures

The structure of the Vital Signs directories and files supports a version tracking system based on file name that avoids creating multiple subfolders. The master file in each Vital Sign subfolder is indicated by the word 'current' in the file name. When a master file meets the criteria for a version change (See below) it is copied to the same folder and given a different file name that replaces the word 'current' with the next available sequential version number, preceded by the letter 'v'.

For example, the Whitebark pine issues and threats document "isth_Whitebark_Pine_current.doc" is the current, master file that is supported by two previous versions. The most recent version is a file named "isth_Whitebark_Pine_v3.doc"

In addition to the file naming convention for version tracking, a reader can establish the timing of related documents by viewing the file properties, that include the date and time the file was created, modified, and accessed.

What constitutes a version change and how does GRYN track changes in documents?

The scope of this guideline is for documents produced in Microsoft Word, the NPS-standard documenting application. To address compatibility issues and user requirements on various computing platforms, documents may be published and distributed as Adobe Portable Document Format (pdf).

GRYN materials are developed at two levels – one level is draft, internal working documents leading to publication of an initial or subsequent products for distribution. The other level is a previously published, external document that compels changes to network operations. Examples of substantial changes requiring a new version include a change in monitoring objectives, sampling design, data collection, analysis, or distribution methods, or any aspect of the inventory and monitoring program that requires a process adjustment. This might be the result of information learned during a pilot implementation of a monitoring protocol. Document edits that do not require a separate version include text manipulation, grammatical and formatting changes, addition of supporting content not resulting in a process adjustment, etc.

It is necessary to track changes in draft, pre-publication documents, and track versions in published, updated documents.

GRYN content is developed with multiple levels of interaction and review. For example, Individual GRYN staff author documents which may be exchanged with others for review and edits. In order to establish and track the master copy of a working document, the

original author will usually act as Document Steward and be responsible for storing the master copy, keeping a current copy of the master document in the corporate GRYN file system, distributing the document for edits and review, providing instruction for reviewers/editors, receiving tracked changes(edits), comparing and merging edit copies into the master, managing version of the document, etc.

Example: The network coordinator emails a note to several people requesting review and edits to document "standard_MOU_v1.doc". The email includes the local network file path and file name as well as the attached document. The document has the track changes feature turned on. The email message includes instructions to use the track changes feature, how to provide edits and return the edited document. The procedures that follow depend on whether or not the collaborating individual has access to the local network.

Off-Network Collaborators: Each person saves the attached document to a personal working directory and includes their username and the word 'edits' in the file name. For example, the attached document "standard_MOU_v1.doc" is saved locally as "standard_MOU_v1_rdaley_edits.doc" Edits are made using the track changes feature, which allows Cathie as the Document Steward to compare and merge the changes from multiple review copies when they are returned.

ISSUE: Occasionally more than one person will need to review and edit a draft document at the same time.
SOLUTION: It is best to maintain a single edit copy of the network based document. If it is necessary for more than one person to review and edit the document at the same time, then when the second or subsequent users sees the message about "Read only – someone else is using this file", that user will make a copy of the file following the naming convention outlined above, i.e. "standard_MOU_v1.doc" is saved locally as "standard_MOU_v1_rdaley_edits.doc"

Document Identification Standards: Information in the footer of the document to help readers use the documents. Include the following:
Document Steward – name of a single individual responsible for the master document
File path and name
Date file originated
Date file last modified
Page # of ##

U:\Monitoring\Vital_Signs_ (Vital Signs directory structure - DRAFT)
Vital signs folders under the 'Monitoring' folder:
(This list represents the network's overall vital signs list, for some of which GRYN develops monitoring protocols.)

Algae
Amphibians
Aquatic_Invertebrate_Assemblages
Arid_Seep_Spring
Atmospheric_Deposition
Backcountry_Day_Use
Backcountry_Overnight_Use
Beaver
Biogeochemical_Flux
Birds_Of_Concern
Climate
Community_Alpine
Community_Aspen
Community_Cushion_Plant
Community_Riparian_Riverine
Community_Shrub_Steppe
Ecoli
<example_structure> (standard subfolders)
Exotic_Aquatic_Assemblages
Fire
Forest_Insect_Disease
Geothermal_Features
Geothermal_Water_Chemistry
Glaciers
Ground_Water_Quantity
Insects
Invasive_Plants
Land_Birds
Land_Cover
Land_Use
Large_Carnivores
Mesocarnivores
Native_Aquatic_Assemblages
Oversnow_Emmissions
Reservoir_Lake_Elevation
Seismic_Activity
Soil_Structure_Stability
Soundscapes
Stream_Sediment_Transport
Streamflow
Ungulates
Vertebrate_Disease
Visibility
Visitor_Use
Water_Chemistry
Water_Quality_Regulatory
Water_Temperature
Whitebark_Pine (example below)

Common (required) subfolder structure under each vital sign folder:

<vital_sign>
- !Overview
- Conceptual_Models
- Current_Historic_Monitoring
- Data_Management
- Issues_Threats
- Meetings
- Monitoring_objectives
- Projects
  - <specific project folder> *(replace with project name)*
    - !Bin
    - Agreements
    - Project_Deliverables
    - Proposals
- Protocol
- Resources
  - !Bin
  - Guidance_Documents
  - Images
    - Restricted
    - Unrestricted
  - Journal_Articles
  - Maps
  - Other
  - Popular_Articles
  - Presentations
  - Related_Protocols
  - Reports
  - Web
- Sampling_Design

Below is an example with explanation of common subfolder structure shared by all folders with a vital sign name. The example uses the Whitebark Pine vital sign name:

Example of common subfolder structure shared by all folders with a vital sign name:

U:\Monitoring\Vital_Signs\Whitebark_Pine\

!Overview

This folder contains the following documents:

Protocol Development Summary(PDS) *for all protocols scheduled for implementation by year 2009. The PDS briefly explains why this vital sign is important, lists specific objectives, outlines the basic approach to develop the protocol (e.g. borrowing from existing protocols), and information about who will develop the protocol, how long it will take, what it will cost, etc. Summarizing and formatting this information to share among the networks will enhance opportunities for collaboration and consistency. PDS's are for internal use to promote communication and collaboration.*

Example: Whitebark_Pine_PDS_current.doc

Vital Sign Summary *for those Vital Signs not scheduled for implementation by year 2009. The Vital Sign Summary describes the vital sign, provides background, and explains the justification for developing the vital sign plan and protocol.*

The "Technical Notes" from Phase 2 planning *are a source of information that relate to Parts 1 and 2 of the monitoring protocol document.*

Project Status Summary *lists by date those efforts and resources related to the Vital Sign, and may contain hyperlinks to materials stored in the 'Projects' subfolders for this Vital Sign.*

Workshops Summary *lists by date those workshops related to the vital sign.*

Change Log *lists substantive changes related to the vital sign.*

Conceptual_Models

Current_Historic_Monitoring

This folder contains a document that describes the who, what, when, where, and why for monitoring projects taking place in the network, but not directly by GRYN.

Data_Management

Issues_Threats

Meetings

Monitoring_objectives

Protocol

This folder contains a structured document compiled from master component documents stored in the other folders for this Vital Sign, in addition to Standard Operating Procedures stored in folder U:\Monitoring\SOPs. Versions of this document are compiled as needed for hardcopy publication and distribution.

Projects

<specific project folder> *(replace with project name)*

!Bin

Agreements

Proposals

Project_Deliverables

Resources

!Bin

Guidance_Documents
This folder includes documents concerning legislation, directives, policies, etc. related to this vital sign. This may include a html file with URL links to current information sources.

Images

Restricted
Contains images with known copyrights

Unrestricted
Contains images with no known copyrights

Journal_Articles
Contains peer-reviewed articles from scientific journals, generally in Adobe portable document format (PDF)>

other

Popular_Articles
Contains articles that are not peer-reviewed

Presentations

Related_Protocols

Reports

Web
includes cited copies of web content and a html file containing links to web sites related to this vital sign

Sampling_Design

<other subfolder(s) > *(add additional folders for this vital sign when the time is right and after discussion with GRYN staff)*

Best Practices for Folder and File Naming:

Use official/original file sources
Where possible, avoid storing local copies of files that can be accessed via web link to the entity or organization that keeps the master file. This prevents storing and using an outdated copy and relieves network staff from monitoring the source for updates. An example is a web site with federal or NPS forms that can be accessed when needed.

It is necessary to use GRYN corporate folders to store files that support a particular version of a GRYN product or document. For example, files containing current NPS policy and I&M guidance that support GRYN monitoring protocols must be archived with the protocol documents to avoid confusion as policies and protocols change over time. Likewise, data records and data sets and the subsequent use, analysis, and reporting of the data link to specific protocols. Since protocols will change over time, each preceding protocol is archived with supporting documentation, and all data associated with each version of a protocol is documented to support the utility and longevity of the data and resulting information.

Avoid spaces in file names

Avoid using special characters, other than underscore, in file names

Avoid uncommon acronyms, abbreviations and codes
Avoid codes that require any user unfamiliar with GRYN business to refer to another table or document for the code description.
Use recognizable abbreviations or spell it out.

Exceptions: Park Service Unit acronyms like GRYN, YELL, GRTE, BICA
Acronyms in common use within and outside the National Park Service and related to natural resource management.

For additional details and reference, refer to:
http://science.nature.nps.gov/im/apps/template/IM_DB_Naming_Recs_v3.pdf":
This file stored at this location on the GRYN server:
U:\Data_Management\Library\Guidance_Documents\ IM_DB_Naming_Recs_v3.pdf

Definition and Examples of file naming convention

The GRYN file name conventions are as follows:

For articles published in peer reviewed journals:
GRYN staff will comply with the terms set forth in each journal publication regarding use and distribution of journal articles.

Files are stored in the following folder:
U:\Monitoring\Vital_Signs\<vital_sign>\Resources\Journal_Papers\

The file name is composed of the following elements separated with the underscore character:

- last name of the first listed author
  If a publications has two authors:
  - after last name of first author include last name of the second listed author
  If a publication has more than two authors:
  - after last name of first author include "et_al"
- year published (if necessary use <Year>a etc. for multiple articles by the same author in the same year)
- journal title abbreviation. Once source for abbreviations: http://www.bioscience.org/atlases/jourabbr/list.htm
- article title {optional} - a reasonable portion of the title with limited use of arbitrary abbreviations
- file extension – a three-place file format extension.

syntax:
<Author>_<Year>_<Journal_title>_{Article_title}.<ext>
<Author1>_<Author2>_<Year>_<Journal_title>_{Article_title}.<ext>
<Author1>_et_al_<Year>_<Journal_title>_{Article_title}.<ext>

examples:
single author example: **Corn_2003_conserv_biol.pdf**
two-author example: **Haines_Pollock_1998_Environ_Ecolo_Stats.pdf**
more than two-author example: **Vos_et_al_2000_Env_Mon_Ass.pdf**

For reports such as status reports of inventory or monitoring work required as a deliverable from an agreement with a cooperator or a contract.
syntax:
<vital_sign>_<Author>_<Report_title>_<Year>

References not fitting into other categories

Directives folder:

Meetings folder:
<vital_sign>_<Date>_<Meeting_location>_<Key_group(s) or Key_Individual(s)>

Actions folder:

Decisions folder

Issues_Threats folder:

The following file name prefixes were considered for use by GRYN staff using as a convention to prefix document and file names. Since the directory structure provides context to such material, use of these prefixes is optional and generally will not be used.

File prefix	type of document or file
lit_	peer reviewed journal article
rep_	report title, e.g. a deliverable from a cooperator
ref_	reference documents
pres_	presentations such as PowerPoint
reg_	regulation
pol_	policy
exec_	executive order direction
mtg	meeting notes
act_	management actions
dcsn_	management Decision
isth_	issues and threats

Appendix C: Freedom of Information Act (FOIA) and Sensitive Data

From
Northeast Coastal and Barrier Network Data Management Plan
Marc Albert and Sara Stevens
November 2004

This appendix summarizes the laws and policy related to protected information about Park resources and the Freedom of Information Act (FOIA). It also describes the procedures for classifying and managing protected information from Inventory and Monitoring Program projects, as well as the procedures for responding to FOIA requests. Much of the material contained in this section is copied or derived from NPS Director's Order #66: Freedom of Information Act and the Protection of Exempted Information (Drafts 12-4-03 and 4-12-04).

C.1 Summary

The FOIA specifies a process through which all United States Government entities must respond to requests for information by any member of the public. FOIA and National Park Service policy require that NPS staff routinely make available information that is of interest to the public, including data regarding park resources and management. Resource information collected through the Greater Yellowstone Network, whether by NPS staff or partners, is intended to be available not only to parks but also to the public, and the routine dissemination of resource information is an important component of the Network Inventory and Monitoring Program.

However, information that could result in harm to resources may be withheld from public release. Four resource confidentiality laws and an Executive Order direct the NPS to protect information regarding the nature and location of certain sensitive park resources. One of these laws, the National Parks Omnibus Management Act, states that information that could result in harm to specific natural resources, including endangered or threatened species, may not be released to the public, and that records containing such information are exempted from release through FOIA.

Only a small subset of the information collected through the Inventory and Monitoring Program is likely to be considered protected. Nevertheless, all data sets and associated information from Inventory and Monitoring Program activities, including spatial data such as GIS files, should be assessed to determine sensitivity, and any protected information should be carefully managed to prevent its release. When publishing or posting resource information, or when responding to a FOIA request in collaboration with the regional FOIA officer, Inventory and Monitoring Program staff should try to ensure that only the protected information is withheld and not associated non-sensitive information.

C.2 Definitions Relating to Management of Protected Information

Endangered or threatened National Park System resources. For natural resources, this indicates a species or population that has been formally designated as endangered, threatened, a species of concern, or proposed for such a designation by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service, or a similar designation by an appropriate state agency. A parallel definition exists for cultural resources.

Partners are individuals or entities that enter into cooperative or collaborative relationships with NPS for the purpose of achieving overlapping goals, where at least some goal is held in common by both the partner and the NPS. This relationship is documented through a letter, VIP appointment, general agreement, permit, contract, or some similar written arrangement. Partners can include both private entities and other federal agencies.

Protected information indicates information about a sensitive park resource that must not be released to the public according to any of the four resource confidentiality laws and the Executive Order applicable to NPS.

Principal Investigator in this context means the person primarily responsible for the implementation of an inventory or monitoring project, whether that person is a partner, is affiliated with a partner institution, or is an NPS employee.

Record includes all books, papers, maps, photographs, machine-readable materials, or other documentary materials, regardless of physical form or characteristics. Records are made or received by an agency of the United States Government under federal law or in connection with the transaction of public business and preserved by that agency as evidence of the organization, functions, policies, decisions, procedures, operations, or other activities of the Government, or because of the informational value of the data in them (44 U.S.C. 3301).

Resource confidentiality laws refer specifically National Parks Omnibus Management Act (16 U.S.C. 5937), National Historic Preservation Act (16 U.S.C. 470w-3), Federal Cave Resources Protection Act (16 U.S.C. 4304) and Archaeological Resources Protection Act (16 U.S.C. 470hh).

Sensitive park resource indicates a park resource covered by the resource confidentiality laws that is considered susceptible to significant harm, theft or destruction, and about which information should be protected from public release.

C.3 Legal and Policy Framework for NPS Natural Resources Information Dissemination

C.3.1 Freedom of Information Act, 5 U.S.C. § 552

The Freedom of Information Act of 1966 (FOIA), amended in 1F6 to provide guidance for electronic information distribution (the amendments are commonly referred to as EFOIA) applies to records that are owned or controlled by a federal agency, regardless of whether or not the federal government created the records. FOIA is a broad disclosure law intended to establish a right for any person to access federal agency records that are not protected from disclosure by exemptions. Under the terms of FOIA, agencies make some non-protected records generally available for inspection and copying in public reading rooms and via the Internet. Other records are provided in response to specific requests through a specified process. The Department of the Interior's revised FOIA regulations (43 CFR Part 2, Subparts A through E [see 67 FR 64527]) and the Department's Freedom of Information Act Handbook (383 DM 15) can be accessed at http://www.doi.gov/foia/.

C.3.2 National Parks Omnibus Management Act, Section 207, 16 U.S.C. § 5937

The National Parks Omnibus Management Act (NPOMA) prohibits the release, under FOIA, of information regarding the nature and specific location of certain cultural and natural resources in the National Park System. Information prohibited from release includes the location of endangered or threatened species–specifically maps or narrative descriptions indicating site specific locations. The law also identifies conditions under which the Secretary may release this information.

C.3.3 National Park Service Management Policies

The NPS Management Policies (2001) explain the dual goals of the National Park Service with regard to information on resources–to withhold information that will put particular resources at risk and to expeditiously release information that does not.

C.3.4 Director's Order #66 Freedom of Information Act and the Protection of Exempted Information (Drafts 12-04-03 and 4-12-04)

The final Order will function as a supplement to the Department of the Interior FOIA regulations. It is intended to clarify internal NPS operational questions and responsibilities regarding procedures, signature authority, security requirements, and the relationship of paper and electronic records to FOIA and EFOIA. Also, the final Order will specifically address records concerning the location and nature of specific types of park resources that are prohibited from disclosure by the resource confidentiality laws. The draft of the Order states "In general, any federal agency that holds information about the nature and specific location of park resources that qualifies as protected information under the provisions of NPOMA must withhold that information from the public unless the Director of the National Park Service or designee determines that its release would:

1) further the purposes of the unit of the National Park System in which the resource is located
2) not create an unreasonable risk of harm, theft, or destruction of the resource

3) be consistent with other applicable laws protecting the resource–the expected Order will be accompanied by Reference Manual 66 which will give more detail (refer also to NPOMA)

C.4 Public Access to Network Inventory and Monitoring Data

According to NPS Management Policies and Inventory and Monitoring Program goals, each Network will make information on park resources readily available. In addition, the 1F6 amendments to FOIA require that all information that is regularly requested, except exempted records, must be made available to the public via reading rooms and the internet. The five internet portals through which information from Greater Yellowstone Network projects will be made available to the public are listed in Table C.1.

Table C.1 Greater Yellowstone Network Internal Portals for Projects

Name	Description of Content	For More Information
GRYN Web Site	Reports and other information on all Network projects as well as Network parks, operations and staff	http://www1.nature.nps.gov/im/units/gryn/
NPSpecies	Information on species in the National Parks, including all records generated through the I&M Program	www.nature.nps.gov/im/apps/npspp/
NatureBib	Bibliographic references that refer to National Park System natural resources	http://www.nature.nps.gov/nrbib/index.htm
NR-GIS Metadata and Data Store	Documents, maps, and data sets containing resource information from all sources, and their associated metadata	http://science.nature.nps.gov/nrdata/docs/about.cfm
Biodiversity Data Store	Documents, GIS maps, and data sets that contribute to the knowledge of biodiversity in National Park units	http://science.nature.nps.gov/im/inventory/biology/

Both secure and public interfaces are maintained for each of the databases associated with these portals (the NatureBib interface is in development currently), and the public will have access to all information in these databases except those records marked as 'sensitive.'

C.5 Classifying and Managing Protected Information

The procedures for classifying protected information and managing information about sensitive park resources can be summarized as follows:

- Network staff (Coordinator, Data Manager, and/or other designated staff) will ensure that all known potentially sensitive park resources are identified.
- Network staff will ensure that investigators working on Network projects understand that (1) all data and associated information must be made available for review by Network staff prior to public release in any

format, and (2) that any information classified by the NPS as protected should not be released in any format except as specifically coordinated with the NPS (see section 9.2.5.2.2).

- Network staff will identify all known potentially sensitive park resources to the principal investigator for each project.
- All known references to potentially sensitive park resources that are generated from each project will be identified to the Network by the principal investigator for that project.
- For each project, the Network staff will provide a complete list of all references to potentially sensitive park resources in each park to the park superintendent for review.
- Each superintendent determines which information should be protected.
- The Network staff will ensure that all protected information is properly identified and marked before uploading into Network or National databases, and before archiving the databases.
- Network staff will ensure that all references to protected information are removed or obscured in any reports, publications, maps, or other public forum. Following the standard for FOIA requests, the Network will segregate the non-releasable information and where practical will not withhold associated releasable information.

C.5.1 Classifying Protected Information

The classification of protected natural resource information from Inventory and Monitoring Program activities will be done on a case-by-case, project-by-project basis. According to NPOMA, if the NPS determines that disclosure of information would be harmful, information may be withheld concerning the nature and specific location of:

- endangered, threatened, rare, or commercially valuable National Park System resources
- mineral or paleontologic objects
- objects of cultural patrimony

The Federal Cave Resources Protection Act (16 U.S.C. § 4304) similarly authorizes the withholding of information concerning the specific location of any significant caves.

The Network will work closely with the investigators for each project to ensure that potentially sensitive park resources are identified and that information about these resources is tracked throughout the project. Network staff will be responsible for identifying all potentially sensitive resources to the principal investigator(s) working on each project. The investigators, whether NPS staff or partners, should develop procedures to flag all potentially sensitive resources in any products that come from the project, including documents, maps, databases and metadata. All records and other references to the potentially sensitive resources should be specifically identified by the investigator when submitting any products. Partners should not release any information before consulting with NPS staff to ensure that the information is not classified as protected. See section C.5.2.2.

Network staff should compile information about potentially sensitive resources from each project and forward it in the context in which it would be made available to the public (report, map, database etc.) to each appropriate park superintendent (or his or her designee). Each superintendent will determine whether or not to protect the information. For inventory reports, monitoring project reports, or other stand-alone documents, this process will be most efficiently conducted as part of the final draft review for each document. For information contained in other formats that will not have a discrete review process, Network staff will be responsible for flagging any potentially sensitive information and forwarding a request to the appropriate Superintendent(s).

The following guidance for determining whether information should be protected is suggested in the draft Director's Order #66 (the final guidance may be contained in the Reference Manual 66):

1) Has harm, theft, or destruction occurred to a similar resource on federal, state, or private lands?
2) Has harm, theft, or destruction occurred to other types of resources of similar commercial value, cultural importance, rarity, or threatened or endangered status on federal, state, or private lands?
3) Is information about locations of the park resource in the park specific enough so that the park resource likely could be found at these locations at predictable times now or in the future?
4) Would information about the nature of the park resource that is otherwise not of concern permit finding the resource if the information were available in conjunction with other specific types or classes of information?

5) Even where relatively out-dated, is there information that would reveal locations or characteristics of the park resource such that the information could be used to find the park resource as it exists now or is likely to exist in the future?
6) Does NPS have the capacity to protect the park resource if the public knows its specific location?

In the Greater Yellowstone Network, most information that may qualify as protected will pertain to rare species of plants and animals, including federal and state-listed species. The information that may be protected could include the location, density or abundance, or presence/absence of the resources in question. Specific examples are maps, narrative descriptions, or monitoring plot locations indicating site specific locations of species.

Information that is already in the public domain can be released. For instance, the return of condors to the Grand Canyon has been well documented by the press. If parties request site-specific information about where the condors have been seen, this information can be released. However, specific nest site locations must not be released.

C.5.2 Managing Protected Information

C.5.2.1 General Procedures

Any information that a superintendent determines should be protected will be removed by Network staff, or by partners with Network staff guidance, before publication or the posting of documents or other media in which the information is contained. Following the standard for FOIA requests, the Network will segregate the non-releasable information and where practical will not withhold associated releasable information.

The method used to withhold protected information depends on the nature of the particular park resource and the medium in which the information is contained. It is the responsibility of Network staff, with guidance from park superintendent(s), to determine the appropriate measures to withhold protected information. In the Greater Yellowstone Network, protected information is likely to refer to the presence or absence and location of rare species.

It may be appropriate to generalize location data in order to make an area large enough so that the public will be provided some information without learning the specific location of the park resource. This principle can be applied to text descriptions of locations, to text or coded data located on field data sheets or in databases, to GIS files, or to printed maps. In the case of databases, all references to any resource regarding which information is protected should be deleted or otherwise concealed in any publicly accessible version. For example, when providing location information, cutting off the last digits in UTM coordinates will make the location general enough in some cases. This could apply to metadata files associated with GIS data as well. An option for GIS-based displays or printed maps would be to increase the pixel size to the point that finding the object of interest is not possible.

Four of the databases for natural resource related information from the Inventory and Monitoring Program–NatureBib for bibliographic references, NPSpecies for species records, and the Biodiversity Data Store and NR-GIS Data and Metadata Store for documents, GIS maps, and data sets–are equipped with the capacity to mark protected information when records are being uploaded. All records that are marked ‘sensitive’ upon uploading will only be available through the secure applications. Thus, access to information on sensitive park resources will be limited to NPS staff or partners who have signed a confidentiality agreement and procedures regarding the release of protected information can be provided along with access to the databases. It is critical that the Network implement quality control and quality assurance measures to ensure that anyone uploading records into these databases will know the procedures for identifying and entering protected information.

Precautions should be taken to avoid inadvertent releases of protected information. Examples of inadvertent releases are the use of protected information in the development of NPS interpretive and public information programs or the inclusion of protected information in National Environmental Policy Act documents.

C.5.2.2 Procedures for Working with Partners

Network staff must work with any partners that are collecting or reporting information from Inventory and Monitoring Program projects to ensure that:

- all of the records and other information associated with projects are submitted to the NPS
- protected information is identified as described in section C.5
- protected information is withheld from public release
- the NPS and the partner have a signed agreement including a confidentiality clause
- specific procedures for review of information that may be reported by partners are established (This consultation must occur before the partner releases potentially sensitive information to any outside party, whether as part of a publication, posted to a website, or pursuant to a FOIA request or any other request.)

C.5.2.2.1 Partner Agreements

The rights and responsibilities of the NPS and partners regarding potentially sensitive park resources should be stated clearly in any Cooperative Agreement, contract, Interagency Agreement, VIP agreement, or other written confirmation of a working relationship. Each agreement should address the following:

- Clarification of the ownership of data and associated information–the following text, adapted from guidelines developed by Acadia National Park, is recommended: “All associated data (including, but not limited to field notes, maps, slides, photographs, charts/graphs, tabular and GIS data with associated metadata) are required to be submitted to the Network annually and are owned by the National Park Service.”
- All known potentially sensitive park resources should be named. Since the agreement itself is a public document only the names of the resources should be provided, not specific information about their distribution or abundance, in case that information should be protected.
- The procedures for the classification of protected information should be summarized, especially with regard to cooperation between the Network staff and the project staff (as described in section C.5.1).
- A requirement for the partner to withhold protected information and to consult with the NPS before releasing any information on sensitive park resources should be stated. Thus, the document should include a confidentiality agreement.

If agreements do not contain specific responsibilities for the NPS and the partner regarding protected information, then Network staff must work with partners to institute the appropriate procedures. Note that Federal ownership of information means that the information is subject to public release through FOIA.

C.6 Responding to FOIA Requests

When a Network or a Network park receives a specific FOIA request for Inventory and Monitoring Program information, they will handle it according to standard Department of the Interior and NPS procedures, following the Department’s Regulations, the Department’s FOIA Handbook, and the NPS Directors Order #66 and Reference Manual 66. General information and web links regarding FOIA are located in section C.3.1. (The NPS Northeast Region’s FOIA Program Officer is currently Annette Sasso, and the Regional FOIA Officer is currently Edie Shean-Hammond.)

The procedures for responding to FOIA requests for Inventory and Monitoring Program-related information can be summarized as follows:

- When a request is received by a park or the Network, it is the responsibility of the NPS official recipient (the superintendent for a park, or the Network Coordinator) to comply with FOIA. Notification of the request is forwarded to the regional FOIA program coordinator and the request is logged into the Electronic FOIA Tracking System.
- The request is ‘perfected’ (finalized) by estimating fees and determining the requestors payment limit or request for payment exemption; from this date the NPS has 20 days to respond.

- The requested records are compiled by the recipient office, noting any records that contain protected information and thus are exempted from release. The recipient must consult with the NPS solicitor regarding any exempted records.
- When a record contains both exempt and nonexempt material, a reasonable attempt should be made to segregate and release nonexempt information.
- A draft response to the request containing the requested records along with an explanation of any records that have been withheld should be submitted to the Regional FOIA Program Coordinator, then forwarded to the Regional FOIA Officer and finally to the Regional Director for signature and release.

C.6.1 Inquiries for Information and/or Records

Upon receipt of a request, the FOIA Officer will make a determination as to whether it is subject to FOIA (i.e., a request for records) or merely a request for information. If the requester seeks an answer to a specific question, or an explanation of policy, procedures, or a Departmental action, DOI is not required to process the request under FOIA. Nonetheless, the FOIA Officer should refer the request for information to the appropriate office for response in a timely manner.

C.6.2 Exemptions from Release of Records through FOIA

Nine exemptions and three special law enforcement record exclusions permit the withholding of sensitive or confidential information from release through FOIA. Although the NPS does not rely on any particular exemption, the one most likely to be used in the context of park natural resources requires withholding records that are prohibited from disclosure by another statute. Four resource confidentiality laws and one Executive Order direct the NPS to protect information regarding the nature and location of certain sensitive park resources. These include the Federal Cave Resources Protection Act and the National Parks Omnibus Management Act (NPOMA), which requires that information potentially harmful to particular natural resources, including listed endangered or threatened species, be withheld from public release.

In some instances, acknowledgement that a particular resource exists at all in a park may reveal too much information. In such cases, a response that neither confirms nor denies the existence of such records may be appropriate in reply to a FOIA request. Such a reply is known as a Glomar response.

C.6.3 Release of Records through FOIA for Projects with Partners

FOIA dictates that once an agency has shared records with any party outside the federal government without a pre-release agreement, it must make the records available to any and all other parties who request them. This provision is referred to as the “release to one, release to all” rule.

When published research findings are produced under a grant or other Federal assistance, including funding from the Inventory and Monitoring Program, and the findings are used by a bureau in developing an agency action that has the force and effect of law (e.g., a policy or regulation), the research data related to such findings are considered agency records even if they are in the possession of the recipient.

C.6.3.1 Procedures for Working with Federal Agency Partners

In general, any federal agency that holds information about the nature and specific location of park resources that qualifies as protected information under the provisions of NPOMA must withhold that information from the public unless the Director of the National Park Service or designee determines that its release would:

1) further the purposes of the unit of the National Park System
2) not create an unreasonable risk of harm, theft, or destruction of the resource
3) be consistent with other applicable laws protecting the resource

When another federal agency informs NPS that it has received a FOIA request regarding information that the other agency holds about park resources, NPS first assists the agency in determining whether the requested records fit within the definition of protected information. The agency must withhold the information pending action from the NPS. NPS will ask the agency to forward the FOIA request to the NPS with either: 1) a preliminary recommendation that the information be withheld; 2) a preliminary recommendation that it be released; or 3) a statement that the agency will not be making a recommendation whether the information should be released.

The NPS will make its determination about what information, if any, is to be withheld based on information the NPS receives from the agency, the requester, any other party that it consults, and its own inquiry into whether the information can be released under the provisions of NPOMA.

C.6.3.2 Requests for NPS Records Held by a State Agency or Partner

Before sharing information with state employees, whether from state agencies or state funded universities, NPS must be aware that those state employees may be obligated to release information in their possession to any party requesting it because state freedom of information or sunshine laws require such release. In states with Freedom of Information laws that allow the withholding of certain types of information, it may be possible that state employees would have the authority to enter into contractual agreements with NPS to withhold protected information. NPS must not share protected information with any state employee where state laws require the release of all information in state records.

C.6.3.3 Requests for Information Received by NPS from Non-NPS Entities

The NPS cannot guarantee confidentiality of information received from any non-NPS entity. Once NPS receives information from others, its treatment of the information is governed by FOIA. Such information must be released in response to a FOIA request if it does not qualify as protected information. The NPS must, however, withhold any information it receives that does qualify as protected.

Appendix D: Using the Global Positioning System and Portable Data Recorders

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The Global Positioning System (GPS) and the associated data collection equipment and data processing software are important tools for natural resource data acquisition and management. Poorly organized GPS efforts waste time and money, while thorough and well-planned projects with well trained GPS operators result in efficiently acquired, high quality data that forms the basis of credible inventory and monitoring projects.

> It is the responsibility of each person conducting business for the Greater Yellowstone Inventory and Monitoring Network to consult and follow the most current procedures and guidelines in three information sources:
> 1. National Park Service standard GPS operating procedures: *Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines, 02/10/2004*.
> 2. This GRYN GPS/PDR Operating Guide
> 3. Individual Vital Sign Standard Operating Procedures for Data Management or individual inventory study plans.

This Greater Yellowstone Network Standard Procedure Guide for Data Collection Using the Global Positioning System and Portable Data Recorders supplements the National Park Service's *Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines, 02/10/2004*. Readers should be familiar with and follow both sets of guidelines as well as individual inventory project criteria and Vital Sign monitoring protocols that may contain additional detailed procedures. This document outlines Best Practices to effectively collect feature location and feature attribute data for the Greater Yellowstone Network Inventory and Monitoring Program. It is not an instruction manual on GPS or PDR theory, equipment, or software, but includes some details about steps that should be performed on every project involving GPS and field data recording. Several references are listed that provide more specific information on all aspects of the GPS.

It is important for everyone involved with National Park Service inventory and monitoring projects to understand the capabilities and limitations of GPS technology in order to use it effectively. The decision to include GPS with other resource management information technology depends on how specific monitoring protocol or inventory criteria relate to existing data and information management tools. For example, it is not appropriate to spend hours or days in the field collecting GPS data when the same features can be adequately mapped in the office using a Digital Orthophoto Quadrangle as a background image in a GIS application.

Effective use of GPS for resource information management involves shared responsibilities that include strong communication and understanding by each person involved in the collection, management, and use of data resources. In order to promote understanding and inform good decisions about using tools like GPS, field crew members and crew leaders should receive briefings from higher level supervisors, project managers, and data managers at least once per season about how their efforts fit with park and network management objectives, National Park Service and Department of Interior Policies, and federal government requirements, including those of congressional offices, the Federal Geographic Data Committee(FGDC), etc. Inventory and Monitoring project managers should have a good understanding of resource information management issues and requirements and be aware of the challenges and limitations of field data collection, including the use of GPS. This is achieved by detailed and regular briefings and/or accompanying field crews to perform data collection at least once each season. Table 1 provides a framework for the roles and responsibilities involved in using GPS for inventory and monitoring projects.

Table 1. Data Stewardship Framework for GPS and Field Data Collection Activities

Position or Office	Primary Role(s)	Primary Responsibilities related to GPS & Field Data Collection	Recommended Awareness Level
Field Crew Member	Collect and Record Data	▪ Obtain training in GPS theory and equipment. ▪ Read and follow all three levels of NPS GPS Operating Guidelines. ▪ Communicate with Crew Leader, Project Manager, and Data Manager. ▪ Perform regularly scheduled data transfer and backup data for further processing. ▪ Review, validate, and correct field data. ▪ Assist with data documentation.	▪ Good understanding of specific protocol and related discipline. ▪ Some awareness of any related protocols. ▪ Briefed on Network Program, NPS I&M Program, and relationships with e-Gov and other agencies efforts and initiatives.
Field Crew Leader	Supervise crew	▪ Ensure crew members receive GPS training and briefings. ▪ Read and follow all three levels of GPS Operating Guidelines. ▪ Communicate with Crew Members, Project Manager, and Data Manager. ▪ Ensure data is regularly transferred, backed up, verified, and entered into the appropriate NPS database(s). ▪ Assist with data documentation.	

Position or Office	Primary Role(s)	Primary Responsibilities related to GPS & Field Data Collection	Recommended Awareness Level
Project Leader	Supervise or Advise Field Crew Leader. Oversee and coordinate the project.	▪ Ensure crew leader receives pertinent training and briefings. ▪ Read and follow all three levels of GPS Operating Guidelines. ▪ Communicate with Crew Leader, Data Manager, and I&M Network Coordinator.	
I&M Network Coordinator	Supervise or Advise Project Manager. Coordinate all projects in general.		
Network Data Management Office	▪ Ensure inventory and monitoring data is organized, useful, compliant, safe, and available. ▪ Coordinate with Network parks, other Networks, and regional and national I&M and Natural Resource Programs as well as other agencies and entities.	▪ Assign and enforce data stewardship roles and responsibilities. ▪ Review and approve all data acquisition plans, hardcopy and electronic field forms, and GPS/GIS data dictionaries. ▪ Communicate with Crew Leader, Project Leader, I&M Network Coordinator, and Park GIS/Data Management office. ▪ Develop and maintain overall Network and individual Vital Sign GPS Operating Guidelines and relationship to national standards and procedures.	
Park GIS/Data Management office	▪ Coordinate and integrate local GIS and resource information management with Network, regional, and National standards. ▪ Support park management objectives.		

Information Resources Lifecycle

Data collected using GPS-enabled equipment represents all or part of the acquisition stage of an information resources lifecycle that includes several other stages (see Table 5.1 in GRYN Data and Information Management Plan). Data collection using the same equipment may also relate to the data maintenance stage of the Lifecycle. Whether GPS equipment includes data logging functionality, or Portable Data Recorders (PDR's) are GPS-enabled, it is most efficient to use a single device to collect and store data about both the location and characteristics of features for inventory and monitoring projects. The process and methodology used for acquisition planning, data collecting, and post-processing incorporate several aspects of data management, including quality assurance, data storage and organization, and data stewardship. To promote data quality and simplify data management, the Greater Yellowstone Network expects to use electronic data logging equipment for some data acquisition. However, parallel or complementary use of hand written data sheets and field notes will remain important for data collection activities.

Mission Planning and Preparation

Information gathering and mission planning are essential requirements that help protect investments in field data collection efforts that result in data that meet the requirements of the inventory or monitoring project. It is a chance to anticipate and prepare for the challenges as well as take advantage of the opportunities related to field data collection.

Read the monitoring plan and protocol for the vital sign or the inventory project plan. It provides the context and details for the overall effort and approach, which may include using the GPS and GPS-enabled equipment.

Read National Park Service standard GPS operating procedures: *Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines*.

Obtain training on GPS theory and on the use of GPS equipment. This may include commercially or academically available training and GRYN-sponsored training.

Obtain training and experience in map reading, using a compass, and orienteering because battery powered electronic GPS equipment is not fail-proof and should not be relied on as the only means of navigation.

Work with the network data manager to identify and become familiar with the database(s) that will store and manage the results of the GPS data collection. In most cases the data will ultimately reside with related data in one or more corporate databases managed by the National Park Service, other federal agency databases, national park databases, and I&M Network databases.

Work with the Network data manager and project leader to design field forms and electronic data collection forms (e.g. Trimble© Data Dictionary, ArcPad© application, or other). The design of the form(s) is determined by the inventory and monitoring objectives, their protocols, and existing or co-developed database structures. For example, know and use existing database field names in forms rather than locally invented names. **All data dictionaries and field forms will include the Vital Sign Monitoring Plan or inventory study plan title, version number and publication date.** This information is a critical element of required metadata for all data

collected based on a given monitoring plan or inventory study plan. The NPS Natural Resource Database Template (NRDT) Data Dictionary documentation and database design structure is the appropriate starting point for database development. The NRDT sample databases and the I&M web-based monitoring protocol clearinghouse should also be consulted for existing databases that can be adapted to serve GRYN data management requirements.

Obtain as much information as possible about the field site(s) through site reconnaissance, dialogue with individuals who are familiar with the site and topographic or other maps.

Use GPS planning software such as Trimble Planning Software (www.trimble.com) or equivalent to predict satellite availability, account for site visibility obstructions, and determine the best observation periods related to GPS receiver settings, as well as predict hours which the field crew can work on site under favorable conditions for satellite reception. Print tables and graphs from the planning software to take to the field. Reliable results from planning depend on a current almanac file. Current almanac files can be downloaded from a recently used GPS unit to the planning software. If the GPS unit has not been used for more than three weeks, first acquire an updated almanac by powering on the unit outdoors. The almanac file can take up to 15 minutes to refresh.

Practice collecting and post-processing data in real-world conditions before undertaking official data collection missions. Expect to learn a lot during initial field sessions and post-processing efforts, and expect to learn some little tip or trick on every subsequent data collection mission.

Understand the power requirements of the equipment and plan for the batteries and other power sources (battery recharging, 12V DC (auto) adapters, etc) necessary to support the duration of your mission.

Document and communicate any and all deviations from these procedures along with any events or circumstances from the field that affect the viability of using these procedures. This feedback is necessary for data documentation and to continually improve these procedures.

Include in electronic field data forms (e.g. Trimble GPS data dictionaries) only those parameters or attributes specified in the monitoring protocol or inventory criteria that require on-site measurement, observation, or description. This reduces data collection cost and promotes data quality. Other required attributes for a given database will be incorporated with the data following field work. This approach allows field personnel to focus on protocol-specific data collection using uncomplicated forms that include pick lists of valid attribute values. It also saves space on portable electronic data recorders and helps to enforce proper data flow and prompt verification of field data. For example, don't include or require the entry of administrative data such as state, county, or quad names. These known geospatial attributes are easily joined later using a GIS and unnecessarily take up field time and PDR space.

Field Data Collection

Only collect data with equipment and field forms that are approved by the GRYN project leader and GRYN data manager.

Consider using an external antenna with a ground plane where appropriate to maximize satellite reception. External antennas can be mounted above a person's head and body to provide better reception and remove the sensor from internal noise of the GPS receiver.

Always use a restraint system (neck/wrist lanyard, hand strap, clamp, etc) to secure the equipment and prevent accidental damage or loss.

Verify or set GPS configurations. Do this at the beginning of each session unless you were the last person to use the equipment, in which case you probably already know the settings. Use proper receiver settings from NPS *Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines.* This includes PDOP, SNR, elevation masks, minimum satellites, and antenna height.

Distinguish between the navigation and data collection portions of the mission and use appropriate GPS configurations for each. For general navigation use more forgiving settings. For precise navigation in the vicinity of a target location and for feature data collection, use settings that yield the most precise location possible while still allowing the receiver to record positions. When field conditions, including terrain and canopy, and/or timing conditions, such as fall and winter missions, prevent reception using NPS recommended settings, use the best possible settings that permit the receiver to record positions. In all cases perform differential correction during post processing to improve the precision of the location data.

With Trimble GeoExplorer equipment, use only one rover file per day for each data dictionary. (In some cases a GPS operator may support integrated monitoring using more than one data dictionary, but preferably the integrated data elements will reside in a single data dictionary.) This minimizes post-processing time required to merge multiple field files.

For extended backcountry missions over multiple days, the investment in data collected is at risk from accidental loss and a field backup solution is desired but sometimes not practical depending on the PDR equipment. Whenever possible, back up field data at least once each day to a secondary device.

Post Processing

The Greater Yellowstone Network requires all GPS data to be post processed, including differential correction and data verification, preferably by the individual(s) who collected the data. It is important to perform the differential correction and verification as soon as possible following the field work (strongly preferred within two weeks) in order to maintain and apply the knowledge and memories of the field crew to the data.

> What about Real Time Differential Correction? Due to predominantly mountainous terrain in and around the parks and the lack of coverage by land based beacons transmitting the differential correction signals, most missions will not benefit from real time differential correction. Exceptions include operating in areas covered by real time signals and subscriptions to satellite based real time signals.

Processing location and attribute data once the equipment and personnel return to the office after a data collection mission involves several steps that serve key data management requirements. Processing stages include organizing and securing the data, improving the accuracy of feature locations (differential correction), verifying and making corrections where necessary, and

exporting the data to GIS and/or other required formats. Once the data makes it through post processing it can be merged with related data using GIS and RDBMS, become part of larger datasets, and enter the realm of corporately managed data in relevant database structures and at administrative levels including park and national databases.

Establish a PC file structure
Use a standard file structure to manage the various stages of file processing. All files should be stored on a disk that is backed up daily. Subfolders for each data collection project should accommodate field (rover) files, base files, differentially corrected files, validated files, exported files for incorporating in a GIS, and any other required export formats.

Transfer PDR Data
Use Trimble's Data Transfer program to copy the rover files from the GPS receiver to the local PC. Be aware that rover files and differentially corrected files must be stored in the same folder so they can be opened together in Pathfinder Office's Map View for a visual representation of the differential correction results. Comparing uncorrected and corrected data is not mandatory but it is useful in building trust in and understanding the process.

Look at (don't touch) rover file(s)
While it doesn't make sense to edit rover files that aren't differentially corrected, you should look at and understand each stage of the data so you know what is happening during the process. Looking at the 'raw' rover data provides visual verification that the rover file contains the data you expect to see and is adequate for further processing. You probably also verified this in the map screen on the GPS receiver or portable data recorder, so it should look similar (nicer and bigger) on the PC screen.

Perform Differential Correction
Use Trimble's Differential Correction Utility to improve the precision of the features.

Use the closest base station provider if possible. If the closest station's data is unavailable or the base files will not transfer, try the next closest station. Call the GRYN data manager if you cannot obtain any base data for your rover files. Base station operators might archive the station data after two or three months, so it is advised to correct (and validate) your data immediately – within a few days of field work.

Verify and correct the differentially corrected data
Many times the differentially corrected data requires additional edits to fix missing or extraneous positions and correct attribute values. Differential Correction in the previous step uses available positions and geometry to improve the location accuracy of your feature data. The most important part of post processing is verification of the feature types and attributes by the person who collected the data. <u>It is especially important to verify and "manually correct" for potentially missing positions during periods of poor satellite signal reception when the GPS receiver may not have logged enough positions to describe the feature alignment or location</u>.

<u>IMPORTANT</u>: Prior to performing any edits to the corrected file make a copy in the folder that will hold validated data files. Depending on the feature type(s) and number of attributes, verification and edits can take a substantial amount of time. Save often during lengthy edit sessions. Remember, this is the last best chance for verifying and improving data quality for

data that is expected to support inventory and monitoring objectives over several years or decades.

One goal of verification is to delete errant positions that result in spikes or 'spaghetti' in line and area features (point features generally don't need to be edited due to their spatial simplicity). Spikes in line and area features are usually caused by unavoidable multi-path signals, and messy spaghetti of overlapping lines are caused by collecting too many positions in too short a distance along the feature – this can be avoided by using the Pause/Resume key on the GPS receiver while collecting positions. Another part of data verification is to check, and change if necessary, the attribute values for the features.
The features should represent a mapped model of what exists on the ground but should not be 'perfect'. That is, don't zoom in so much that you spend hours fine tuning one feature. Use the scale factor displayed in the upper left of the Pathfinder Office Map View window to relate to the purpose of the data. Data is expected to at least meet National Map Accuracy Standards for maps on publication scales larger than 1:20,000 scale (http://rockyweb.cr.usgs.gov/nmpstds/nmas.html). Sometimes you need to zoom in at larger scales (smaller areas) to find and fix the spaghetti and spikes in your features, but don't zoom to 1:100 scale and spend a lot of time there. Usually with position log intervals of 1 second or greater, you can see most of the 'messy stuff' at scales less than 1:2000.

> Understanding map scale. It is helpful to know that generic use of the term 'scale' in many natural resource discussions contrasts with explicit numeric ratios (map scales) that relate distance between features on a map to the true ground distance represented. For example, a map with scale 1:100 (**0.01**) means that one distance unit on the map represents 100 of the same distance units on the ground. Compared to a 1:100,000 (**0.00001**) scale map, the 0.01 scale ratio is larger and the map depicts a smaller area. So, maps with small scale ratios represent larger areas than maps with large scale ratios and vice versa. This differs from the more intuitive understanding of scale in a statement like "The project involves a large scale analysis of several ecological parameters," which is normally interpreted as a project involving a large area.

However, pay extra attention to data that represent places where you collected several positions in a line feature over a short distance, or stood in one place without pausing the collection of positions. These are circumstances where the data tends to get 'messy' and needs to be edited to clean it up. As you become familiar with the relationships between equipment operation, your movements in the field as the 'platform' for the GPS equipment, and the resulting data, you will collect and produce cleaner data that takes less post-processing effort.

Open the corrected file in Pathfinder Office. (Optionally and carefully, you can open both the rover file (.ssf) and the corrected file (.cor) for the same Trimble data to compare the two. If you do this, it is recommended that before you edit the corrected features, you close all open files and reopen only the corrected file to avoid confusion about which file is which because you want to be sure to edit the corrected file rather than the rover file.)

IMPORTANT: Prior to performing any edits to the corrected file, create a copy of the corrected file in the folder for validated files. This helps keep track of the processing stage of the data file, and effectively leaves a 'backup' of the differentially corrected file in case there is a problem during the edit session. The "validated" folder will hold all the data that you've spent significant time processing and cleaning up.

From the "Data" menu in Trimble Pathfinder Office, make sure "Feature properties" and "Position Properties" are checked so they are visible on screen. If you don't see them, use the "Window" menu to tile or cascade the windows and then arrange them agreeably. You can also make the 'timeline' visible if it helps. Keeping the feature properties window bigger than position properties lets you see all or more of the attribute values and distinguishes between the windows so you don't accidentally delete a feature when you meant to delete a position. Remember that you can undelete until you save the edits. If you really mess up the edits, you can always start over with a fresh copy of the corrected file or by differentially correcting the rover file again.

Use the tools for zooming and panning to navigate among and along the features to examine them for spikes and spaghetti. Remember not to zoom in too much in an attempt to make the features perfect. Try a zoom scale of 1:2000. You may need to zoom in more on a certain messy area, but remember to zoom back out again to validate other parts of the feature.

Use the arrow tool to select features and positions.

Look at the position properties and feature properties windows for information and clarification.

Once the corrected data is validated and edited make sure it is saved to the folder containing validated files for that project.

Copy the validated data to a network drive or other backup device before proceeding. Once the same file is on both the local PC and the backup device (always try to keep each file in two places), it is safe to delete the rover file from the PDR in preparation for the next collection session.

Inform the project manager and data manager about the validated status and file location.

Work with the project manager and data manager to document the data fields, value domains, and other required metadata elements according to FGDC Metadata Standards.

Creating the GIS Data

Exporting files from GPS format to GIS format is an important step that nearly completes the GPS data acquisition portion of the information resources lifecycle, and provides an important opportunity to add value and utility to the data by including feature level metadata with the exported files.

Use the Trimble Pathfinder Office export utility to output the appropriate GIS format based on discussion with the network data manager. The network requires the following GPS Generated Attributes with exported data:

Generated Attributes for all feature types:

PDOP, Correction Status, Receiver Type, Date Recorded, Update Status, Data File Name, Total Positions, Data Dictionary Name (As specified in the Mission Planning section of this document, the data dictionary name represents and links to the specific version of a Vital Sign monitoring protocol).

Generated Attributes for point features:
Height, Vertical Precision, Horizontal Precision, Standard Deviation

Generated Attributes for line features:
Length (2D), Length (3D), Average Vert. Precision, Average Horiz. Precision

Generated Attributes for area features:
Area (2D), Perimeter (2D), Perimeter (3D), Average Vert. Precisions, Average Horiz. Precision

Verify the GIS data generated from the GPS data source to make sure the conversion was successful and the spatial, attribute, and GPS metadata elements exist. If problems are discovered, reexamine the GPS data source and the procedures used to convert to GIS format. If necessary, consult with the network data manager or park GIS Specialist to solve the problem.

Cleaning Up Unneeded Files

If the GIS data from the PDR/GPS source is complete and backed up in at least one other location, archive the corrected and validated GPS data files and delete the rover files, base data files, and other files generated during the GPS portion of post-processing. Provide the archived GPS data to the network data manager in a standard compressed and zipped format, i.e. Winzip.

References

References are available online or by request from GRYN Data Manager.

Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines, NPS, 02/10/04
http://www.nps.gov/gis/fm/documents/Field_Data_Collection_with_GPS02-04.doc
GRYN Server: U:\Data_Info_Management\Acquisition\Field_Data_Collection_with_GPS02-04.doc(6/29/04 download)

DRAFT GPS Data Accuracy Standard, US Forest Service, March 14, 2000
http://www.fs.fed.us/database/gps/gps_standards/GPS_Data_Standard.pdf
GRYN Server: U:\Data_Info_Management\Acquisition\USFS_Draft_GPS_Data_Standard.pdf (6/29/04 download)

National Park Service GPS for GIS Workflow, www.nps.gov/gis/gps/gps4gis/

Natural Resource Database Template, Inventory and Monitoring Program, National Park Service, http://science.nature.nps.gov/im/apps/template/index.htm

Protocol Database, Inventory and Monitoring Program, National Park Service, http://science.nature.nps.gov/im/monitor/protocoldb.cfm

GPSToolBox, Alaska Support Office, National Park Service, http://www.nps.gov/gis/gps/aksogps/

GPS to GIS Procedural Handbook & Reference Guide *VERSION 6.0,* San Juan National Forest, US Forest Service, 12/08/2003.
GRYN Server: U:\Data_Info_Management\Acquisition\USFS_San_Juan_gps_gis_v6-0.pdf

Class Notes – Design, Capture, Edit, And Integration Of Resource-Grade Trimble® GPS Data, Coconino National Forest, US Forest Service, January 2004

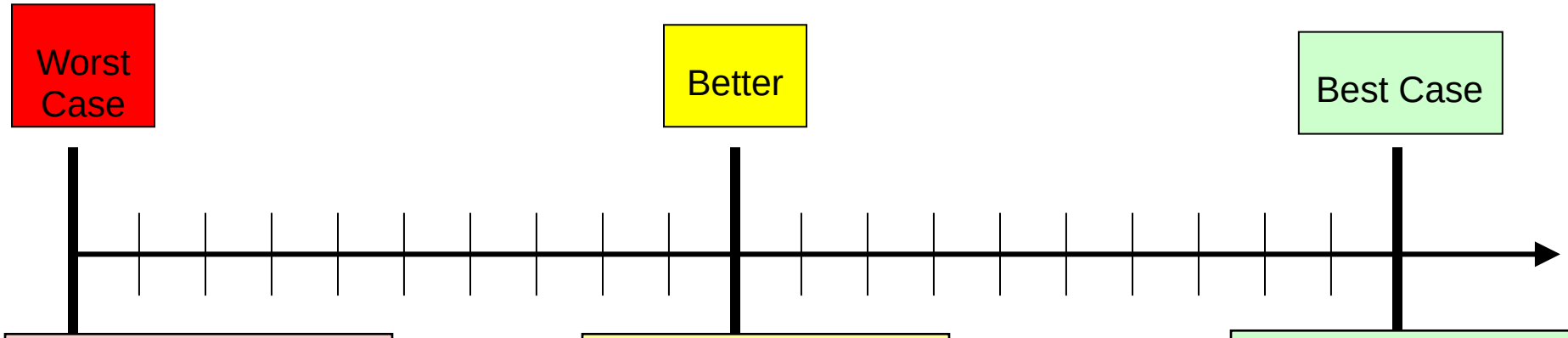
National Park Service Geography and Mapping Technologies, www.nps.gov/gis

National Park Service Global Positioning Systems, www.nps.gov/gis/gps/

USDA Forest Service GPS, www.fs.fed.us/database/gps/

Trimble Navigation Limited, 2004, www.trimble.com

The Continuum of GPS Data Collection



Worst Case

GPS user works alone.

No mission planning.

No data dictionary or dictionary does not reflect monitoring protocol.

User does not promptly download, correct, verify, edit, and export the data.

Data is not communicate/shared with others.

Data is not related to National Park Service protocols.

Better

GPS user works with others occasionally.

Some mission planning is done, if convenient.

User downloads and looks at data sometimes.

Data is shared with others at the Unit.

Data is related to NPS protocols in some ways, not in others.

Best Case

GPS user maintains a network of contacts.

Mission planning is part of the work flow.

User follows through with downloading, differentially correcting, editing if necessary, and exporting.

Data is collected, processed, and shared to meet or exceed agency standards.

The user has a good understanding of filing structure and organization.

GPS/PDR Appendix B. NPS Natural Resource Database Template Data Dictionary

The NRDT is a developing tool for data management that will change over time.

For the current version of the NRDT Data Dictionary refer to the NRDT web site (checked 9/27/2005): http://science.nature.nps.gov/im/apps/template/index.htm

For hardcopy distribution of the NPS Natural Resource Database Template Data Dictionary as an attachment to this GPS/PDR Standard Operating Procedure, print and attach the latest version from the online link above. The latest version is filed at this location on the GRYN server:

G:\Natural_Resource_databases\Database_template\DATA DICTIONARY.DOC (version 10/9/2002)

APPENDIX VIII: GREATER YELLOWSTONE NETWORK COOPERATORS AND PARTNERS

Name and affiliation	Project Name
Beauvais, Gary and Doug Keinath *University of Wyoming*	Bat & Small Mammals Inventories in the Greater Yellowstone Network
Bengeyfield, Pete *Beaverhead-Deerlodge National Forest*	Greater Yellowstone Area Stream Reference Reach Study
Bischke, Scott *Clear Creek Company*	Professional science writing: Phase II Vital Signs Monitoring Plan
Campbell, Don and Leora Nanus *USGS-Water Resource Division*	Air Quality and Deposition Data Analysis
Cherry, Steve *Montana State University*	Whitebark Pine Data Analysis and Sample Design
Clements, Will and Donna Kashian *Colorado State University*	Development of Water Chemistry Monitoring Protocols for the Greater Yellowstone Network
Debinski, Diane *Iowa State University*	Background Information for Insects as a Vital Sign
Gipson, Rob *Wyoming Game & Fish*	Inventory of Fish in Alpine Lakes in Grand Teton National Park.
Graumlich, Lisa *Montana State University*	Development of Monitoring Protocols for the Greater Yellowstone Network
Gray, Steve *Montana State University*	Development of Climate Monitoring Protocol for the Greater Yellowstone Network
Hall, Bob University of Wyoming	Aquatic Ecosystems Conceptual Model Development
Hansen, Andy and Danielle Jones *Montana State University*	Development of Land Use Monitoring Protocols for the Greater Yellowstone Network
Hawkins, Chuck and Tres Simmons *Utah State University*	Synoptic Review of River Invertebrate data
Kalinowski, Steve *Montana State University*	Genetic Analysis of Trout in the Upper Snake River Watershed, Yellowstone NP
Krumpe, Ed & Troy Hall *University of Idaho*	A Survey of Science Professionals: Delphi I-III.
Lawrence, Rick and Lisa Landenburger *Montana State University*	Mapping Whitebark Pine Distribution throughout the Greater Yellowstone Network
Markow, Stuart *University of Wyoming*	Report on a Survey for Stephanomeria fluminea in Grand Teton National Park
Maxwell, Bruce and Lisa Rew *Montana State University*	A Survey of Non-indigenous Plant Species in the Northern Range of Yellowstone National Park.
McGlynn, Brian and Denine Schmitz *Montana State University*	Development of a Seep & Spring Monitoring Protocol for Bighorn Canyon National Recreation Area
Novak, Mark *Bridger-Teton National Forest*	Cutthroat trout Inventory in the Upper Snake River Watershed
Patten, Duncan *Montana State University*	Riparian, Wetland and Alpine Ecosystems Conceptual Model Development
Peterson, Charles and Deb Patla *Idaho State University*	Development of Amphibian Monitoring Protocols for the Greater Yellowstone Network
Selkowitz, David	Compilation and Analysis of Snow and Climate Data
Swartz, Chuck *USGS Northern Rocky Mountain*	Development of Whitebark Pine Monitoring Protocols for the Greater Yellowstone Network

Science Center	
Sweat, Mike and Kendra Remley *USGS Water Resources Division*	Hydrologic Characterization of Bighorn Canyon National Recreation Area Freshwater Seeps and Springs
Tinker, Dan *University of Wyoming*	Forest Ecosystems Conceptual Model Development
Williams, Steve *University of Wyoming*	Background Information for Soil Biota as a Vital Sign
Williams, Mark and Meredith Knauf *University of Colorado*	Soda Butte Creek and Reese Creek :Vital Signs Monitoring Program
Woods , Scott and Jenny Corbin *University of Montana*	Water Quality Data Mining and VSM Recommendations
Park Affiliates (past and current)	**Project Name**
Arnold, Jeff	Evaluation of Stream Quality Using Benthic Macroinvertebrate Communities
Bromley, Cassity	Regulatory Water Quality Monitoring
Haynes, Steve	Exotic Plant Inventory at Grand Teton National Park
Heasler, Hank and Cheryl Jaworowski	Geothermal Conceptual Model Development
Hektner, Mary	Vascular plant inventory in Yellowstone's Alpine areas
Koel, Todd and Dan Mahony	Cutthroat trout Inventory in the Upper Snake River Watershed
Koch, Alison and Vincent Santucii	Paleontological Resource Inventory and Monitoring
Lindstrom, Peter and Richard Easterbrook	Exotic Plant Database for Grand Teton National Park
Maj, Mary	Greater Yellowstone Coordinating Committee
McCloskey, Kelly	NPSpecies database
Morstad, Suzanne	NPSpecies database
O'Ney, Susan	Regulatory Water Quality Monitoring Plan for the Greater Yellowstone Network
Plumb, Glenn	Ecosystem Conceptual Model Development
Reinhart, Dan	Development of Whitebark Pine Monitoring Protocols for the Greater Yellowstone Network
Rodman, Ann	Watershed Classification Project
Whipple, Jennifer	Vascular Plant Inventory in Yellowstone's Alpine areas; NPSpecies database
Wolff, Sue	Bald Eagle and Sage Grouse Surveys GRTE

APPENDIX IX: COMMUNICATION PLAN

GREATER YELLOWSTONE INVENTORY AND MONITORING NETWORK

NATIONAL PARK SERVICE

COMMUNICATIONS PLAN

NOVEMBER 26, 2004

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http://www.nature.nps.gov/im/units/gryn/index.shtml

INTRODUCTION

The Greater Yellowstone Network (GRYN) is an inventory and monitoring network within the National Park Service (NPS) Inventory and Monitoring (I&M) Program. The mission of the National Park Service (NPS) is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations". To uphold this goal, the NPS created the Natural Resource Challenge in 2000 to encourage national parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories and expanded resource monitoring and management. This Challenge was legally guided by the *National Parks Omnibus Management Act of 1998*. Through the Natural Resource Challenge, the 265 parks of the NPS were placed into seven regions and, subsequently, organized into thirty-two inventory and monitoring networks, based on geographic and ecological similarities. The overarching goal of the networks can be summarized by the following quote from the NPS Advisory Board in July 2001: "A sophisticated knowledge of resources and their condition is essential. The Service must gain this knowledge through extensive collaboration with other agencies and academia, and its findings must be communicated to the public. For it is the broader public that will decide the fate of these resources". The goals of the National I&M Program are:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of "abnormal" conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress toward performance goals.

COMMUNICATIONS PLAN GOALS

The GRYN Communications Plan outlines the communications products and strategies (those required by the National I&M Program and those more specific to the GRYN) and the target audience of these products. As well, after implementation, the communications plan should lead to:

- consistency and repetition in communicating the goals and purposes of the GRYN
- increased cooperation within the GRYN and effectiveness in communicating these goals
- the elimination of contradictory/conflicting messages
- the reinforcement and strengthening of the overall goal of the network
- increased awareness of the network to internal/external members
- increased understanding of network goals by internal/external members
- increased willingness to accept and support network

MAIN AUDIENCES

For the GRYN to be successful in communicating its purpose and progress toward inventory and monitoring, it is essential that the network focus on five audiences: 1) the National I&M Program

and Congress; 2) the GRYN Board of Directors, Technical Committee and Science Committee; 3) Yellowstone National Park, Grand Teton National Park and Bighorn Canyon National Recreation Area park managers and employees and audiences external to the NPS including: 4) academic community; 5)other government agencies; 6) non-profit/non-governmental organizations; and 7) the general public.

PRODUCTS

PRODUCTS RECOMMENDED BY THE NATIONAL I&M PROGRAM

The following reports are highlighted by the National I&M Program as methods for information dissemination:

- Annual Administrative Report and Work Plan
- Annual reports for specific protocols or projects
- Inventory project reports
- Analysis and synthesis reports—trends
- Program and protocol review reports
- Scientific journal articles and book chapters
- Symposia, workshops and conferences
- State of the Parks Report

ADDITIONAL COMMUNICATION TOOLS USED BY THE GRYN

In addition to the products recommended by the National I&M Program, the GRYN will use the following methods for informing a variety of audiences:

- Monthly reports
- Submissions to the BNR report at Yellowstone
- Submissions of links for the Intermountain Region report
- Visual identity system
- Public brochures
- Posters for network parks about the I&M program
- Data management reports
- Ongoing list of network cooperators
- Website
- Popular press articles

The intended audiences for these reports will be covered in the following section.

SPECIFIC INFORMATION CONCERNING COMMUNICATIONS PRODUCTS

Each of the listed communication products will be covered in more detail, including the following information: 1) definition and intended audience; 2) frequency of reporting; 3) purpose and content of the report; 4) author of the report; and 5) reporting format.

ANNUAL ADMINISTRATIVE REPORT AND WORK PLAN

Definition: The Annual Administrative Report and Work Plan (AARWP) is required by the National I&M Program and the Washington Office (WASO) as a way to account for funds used during the fiscal year. In order to accomplish this, the report requires that the network account for funds used during the past fiscal year towards completing a list of accomplishments written in the previous year's work plan. Furthermore, the AARWP requires the creation of a budget and work plan for the following year, including staffing, cooperative agreements, contracts, miscellaneous, etc.

Frequency: The AARWP is due on an annual basis. The Annual Administrative Report and *Draft* Work Plan should be reviewed by the Technical Committee prior to submission to WASO on November 8. The final Work Plan is due to WASO by January 31.

Purpose: The purpose of the report is to account for money spent and employees hired during the fiscal year. A section of the report called "Summary of Major Accomplishments" is inserted into the annual report to Congress to obtain future funding for the program.

Author: The primary author of the report is the network program manager, with additional input from network staff on the year's accomplishments. The Technical Committee will review the report, and the Board of Directors must approve the report before submission. Then, the Intermountain Regional Office and the National I&M Program Manager will review the report and give approval.

Format: The format of the report is outlined by the national program each year.

MONITORING PROTOCOLS

Definition: Protocols created for the network are required to follow a Service-wide format, which is documented by Oakley et al. (2003). When a final protocol format has been decided upon, it will then serve as the template for all further protocols developed for the network.

Frequency: Protocols will be developed once for each vital sign; they will be updated on an as-needed basis and after the program review occurs.

Purpose: Protocols are used to integrate information concerning applicability, reliability and feasibility into a coherent whole that guides sampling design and data collection for vital signs monitoring.

Author: Protocols will be written by staff with help from collaborators in the academic community and other agencies.

Format: The protocols will follow the guidelines in Oakley et al. (2003) at a minimum, with additional information provided in a format agreed upon by network staff.

INVENTORY PROJECT REPORTS

Definition: An inventory project report documents the products of an inventory project, including species documented, new species found, data collected, etc.

Frequency: Inventory reports should be completed at the end of the inventory, although an annual synopsis of interesting results is helpful to network staff.

Purpose: The inventory report should detail the methods and results of the inventory project, as well as provide a list of species officially documented as occurring in the network parks. This report should also include the sites sampled and the distribution of the species within these sites.

Author: This report will be completed by the inventory project leader.

Format: Inventory reports follow a variety of formats.

Analysis and Synthesis Reports

Definition: Three synthesis reports will be developed by the GRYN. First, a full-length report detailing the status and management options with regard to the vital signs will be developed to provide a synthesis of the progress of monitoring, as well as a picture of overall ecosystem health. Also, a detailed synthesis report will be provided that includes information needed to make day-to-day, on-the-ground management decisions. Finally, an annual progress report will synthesize the year's activities and provide a synopsis for interested parties.

Frequency: Full-length synthesis report: every ten years; detailed synthesis report: at least once every ten years; and the annual progress report: once per year

Purpose: These reports will provide a synthesis of monitoring progress and a picture of the overall state of the ecosystem.

Author: The synthesis reports will be written by network staff, particularly the ecologist.

Format: To be determined.

Program Review Reports

Definition: Review reports of the program are used as a formal review of program progress at various intervals.

Frequency: The National I&M Program recommends the completion of these reports on five-year intervals, and the network will begin these reviews in 2008.

Purpose: These reports are meant to review operations and results obtained by the program. If changes in protocols are determined to be necessary, they should be included in this report.

Author: This report will be initiated by the program manager, with input from other cooperators and network staff.

Format: The format will be determined once monitoring begins.

Scientific Journal Articles and Book Chapters

Definition: This includes articles published in peer-reviewed scientific journals or chapters published in books.

Frequency: Variable.

Purpose: These articles and chapters represent a method for the network and its cooperators to disseminate information gained through the I&M program to a larger scientific audience.

Author: These articles will be prepared by network staff or cooperators.

Format: The format is determined by the journal or book publisher.

Symposia, Workshops and Conferences

Definition: Symposia, workshops and conferences are interactive methods for engaging interested parties and communicating the objectives and progress of the I&M program and the GRYN to a wider audience, including external scientists and park managers.

Frequency: Variable

Purpose: These interactive methods help to connect with a wider audience, review progress, create new ideas or directions and communicate the purpose of the I&M program and the network.

Author: These workshops are generally initiated by the program manager, with reports written by staff.

Format: Workshop reports should be completed as soon as possible after the end of the workshop. Reports for large workshops should follow the GRYN Vital Signs Monitoring Workshop Report as a template. Smaller workshop reports should use the meeting note template created for the GRYN.

Monthly Reports

Definition: This report describes current happenings in the GRYN and is distributed to interested parties, including the Technical and Science Committees, Board of Directors, other network coordinators and participants in GRYN workshops.

Frequency: This report is distributed during the latter half of each month.

Purpose: The reports are meant to inform a large audience about current GRYN activities.

Author: The GRYN research associate, with input from network staff, will create and distribute the report.

Format: The format should follow the standard monthly report format.

SUBMISSIONS TO NETWORK PARK REPORTS

Definition: Short synopses of current activities in the GRYN are distributed to network parks for inclusion in their monthly reports.

Frequency: These reports are compiled on a monthly basis.

Purpose: The reports will help to inform managers at the parks about current happenings in the GRYN.

Author: The research associate and program manager will prepare these reports as relevant activities are completed.

Format: The reports are submitted to the parks in standard text format.

VISUAL IDENTITY SYSTEM

Definition: The visual identity system defines the network and identifies it to external parties.

Frequency: The system (including the logo, memorandum style and report style) should be used as frequently as possible. The NPS banner is another symbol that is encouraged by the NPS.

Purpose: This system is meant to identify the network within the NPS, as well as increase awareness of the network to outside parties.

Author: N/A

Format: Standard NPS visual identity system components (such as the NPS banner) should be used on official documents, while internal documents can follow the format developed by the network (i.e., memos, reports, etc.).

PUBLIC BROCHURES

Definition: Brochures that describe ongoing monitoring efforts and problem statements pertaining to vital signs of interest. These brochures may also be used to provide a synopsis and update on the current progress of the network.

Frequency: Variable.

Purpose: These brochures will inform interested parties, in a concise manner, of the background of the I&M program, the GRYN and current happenings and can be distributed to interested parties (i.e., park managers, superintendents, the public) on an as-needed basis.

Author: Network staff will develop these brochures, with input from participating collaborators, agencies, etc. when possible.

Format: Varies, depending on topic.

DATA MANAGEMENT PLAN

Definition: The data management plan describes the method for managing data pertinent to GRYN monitoring.

Frequency: The final version of the plan should be complete in FY2005, with continual revisions as needed.

Purpose: The purpose of the plan is to effectively communicate the scope of data management in the network and the method for managing data collected by and for the network.

Author: The data management plan is written by the data manager, with help from other network data managers.

Format: The format is determined by the national data management plan authors.

WEBSITE

Definition: The website serves as an online method for distributing information about GRYN activities, as well as providing a repository for reports and publications and templates for cooperators.

Frequency: To be determined.

Purpose: The website represents an efficient method for information dissemination to various parties quickly.

Author: The data manager, with help from a web designer, will develop the new web-based interface for the GRYN.

Format: To be determined.

APPENDIX X:
GREATER YELLOWSTONE NETWORK CHARTER

CHARTER
OF THE
GREATER YELLOWSTONE INVENTORY AND MONITORING NETWORK (GRYN)

INTRODUCTION

The purpose of this document is to describe the basic practices that will be used to plan, organize, manage, evaluate and modify the efforts of the Greater Yellowstone Inventory and Monitoring Network (GRYN) in its pursuit of the intent and purposes of the of the National Park Service, Natural Resource Challenge with respect to the inventory and monitoring of natural resources.

The Network is comprised of four units of the National Park system. They are Yellowstone National Park (YELL), Grand Teton National Park (GRTE), John D. Rockefeller National Parkway (JODR), and Bighorn Canyon National Recreation Area (BICA).

BOARD OF DIRECTORS

The Board of Directors of GRYN is committed to operate in and foster an atmosphere of fairness, trust, and mutual respect with all of the network partners. It will pursue a holistic approach in implementing the I&M program using scientifically credible standards while serving the needs of all network partners.

RESPONSIBILITIES OF THE BOARD OF DIRECTORS

The major responsibilities of the GRYN Board of Directors will be to:

- Promote accountability and oversee the I&M Program by reviewing progress towards Servicewide and GRYN I&M goals as described in annual accomplishment reports and work plans.
- Provide guidance to the Technical Committee and natural resource staffs of the GRYN in the design and implementation of vital signs monitoring and other management activities related to the Natural Resource Challenge.
- Decide on strategies and procedures for leveraging GRYN funds and personnel to best accomplish the I&M and other natural resource needs of GRYN units.
- Consult on hiring of new personnel using funding provided to the GRYN, and from base funds or other sources.
- Seek professional guidance with other individuals, organizations and networks and promote productive partnerships between groups.
- Communicate the progress of the I&M program to park managers and park staff

MEMBERSHIP
The GRYN Board of Directors is comprised of the superintendents of Yellowstone, Grand Teton (including JODR), and Bighorn Canyon units, or their designees, the NPS Research Coordinator of the Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU) and the Intermountain Region's Inventory and Monitoring Coordinator (ex officio). The staff to the Board of Directors will be the I&M Program Manager and the chair of the Technical Committee.

The initial Chair of the Board of Directors shall be the Yellowstone representative but Chair will rotate at two-year intervals to Bighorn Canyon NRA, Yellowstone NP and then Grand Teton NP representatives.

BOARD MEETINGS
Any member can call meetings of the Board, but there will be at least two formal, announced meetings annually. Formal meetings will be called by the Board Chair, who will assure proper logistics and planning is done, and that a written agenda is distributed at least one week prior to the meeting. Conference calls may be scheduled by any Board member at any time.

ALTERNATES AND QUORUMS
Any Board member who cannot attend a meeting of the Board may assign an alternate who shall have full voting authority. Three *officio* Board members constitute a quorum.

DECISION MAKING
Every effort will be made by the Board members to reach unanimity on all significant decisions. When this is not possible, three of the four voting members constitute a majority decision. Decisions will be recorded in the meeting minutes and sent to all members in a timely fashion. If needed, the IMR Regional Director or designee will cast the tie-breaking vote.

SCIENCE COMMITTEE

The Science Committee (SC) will include five members of the scientific community who will assist the Technical Committee and the Board of Directors over the long term of the Inventory and Monitoring program to accomplish the following:

- Ensure the scientific credibility of the program by reviewing and commenting on GRYN monitoring plans and protocols
- Review the overall direction and program plans for the GRYN network
- Make recommendations for future directions for the long term monitoring
- Assist the network in leveraging activities with other groups and funding sources

The SC will meet twice a year to provide guidance to the network. They will also be asked to attend some workshops convened by the network. The Inventory and

Monitoring Program Manager is primary staff to the SC, with the Technical Committee providing assistance with meetings.

TECHNICAL COMMITTEE

The Technical Committee provides advice to the Board of Directors and assists as staff to the Science Committee. The primary mission of this committee is to guide the collection of existing information, take the lead in I&M planning for the network, and evaluate proposals, plans and final reports. To achieve these ends, the Technical Committee may call on other members of park staff or outside experts to assist with the review and planning.

The Technical Committee includes at least one member of the natural resource staff from each of the member parks, the I&M Program Manager, the I&M Data Manager, the NPS-Research Coordinator from the RM-CESU and may include the Regional Inventory and Monitoring Coordinator. The chair will rotate every 12 months. The chair of the Technical Committee is responsible for organizing conference calls and workshops, preparing minutes and following up on recommendations of the committee. The chair communicates with the program manager (unless the same) and the program manager will communicate with the Board of Directors on issues that require their involvement.

PROCEDURES

VITAL SIGNS MONITORING (VSM) PLAN: A monitoring plan to guide the long term program of the network will be prepared according to the schedule set out by the WASO-Inventory and Monitoring Program. The VSM plan will follow the outline provided to identify what will be monitored and why, where and how it will be monitored, with appropriate descriptions of protocols, quality assurance procedures and reporting. This plan will include a component for Water Quality Monitoring as specified in guidance from the NPS-Water Resources Division.

ANNUAL ADMINISTRATIVE REPORT & WORK PLAN (AARWP): The I&M Program Manager, working with the Technical Committee, will complete an annual administrative report and work plan for consideration by the WASO-Inventory and Monitoring Program following content and completion guidelines. This plan will include specific tasks, milestones, products and a budget that implements the Inventory and Monitoring plans in place for GRYN. The plan will be reviewed by the Technical Committee and approved by the Board of Directors before being submitted to the Regional Office and WASO representatives.

FUNDING: Available I&M program funds will be distributed in strict accordance with approved annual work plans, following the guidance provided by the Associate Director for Natural Resource Stewardship and Science. All I&M Program funds must be strictly accounted for using a discrete PWE code and disclosed in the Annual Report. The Technical Committee will prepare the annual budgets that will then be reviewed and approved by the Board of Directors. Changes in budget items of less than $25,000 may be made by the Program Manager. Changes greater than $25,000 will require approval from the Technical Committee. Additionally, funds contributed to the I&M program from any other source will be tracked and reported in the Annual Report.

The Board of Directors will approve permanent network hiring decisions. Network employees will be responsible to the program manager for annual performance plan and review. Line supervision of network employees will be determined on a case-by-case basis.

AMENDMENTS: The Board of Directors may make amendments to the Charter at any time. All GRYN members and the Regional I&M Coordinator will be provided at least a 30 day notice of any proposed amendments before they take effect.

APPROVAL SIGNATURES:

Frank Walker, Assistant Superintendent Yellowstone National Park	8/8/03 Date
Steve P. Martin, Superintendent Grand Teton National Park	8/8/03 Date
Darrell Cook, Superintendent Bighorn Canyon NRA	8/8/03 Date
Kathy Tonnessen, Research Coordinator Rocky Mountains Cooperative Ecosystem Studies Unit	8/8/03 Date
Mike Britten, Intermountain I&M Coordinator Intermountain Support Office	8/12/03 Date